UNIVERSITY OF BAHRAIN

College of Engineering

Department of Mechanical Engineering

# Study of Performance of the Mechanical Maintenance Section at Water Transmission Directorate

A Thesis Submitted in Partial Fulfillment of the Requirement for the Degree of Master of Science of Engineering Management

**Submitted by**

**Yaqoob Yusuf Ahmed**

University Number: 19972133

**Supervised by**

**Professor Saad Suliman**

Professor of Manufacturing Systems & Processes

University of Bahrain

**Dr. Yaser Al-Alawi**

Assistant Professor of Mechanical Engineering

University of Bahrain

**Kingdom of Bahrain**

**June, 2014**

UNIVERSITY OF BAHRAIN

College of Engineering

Department of Mechanical Engineering

LIBRARY
UNIVERSITY OF BAHRAIN

# Study of Performance of the Mechanical Maintenance Section at Water Transmission Directorate

A Thesis Submitted in Partial Fulfillment of the Requirement for the Degree of Master of Science of Engineering Management

**Submitted by**

**Yaqoob Yusuf Ahmed**

University Number: 19972133

**Supervised By**

**Professor Saad Suliman**

Professor of Manufacturing Systems & Processes

University of Bahrain

**Dr. Yaser Al-Alawi**

Assistant Professor of Mechanical Engineering

University of Bahrain

**Kingdom of Bahrain**

**June, 2014**

University of Bahrain
Graduate Studies Council

## Thesis Discussion Committee Decision

| | |
|---|---|
| Student Name: Yaqoob Yusuf Ahmed | Student ID: 19972133 |
| Department: Mechanical Eng. | College: Engineering |
| Program: Master of Science in Engineering Management | |
| Thesis Title: Study of Performance of the Mechanical Maintenance Section at Water Transmission Directorate | |
| Supervisor Name: Prof. Saad Sulaiman + Dr. Yaser Al-Alawi | Student GPA: 2.86 |

The Discussion Committee met on ___ (day and date) Wednesday 25/6/2014 in Hall no. 14-162 (hall/room no.) ____. Upon discussing the student whose details are stated above in public, the discussion committee recommends the following:

The student awarded grade B+ In the thesis subject _____

☐ Without making any changes to the thesis

☐ After making the modifications attached with this decision

Discussion Committee Members Approval:

| Name | Signature |
|---|---|
| 1. Prof. Saad Sulaiman (Advisor) | |
| 2. Dr. Mohd Nabhan (Internal Examiner) | |
| 3. Prof. Hesham Alfares (External Examiner) | |

## ملخص البحث

عنوان الأطروحة: دراسة أداء قسم الصيانة الميكانيكية بإدارة نقل المياه

اسم الطالب : يعقوب يوسف أحمد عبدالنبي

التخصص : الهندسة الميكانيكية السنة: يونيو 2014 م

قياس أداء وظيفة الصيانة هي قضية رئيسية بالنسبة للإدارة العليا، وذلك لأن فعالية الصيانة هي جزء من نجاح أي مؤسسة. تسعى الصيانة للحد من احتمالية حدوث الأعطاب من خلال تطبيق الصيانة الوقائية والحد من شدة تأثير الأعطاب للمعدات بعد حدوثها باستخدام الصيانة التصحيحية. هذا البحث هو دراسة لأداء قسم الصيانة الميكانيكية في إدارة نقل المياه في مملكة البحرين لكلا النوعين من الصيانة للتأكد من فعالية القسم في أداء المطلوب منه.

مئات من الاعطاب تم تسجيلها لأربعة وثلاثون مضخة مياه بين عامي 2005 و2011 في خمس محطات ضخ للمياه تنتمي إلى قسم الصيانة الميكانيكية مثل التسرب والتدخين من معدات منع التسرب، وتسربات من الأنابيب الرئيسية المتصلة بالمضخات بالإضافة للضوضاء والاهتزازات في معدات الإسناد، كما توجد عدة أعطاب في الصمامات المانعة لرجوع المياه. استمرارية تكرار حدوث هذه الأعطاب ولماذا لم يتم خفض عدد هذه الأعطاب أو منعها من الحدوث عن طريق إجراءات الصيانة المتبعة هي القضايا المحورية التي تناولتها هذه الدراسة.

تم استخدام مؤشرات الأداء المناسبة لقياس أداء قسم الصيانة باستخدام البيانات التي تم جمعها من المحطات التي تشمل تردد الاعطاب والوقت الذي تم استهلاكه لإصلاح الاعطاب بالإضافة إلى تكلفة الإصلاح وهذه إحدى الطرق التي تم استخدامها لقياس أداء قسم الصيانة الميكانيكية. كما تم تقييم الممارسات المتبعة الحالية للقيام بالإصلاحات والصيانة والزيارات المتبعة للصيانة الوقائية للتأكد من كفاءة وفعالية أعمالهم.

أظهرت هذه الدراسة عدم وجود طرق موحدة لإجراءات الصيانة التصحيحية والوقائية على أساس أفضل الممارسات المتبعة، وكذلك عدم وجود عملية لقياس الأداء للصيانة التصحيحية أو الوقائية والتي تمنع القسم من القيام بمهامه على أكمل وجه. علاوة على ذلك، أوضحت الدراسة أن هناك حاجة لإجراء تدريب إضافي للقوى العاملة في الصيانة لتحسين كفاءة عملهم، بالإضافة إلى التدريب على الصيانة الأساسية لجميع أفراد قسم التشغيل لخلق التكامل بين القسمين. كما يوجد خلل في الاتصالات بين المستويات المختلفة داخل الإدارة وأيضا ضمن قسم الصيانة نفسه. كما يجب تحديد المشاكل القائمة وتتبع الاعطاب المتكررة للمعدات وأسبابها ونتائجها من أجل الحد من تأثيراتها.

## ABSTRACT

Performance measurement of maintenance function is a major issue for management, because maintenance effectiveness is part of any organization's success. Maintenance seeks to reduce the probability of failures by applying the preventive maintenance and reduce the severity of equipment failures once they occur using corrective maintenance. This research is studying the performance of Mechanical Maintenance Section at Water Transmission Directorate at Kingdom of Bahrain for both types of maintenances to ensure the section achieves the desired performance.

Hundreds of defects recorded for 34 pumps from 2005 to 2011 for five water pumping stations belongs to Mechanical Maintenance Section such as leakage and smoking of gland packing, leakage form headers, noise and vibrations of bearings including many failures of non-return valves. The continuity of reoccurrences of these defects, and why maintenance actions and repair works are not reducing or eliminating these defects are the main issues of this study.

Suitable performance indicators are utilized to measure the performance of the maintenance section using data collected from the field which cover the frequency of defects, time to repair and cost of repair. Furthermore, the current applied practices of doing the maintenance repairs and inspections are evaluated including the efficiency and effectiveness of their actions.

The study shows that unavailability of standard procedures for corrective and preventive maintenance actions based on the best practices, and absence of a measurement process for maintenance performance are the hurdles in front of Mechanical Maintenance Section to perform efficiently and effectively. Furthermore, the results of the study indicate a need to conduct extra training for maintenance workforce to improve the efficiency of their work, as well to provide basic maintenance training for all operational personnel to create the integration between operation and maintenance. There is a lack of efficient communications between the different levels within the directorate and within the maintenance department. Identification of the existing problems and tracking the repetitive equipment failures, their causes and consequences must be practiced in order to reduce their occurrences.

## ACKNOWLEDGEMENT

It is a pleasure to thank those who made this thesis possible. First, I would like to express my sincere gratitude for my supervisors Professor Saad Suliman and Dr. Yaser Al-Alawi for their continuous support and encouragement throughout my graduate studies. Because of their input, advice, and challenge, I have matured as a researcher and as a graduate student. I have been very fortunate to have worked with one of the best and most talented supervisors. Thank You!

I owe my deepest thanks to all my colleagues in all sections at Water Transmission Directorate, Planning Department, Mechanical Maintenance Section, and senior management, for their support and great time I spent with them during my study period. I offer my regards to all of those who supported me in any respect during the completion of this thesis.

I am very grateful for my wife, for her great support and happiness she always provides me with. Finally, my sincere thanks and deepest appreciation go out to my parents for their affection, love, support, encouragement, and prayers to succeed in my study.

## TABLE OF CONTENTS


| | Page |
|---|---|
| Thesis Discussion Committee Decision | iii |
| Abstract | iv |
| Acknowledgement | vi |
| Table of contents | vii |
| List of tables | ix |
| List of figures | x |
| List of charts | x |
| List of appendices | xi |
| List of abbreviations | xi |
| **Chapter 1. INTRODUCTION** | 1 |
| 1.0 Introduction | 1 |
| 1.1 Problem Statement | 1 |
| 1.2 Research Objective | 2 |
| 1.3 Research Location | 2 |
| 1.4 Research Equipment | 2 |
| 1.5 Data Collection | 3 |
| 1.6 Thesis Overview | 3 |
| **Chapter 2: LITERAURE REVIEW** | 5 |
| 2.0 Introduction | 5 |
| 2.1 Definitions of Maintenance | 5 |
| 2.2 Maintenance Function | 5 |
| 2.3 Maintenance Importance | 6 |
| 2.4 Maintenance Approaches | 7 |
| 2.5 Maintenance Performance Measurement | 11 |
| 2.6 Performance Measurement | 12 |
| 2.7 Maintenance Performance Measurement Approaches | 12 |
| 2.8 Maintenance Performance Indicators | 20 |
| **Chapter 3: METHODOLOGY** | 22 |
| 3.0 Introduction | 22 |
| 3.1 Problem Definition | 22 |
| 3.2 Gather Relevant Data | 22 |
| 3.3 Data Validations and Verifications | 23 |

3.4 Data Classification 23
3.5 Data Analysis and results 24
3.6 Discussion Conclusion and Recommendations 25
**Chapter 4 : PROBLEM BACKGROUND** 26
4.0 Introduction 26
4.1 Historical Background 26
4.2 Water Transmission Directorate 27
4.3 Types of Water 29
4.4 Blending Process 31
4.5 Maintenance Department 34
**Chapter 5 : DATA COLLECTION** 42
5.0 Introduction 42
5.1 History of Data 42
5.2 Sources of Data 42
5.3 Reasons for Selecting Mechanical Maintenance Section 43
5.4 Pumps Defect Analysis by Station 46
5.5 Planned Preventive Maintenance of Pumps 67
**Chapter 6 : DATA ANALYSIS OF MECHANICAL DEFECTS** 74
6.0 Introduction 74
6.1 Data Analysis of Mechanical Defects for Stations 74
6.2 Common Major Defects in the Stations 88
6.3 Analysis of Common Types of Defects for Stations 91
6.4 Maintenance Corrective Action (Repair Works) 109
**Chapter 7 : DISCUSSION, CONCLUSION AND RECOMMENDATONS** 113
7.0 Introduction 113
7.1 Planned Preventive Maintenance 113
7.2 Corrective Maintenance 116
**REFERENCES** 119
**APPENDICES** 123

## LIST OF TABLES


| | | Page |
|---|---|---|
| Table 1 | Number of pumps and commissioning year of each station | 3 |
| Table 2 | Advantages & disadvantages of different types of maintenance | 10 |
| Table 3 | Plants names and type of water from each plant | 29 |
| Table 4 | Summary of defects for each maintenance section | 43 |
| Table 5 | Sample type of defect for maintenance sections | 44 |
| Table 6 | Summary of frequency, time and cost of defect for pumps for each maintenance sections | 45 |
| Table 7 | Details of defects for each individual pump at Hamala A2 GFS | 48 |
| Table 8 | Summary of defects, frequency, time and cost for all Hamala A2 pumps | 48 |
| Table 9 | Details of defect for each individual pump at HTBS | 52 |
| Table 10 | Summary of defects, frequency, time and cost for all HTB pumps | 53 |
| Table 11 | Details of defects for each individual pump at HTDS | 56 |
| Table 12 | Summary of defects, frequency, time and cost for all pumps at HTDS | 56 |
| Table 13 | Details of defects for each individual pump at WR#1 BS | 60 |
| Table 14 | Summary of defects, frequency, time and cost for all pumps at W.R#1 BS | 61 |
| Table 15 | Details of defect for each individual pump at WR#2 BS | 64 |
| Table 16 | Summary of defects, frequency, time and cost for all pumps at WR#2 BS | 65 |
| Table 17 | Distribution of Defects, time and cost for each maintenance section for all stations | 66 |
| Table 18 | Total summary for frequency, time and cost of defects for each maintenance section | 67 |
| Table 19 | Basic information from PPM Task Sheets from 2006 to 2011 for ground water pump #1 at WR#1 BS | 68 |
| Table 20 | Number PPM visits, time and cost from for individual stations & pumps | 70 |
| Table 21 | Average number of visits, cost and time per year for each individual pump | 72 |
| Table 22 | Mechanical defects, their time and cost for all stations | 75 |
| Table 23 | Mechanical defects data for HTDS pumps | 80 |
| Table 24 | Mechanical defects data for Hamala GFS pumps | 81 |
| Table 25 | Mechanical defects data for WR#2 BS pumps | 83 |
| Table 26 | Mechanical defects data for HTBS pumps | 84 |
| Table 27 | Mechanical defects data for WR#1 BS pumps | 86 |
| Table 28 | Comparison between major defects in each station | 89 |
| Table 29 | Final list of defects for all station including frequency, time and cost | 91 |
| Table 30 | MTBF, failure rate and availability for gland packing | 93 |
| Table 31 | Gland packing defects' information for WR pump #1 at Hamala A2 GFS | 94 |
| Table 32 | Average visits for repairing gland packing compared with calculated and graphed MTBF | 97 |
| Table 33 | Average visits of maintenance, average calculated and graphed MTBF | 98 |

| | | |
|---|---|---|
| Table 34 | Summary of the cost related to replacement and adjustment of gland packing | 100 |
| Table 35 | Corrective maintenance of gland packing (MTTR) | 101 |
| Table 36 | Average MTTR for replacement and adjustment of gland packing | 103 |
| Table 37 | Relationship between PPM and CM of gland packing | 104 |
| Table 38 | MTBF, failure rate and availability for discharge line leakage (from 2005 to 2011) | 106 |
| Table 39 | MTBF, failure rate and availability for drain line and valve leakage, blockage and breakage (from 2005 to 2011). | 107 |


## LIST OF FIGURES


| | | Page |
|---|---|---|
| Figure 1 | Cost of conformance / non-conformance in relation to maintenance | 10 |
| Figure 2 | The hierarchal levels | 14 |
| Figure 3 | The maintenance performance measurement framework | 16 |
| Figure 4 | The performance measurement framework for maintenance | 17 |
| Figure 5 | Leading performance indicators | 18 |
| Figure 6 | Lagging performance indicators | 19 |
| Figure 7 | Water transmission network in Bahrain | 28 |
| Figure 8 | Blending process diagram | 33 |
| Figure 9 | Organization chart of water transmission directorate | 35 |
| Figure 10 | Hamala A2 GFS drawing | 47 |
| Figure 11 | Hamad town blending station drawing | 51 |
| Figure 12 | Hamad town distribution station drawing | 55 |
| Figure 13 | West Riff'a #1 blending station drawing | 59 |
| Figure 14 | West Riff'a #2 blending station drawing | 63 |
| Figure 15 | Main pumping system within water transmission directorate | 74 |


## LIST OF CHARTS


| | | Page |
|---|---|---|
| Chart 1 | Percentage of pump's defect frequency, time and cost for each maintenance section | 45 |
| Chart 2 | Pareto chart between the types of mechanical defects and their cost | 77 |
| Chart 3 | Pareto chart between the types of mechanical defects and their repair time | 78 |
| Chart 4 | Pareto chart between the types of mechanical defects and their frequencies | 79 |
| Chart 5 | Pareto chart for mechanical defects at HTDS | 80 |
| Chart 6 | Pareto chart for mechanical defects at Hamala A2 GFS | 82 |
| Chart 7 | Pareto chart for mechanical defects at West Riff'a# 2 BS | 84 |
| Chart 8 | Pareto chart for mechanical defects at HT BS | 85 |
| Chart 9 | Pareto chart for mechanical defects at West Riff'a# 1 BS | 87 |

## LIST OF APPENDICES


| | |
|---|---|
| Appendix A | Details of pumps in each individual pumping station |
| Appendix B | Activity description for Mechanical Section |
| Appendix C | Planned preventive procedure |
| Appendix D | Pump task sheet |
| Appendix E | Pump overhauling plan |
| Appendix F | Work request card procedure |
| Appendix G | Calibration certificate of thermometer |
| Appendix H | Summary of defects, frequency, time and cost for all Hamala A2 GFS pumps |
| Appendix I | Summary of defects, frequency, time and cost for all HTBS pumps |
| Appendix J | Summary of defects, frequency, time and cost for all HTDS pumps |
| Appendix K | Summary of defects, frequency, time and cost for all WR#1 pumps |
| Appendix L | Summary of defects, frequency, time and cost for all WR#2 pumps |
| Appendix M | Mean time between failure for leakage of gland packing defect |
| Appendix N | Relationship between Preventive and corrective maintenance |
| Appendix O | Cost of corrective action (repair) for Gland packing leakage |
| Appendix P | Mean time between failure for leakage of discharge line defect |
| Appendix Q | Cost of corrective action (repair) for discharge header leakage |
| Appendix R | Mean time between failure for drain valve is blocked or broken |
| Appendix S | Cost of corrective action (repair) for drain line & valve leakage, blockage or breakage |
| Appendix T | Mechanical Maintenance practices for repairing pumps defects |


## LIST OF ABBREVIATIONS

| | |
|---|---|
| AWWA | American Water Works Associations |
| BS | Blending Station |
| BD | Bahraini Dinar |
| BW | Blended Water |
| CBM | Condition Based Monitoring |
| CMMS | Computerized Maintenance Management System |
| DS | Distribution Station |
| DW | Distillate Water |
| DCS | Distributed Control System |
| DFS | Distillate Forwarding Station |
| EWA | Electricity and Water Authority |
| ESR | Elevated Storage Reservoir |
| FS | Forwarding Station |
| GCC | Gulf Council Countries |

| | |
|---|---|
| GFS | Ground Forwarding Station |
| GS | Gulf Standard |
| GST | Ground Storage Tank |
| GW | Ground Water |
| HTBS | Hamad Town Blending Station |
| HTDS | Hamad Town Distribution Station |
| Hrs | Hours |
| HSE | Health , Safety and Environment |
| KW | Kilowatt |
| LCP | Local Control Panel |
| L/S | Liter per second |
| M | Meter |
| MPM | Maintenance Performance Measurement |
| MPIs | Maintenance Performance Indicators |
| MMS | Maintenance Management System |
| MGD | Million Gallon Daily |
| MOV | Motorized Valve |
| MSF | Multi Stage Flush |
| OEE | Overall Equipment Effectiveness |
| PPM | Planned Preventive Maintenance |
| PPM | Parts Per Million |
| PM | Performance measurement |
| PW | Potable Water |
| ROW | Reverse Osmosis Water |
| SPWS | Sitra Power and Water Station |
| TDS | Total Dissolved Solids |
| WTD | Water Transmission Department |
| WHO | World Health Organization |
| WRC | Work Request Card |
| WRBS | West Riff'a Blending Station |

# CHAPTER ONE
# INTRODUCTION

## 1.0) Introduction

Maintenance is a supporting function in any organization. It is part of the production process that transforms raw materials into final products (Arts, Knapp, and Lawrence, 1998), and if it is utilized correctly it will save time, cost and effort. At Water Transmission Directorate (WTD) there are many stations, these stations are responsible to transfer different types of water from tank to tank or from station to another. The main equipment types in all of these stations are tanks, elevated storage reservoirs and centrifugal pumps. Field Operation Section at WTD is responsible for monitoring the performance of all stations and solving any problem that disturbs water supply from these stations in coordination with Maintenance Section. Field section should raise a Defect Job Card for any kind of defects to the concerned section, like mechanical, electrical or instrument. These defects are reviewed and discussed on a daily meeting in order to be rectified. It was noticed through the daily meetings that many types of defects are repetitive and keep reoccurring from certain stations, inspite being repaired and rectified the defects were frequently reported again after a short period of time. The repetition of the defects from certain stations that not rehabilitated was the inspiration to start this project.

It is intended to concentrate the effort of the Mechanical Maintenance Section since they are responsible to maintain pumps running continuously and efficiently. Pumps are the heart of the WTD system, without them the goal of keeping supplying water to the network will not be achieved. It is very important to repair any defects or failures belonging to pumps, keeping in mind that if these defects are not repaired they will affect the performance of the station where the pump belongs to and the other stations as well because all stations are connected.

Tracking the performance of maintenance activities and operations should be an important key management practice for success in any corporation or organization. Therefore, the main purpose of maintenance management is to minimize the adverse effects and number of breakdowns and to maximize productivity and availability of the system at minimum cost (Hans Lofsten, 1998).

## 1.1) Problem Statement

This research focuses on centrifugal water pumps and their accessories including suction and discharge valves, and suction and delivery headers. These pumps are the heart of water transmission process and they are the major equipment in every station within WTD. The time for repairing these pumps should be questioned to ensure high reliability and availability.

The focus is on Mechanical Section since most of the defects are of mechanical nature such as gland packing, noise, vibration, and leakage.

There are many repetitive defects reported by Field Operation for Mechanical Section and specifically for pumps, mainly from five stations. Some examples of these defects are "gland packing of the pump is leaking", "drain valve is blocked", "leakage from discharge header" and "check valve leaking". The repetition is not only for the station, it is also for individual pump.

### 1.2) Research Objective

The objective of this research is to study the performance of mechanical maintenance and the maintenance methods implemented by WTD Maintenance Section and it will be evaluated for improvement.

### 1.3) Research Locations

Only five stations are considered in this study out of twenty two major stations representing the total number of stations within WTD network. These five stations were not rehabilitated yet and all of the pumps are the originally installed since commissioning of these stations. This decision is taken in order to have in depth study of the maintenance activities implemented on these stations, because all main pumping equipment within these stations were not modified or changed, no additional pumps installed or removed. These pumps are equipped with gland packing systems not mechanical seals like new pumps, and both suction and discharge headers with their valves were not replaced. Furthermore, the number of defects for these stations was large. The stations covered in this project are as follows:

1. Hamad Town Distribution Station (H.T. DS)
2. Hamala A2 Gorund Forwarding Station ( Hamala A2 GFS)
3. West Riff'a #2 Blending Station (W.R. #2 BS)
4. Hamad Town Blending Station (H.T. BS)
5. West Riff'a #1 Blending Station (W.R. #1 BS)

### 1.4) Research Equipment

This work focuses only on pumps, since they are the most critical equipment in the directorate, any failure took place to these pumps will affect the water supply to the network. In these stations there are 43 pumps and all of them are centrifugal pumps. Summary of the pumps in each station is shown in Table 1. Details of individual pumps are available in Appendix A.

**Table 1 - Number of pumps and commissioning year of each station**

| No. | Station | No. of Pumps | Commissioning Year (Age) |
|---|---|---|---|
| 1 | Hamad Town Distribution Station (DS) | 2 | 1989 (23 years) |
| 2 | Hamala A2 Gorund Forwarding Station (GFS) | 5 | 1970 (42 years) |
| 3 | West Riffa #2 Blending Station (BS) | 7 | 2002 (10 years) |
| 4 | Hamad Town Blending Station (BS) | 8 | 1985 (27 years) |
| 5 | West Riffa #1 Blending Station (BS) | 12 | 1970 (42 years) |

### 1.5) Data Collection

The data collected for this work was gathered from local Computerized Maintenance Management System (CMMS). This integrated system gathers all information related to the concerned maintenance section including type of defect, priority of the maintenance repair, location of the defect and brief description of defect.

Data was collected for the period from 2005 till 2011. The system was introduced on 2005 and all important data was fed into the system from that year, the previous practice before 2005 was only on papers, unfortunately all the old files were scrapped, hence, no data available before CMMS implementation.

Most of the data was gathered from Planning Section, and some specific data for pumps was gathered from Mechanical Section. CMMS data and Mechanical Section data were in table format, but Planned Preventive Maintenance (PPM) data was in task sheet. Required data from all sources was gathered and fed into separate tables.

### 1.6) Thesis Overview

Chapter 1: Introduction

This chapter gives an overview of this thesis work, such as the problem statement, objective, locations of the equipment, and data collected.

Chapter 2: Literature Review

In this chapter the main concepts and definitions of maintenance performance measurement, maintenance function, and other definitions will be explained. Also a brief description of types of maintenance will be introduced.

Chapter 3: Problem Background

The first section of this chapter is a small summary about the history of water supply in the kingdom. The summary describes the production of water from different production plants and the types of water of each plant. Also it summarizes the main functions of Water Transmission Directorate, and the types of water received in the different stations and the blending process. The second section is dedicated to describe the activities of the Maintenance Department and more concentration on mechanical section which is the subject of the study. Organization structure, main activities and major equipment of this section will be explained. Types of maintenance and procedures implemented by the section are briefly explained.

Chapter 4: Methodology

This chapter is dedicated to describe the methodology of the thesis. It explains how the data is collected, validated and presented. It explains how the data is analyzed for both the corrective and preventive maintenance data

Chapter 5: Data Collection

This chapter is purely introduced to show the data collected from the maintenance management system for target stations. Selection of the mechanical section for this study is justified, and the defects of each individual pump in every station covered in this research are identified and their occurrence frequencies are established.

Chapter 6: Data Analysis of Mechanical Defects

The data of the previous chapter is analyzed in different formats. More concentration is given for the more frequent failures and their causes.

Chapter 7: Conclusions and Recommendations

This chapter concludes and highlights the main outcomes of this study and suggests some recommendations to solve or reduce the defects frequency.

# CHAPTER TWO
# LITERATURE REVIEW

## 2.0) Introduction

This chapter provides a review of literature in the area of maintenance and how to measure its performance. The aim is to create a conceptual and theoretical foundation that can be used to analyze the performance of maintenance section mainly on the corrective and preventive maintenance.

## 2.1) Definitions of Maintenance

Defining maintenance should be done first before measuring it, fixing broken items is the most traditional perception of maintenance's role, taking such a narrow view, maintenance activities will be confined to the reactive action of repair things or item replacement (Tsang, 1999). Thus, this approach is known as reactive maintenance, breakdown maintenance, or corrective maintenance.

Maintenance is defined as "The combination of all technical and associated administrative activities required to keep equipments, installations and other physical assets in the desired operation conditions or restore them to this conditions" (BSI, 1984; Pintelon et al., 1997; Pintelon an VanPuyvelde, 2006). Also it can be defined as "the combination of all technical and administrative actions, including supervision intended to retain an item or restore it to a state in which it can perform a required function" (International Electro- technical Commission, 2006).

The Maintenance Engineering Society of Australia (MESA) defines the maintenance as "The engineering decisions and associated actions necessary and sufficient for the optimizing of specified capability". "Capability" in this definition is the ability to perform a specific function within a range of performance levels that may relate to capacity, rate, quality and responsiveness (Tsang, 1998).

Another definition of maintenance is defined by (Geraerds, 1985) as "all activities aimed at keeping an item in, or restoring it to the physical state considered necessary for fulfillment of its production function". According to this definition, maintenance also includes the proactive tasks like normal routines servicing, annual inspection, preventive, replacement and condition monitoring (Andrew, Jardine and Kolodny, 1999).

## 2.2) Maintenance Function

The purpose of maintenance function is to reduce the adverse effects of breakdown and to maximize reliability and availability at minimum cost (Hans 1998). Deterioration of

manufacturing or service systems occurs, when the system is commissioned and little attention is given to maintenance (Peter, Liliane, Ludu and Harry, 2010). In normal conditions, normal wear will occur if the system run within specified design limits, but if the system pushed to run above its design limits failure may take place due to operational errors. Some of the operational errors outcomes will be quality problems, safety hazards, or loss in production or service. These outcomes will affect the customer satisfaction, productivity, continuity of services and company image as well, it will give a negative impact to the reputation of the company. In order to keep the plant operating within required limits and ensure its production meets the target, management should concentrate on the maintenance part of the plant, and maintenance people should decide what are the maintenance objectives and strategies that should be met (Peter, Liliane, Ludu and Harry, 2010).

Maintenance objectives and maintenance strategies must be determined and linked together to have good maintenance, and both of the objective and strategies should be derived from company policy and manufacturing policy (Swanson 1997; Johnsson and Lesshamar, 1999; Swanson 2001; Pinjala et al., 2006). According to some authors (Kelly 1989; MESA 1995; Tsang, 1999; Visser and Pretorious, 2003), maintenance objectives are linked to fulfillment of production target at predetermined quality, and without breaking the constraints of the system operating condition and safety. In addition, every resources available within maintenance must be used efficiently and effectively in order to keep manufacturing or service equipments in good condition, and the plant must meet its design life, safety standards and energy consumption must be optimized (Dekker, 1996).

### 2.3) Maintenance Importance

Impact of maintenance on any plant performance such as productivity or reliability has increased. If there is any output loss even for one day due to unplanned shutdown will not be recovered without cost being paid, for example overtime for people who repair the problem of the stoppage. It is very important to realize the importance of maintenance function, because of its role to keep and improve the availability, quality of products, environmental requirement and also performance efficiency and total plant cost effectiveness at high levels (Al-Najjar, 1997, 1998, 2000a, b; Riis et al., 1997; Mckone and Elliott, 1998).

Maintenance is still considered as a cost centre, researchers has highlighted the impact of the maintenance function on the overall plant performance, i.e. productivity and profitability (Al-Najjar, 2000a; Al-Najjar et al., 2001; Carter, 2001; Kutucuoglu et al., 2001; Al-Najjar and Alsyouf, 2004).

Stoppages and disturbances in production or service system due to maintenance or any other causes will bring down the productivity and availability, and it will raise the product cost, at the end it will reduce profitability. Any failure in equipments or facilities will cause loss of productivity, and also cause loss of timely services to customers, and may even lead to safety and environmental problems which destroy the company reputation and image. It is important to show how maintenance could contribute to the overall business objective.

"Maintenance has been considered as a necessary evil, but in fact it is a profit centre rather than just unpredictable and unavoidable expense" (Al-Najjar et al., 2001; Al-Najjar and Alsyouf, 2004). Through utilization of effective policies, failures can be minimized to minimum level, and due to this minimization savings can be guaranteed. Maintenance has an impact on quality, safety, cost and capacity as well.

### 2.4) Maintenance Approaches

Usually, maintenance actions are generated with an aim to reduce the consequences of failures of plant or equipment as much as possible. Breakdown and preventive maintenance are examples of these actions. An example of preventive maintenance is replacing parts at predetermined time based on historical failure data, or based on condition-based maintenance (CBM) using condition monitoring techniques. In all cases, decision must be made to select from applicable maintenance approaches the right policy for each equipment or part.

"A maintenance strategy involves the identification, researching and execution of actions such as repairing, replacement and inspection" (Kelly, 1997). The aim of this strategy is to formulate a plan for the plant and its equipments, also formulate an optimal maintenance schedule for the plant with coordination of all parties like production people.

In the maintenance strategy, an events like failure and condition will give an indication about the type of maintenance action to be taken such as inspection, repair or replacement. A maintenance strategy consists of a mix of policies and or techniques, which vary from firm to firm (Dekker, 1996; Zeng, 1997). It depends on several factors like the objectives of maintenance, the nature of the equipment to be maintained, and the work environment (Gallimore and Penlesky, 1988; Pintelon and Gelders, 1992).

#### 2.4.1) Maintenance Methods

Maintenance is required for all types of machinery and applies also to pumps, different types of maintenance can be performed to ensure equipment are running efficiently during its design life. Two types of maintenance will be presented, corrective maintenance and

preventive maintenance, also two types of preventive maintenance will be explained, the scheduled and condition based maintenance.

### 1. Corrective maintenance

Corrective maintenance is basically the "run it till it breaks" also known as operate to failure, corrective maintenance, repair at failure, run to failure. This type of maintenance is defined as "maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function" (Maintenance terminology, Svensk Standard SS-EN 13306, 2001).

The main objective for the corrective maintenance is to bring the component to an operating condition state, repairing or replacement of the failed component are the solutions to return the system to functioning state (Gertabakh, 2000). The breakdown strategy should reduce the preventive maintenance cost to the minimum.

### 2. Preventive maintenance

Preventive maintenance is defined as "maintenance is carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of functioning of an item" "(Maintenance terminology, Svensk Standard SS-EN 13306, 2001). The preventive maintenance is performed regularly in order to keep the equipment in working condition and to prevent failures from occurring.

Preventive maintenance is an activity used to increase the reliability and availability of an equipment. Implementing preventive maintenance can reduce the probability of failure occurring after applying this type of maintenance (Moghaddam S. Usher, 2010). Any equipment in the plant like pumps or motors, should have its own prescribed maintenance procedure and schedules from the manufacturer in order to reduce the risk and cost of equipment failure.

There are two different types of preventive maintenance: the scheduled maintenance and the condition based maintenance. The main difference between these two are the way of deciding when to conduct the preventive maintenance task.

#### a) Scheduled maintenance

Scheduled maintenance is defined as "Preventive maintenance carried out in accordance with an established time schedule or established number of units of use "(Maintenance terminology, Svensk Standard SS-EN 13306, 2001). Scheduled maintenance means that

preventive maintenance is carried out in accordance with an established time schedule. The time schedule for the preventive maintenance is performed based on number of revelation, or number of running hours or sometimes based on the age of the components. Preventive maintenance performed at scheduled intervals should be designed to reduce the probability of failures. Maintenance cycle times will be matched to the requirements of the system.

**b) Condition based maintenance**

Condition based maintenance is defined as preventive maintenance based on performance and/or parameter monitoring and the subsequent actions. Performance and parameter monitoring may be scheduled on request or continuously.

Condition based maintenance is a type of preventive maintenance that is based on the performance of the system, by keeping close monitoring to the main parameters of the system. With this type of preventive maintenance, equipments are monitored to collect machine data. The condition monitoring may be scheduled or achieved through continuous monitoring or by request from operation.

The collected data from the machine can show some indications for predicted failure. Maintenance is initiated when a condition variable approaches or passes a threshold value. The system components will be operated to a defined condition of wear and fatigue. When this condition is reached, the component needs to be maintained or replaced. Examples of condition variables that the system monitors are vibration, temperature, number of particles in the lube oil etc.

### 2.4.2) Comparison between maintenance methods

According to Salonen and Deleryd (2011), preventive Maintenance can be regarded as value adding while corrective maintenance is regarded as waste. It is a fact, machineries need regular maintenance to run in an optimal way. Any stoppages and breakdowns can relate to lack of preventive maintenance, human error, or other kinds of problems that can be avoided, therefore it is considered as waste (Adolfsson, Dahlstrom, 2011).

| | Corrective maintenance | Preventive maintenance |
|---|---|---|
| Cost of Conformance | Indispensable corrective maintenance:<br><br>Corrective Maintenance due to:<br>- Failures with random distribution and no measurable deterioration<br>- Failures which are not financially justified to prevent | Valid preventive maintenance:<br><br>Preventive Maintenance, necessary to uphold necessary dependability<br>Improvements intended to increase the reliability of equipment |
| Cost of Non-conformance | Non-accepted corrective maintenance:<br><br>Corrective Maintenance due to:<br>- Lack of preventive maintenance<br>- Poorly performed preventive maintenance<br>- Poor equipment reliability | Poor preventive maintenance:<br><br>Unnecessary Preventive Maintenance<br>Poorly performed Preventive Maintenance |

**Figure 1, Cost of conformance / non-conformance in relation to maintenance (Ben-Daya and Duffuaa, 1995)**

Figure 1 above shows how each type of maintenance is important, both corrective and preventive maintenance are equally important parts in any maintenance department of an organization, because the preventive maintenance should be carried out to ensure a satisfying working condition while the corrective should handle random distributed error and failures that are financially justified to repair (Salonen and Deleryd ,2011).

Corrective maintenance cost is higher than preventive maintenance since preventive can be planned and it can be executed at a preferred date and time (Campell and Jardine 2001). The corrective maintenance needs to find material quickly, and the maintenance team should do the preparatory works, these will increase the cost according to Campell and Jardine (2001). Corrective maintenance in general cost more than planned stoppages, and breakdowns cost more than planned stoppages. "the cost aspect is a driving for producing companies shift from corrective to preventive maintenance" (Adolfsson, Dahlstrom, 2011).

There are many advantages and disadvantages of each type of maintenance, Table 2 shows advantages and disadvantages of corrective and preventive maintenance.

**Table 2 , Advantages & disadvantages of different types of maintenance**

| Method | Advantages | Disadvantages |
|---|---|---|
| Corrective Maintenance | • Low maintenance costs during operation.<br>• Components will be used for a maximum lifetime. | • High risk consequential damages resulting in extensive downtime.<br>• No maintenance |

| | | | |
|---|---|---|---|
| | | | scheduling is possible.<br>• Long delivery periods for parts are likely. |
| Preventive Maintenance | Scheduled | • Expected down time is low.<br>• Maintenance can be scheduled.<br>• Spare logistics can be made available. | • Components will not be used for maximum lifetime.<br>• Maintenance cost are higher compared to corrective maintenance. |
| | Condition based | • Components will be used up to almost their full life time.<br>• Expected downtime is low.<br>• Maintenance activities can be scheduled.<br>• Spare parts logistics can be made available if failure can be detected early in time. | • Reliable information about the remaining lifetime of the components is required.<br>• High effort to purchase condition monitoring hardware and software is required. |

(John Ribrant, 2005)

**2.5) Maintenance Performance Measurement**

Due to current global competition and increasing demands from stakeholders, improvement of manufacturing performance becomes the basic business demand. The performance and competitiveness of manufacturing companies is dependent on the reliability and productivity of their production facilities (Coetzee,1997; Madu, 2000; Fleiser et al., 2006). The equipment maintenance and system reliability are very important factors which affect organization's ability to deliver the required quality and timely services to customers. Therefore, the sustainability of the performance for any plant is linked with the maintenance function of this plant.

Maintenance Performance measurement (MPM) has received a great amount of attention from researchers and practitioners in the second half of last century's recent years due to a paradigm shift in maintenance. Technology was not in a state of advanced development, there was no other choices to avoid failure, generally the attitude to maintenance was "It cost what it costs". Now with all the developments and technological changes, maintenance become an important support function for production and manufacturing (Parida and Kumar, 2006).

During 1950-1980, with the new techniques such as preventive maintenance and condition monitoring, philosophy of maintenance cost changed to "It can be planned and controlled."

Today maintenance is considered as an integral part of business process and it is perceived as "It creates additional value" (Liyan and Kumar, 2003). The measurement of maintenance performance becomes a fundamental requirement for any industry today. "Performance measurement (PM) has become one of the most popular subjects over the last two decades for the researchers and managers from the industry. The efficiency and the effectiveness of the maintenance system play vital role in the organization's success and survivability" (Aditya and Kumar, 2006).

### 2.6) Performance Measurement

Performance measurement is a fundamental principle of management, it is important in managing maintenance function (Muchiri, Pintelon, Geldres, and Martin, 2010). "Performance measurement is the process of quantifying action and can be defined as measuring the efficiency and effectiveness of action" (Neely et al., 1994; Neely et al., 1995). The main function of any performance measurement system is to control the operations of an organization. Performance measurement is the process to measure work accomplishments. In addition, Performance measurement provides an important link between the strategies and management action and thus support implementation and execution of improvement initiatives (Kaplan, 1983; White, 1996; Neely et al., 2005).

Organizations recognizes the importance of performance measurement and its benefits therefore it is being implemented and documented (Kaplen and Norton, 1992). Furthermore, the efficiency and effectiveness measurements concentrate on the central issues of the business like cost, quality of the product or services, delivery of the product, customers, suppliers, markets and any new product which will be introduced to the market (Bicheno, 2000; Kaplen and Norton, 1992;1996). Performance measurement can help maintenance managers to concentrate on maintenance staff and resources to particular areas of the production and service systems that will affect system performance.

Here in this work the concentration of performance measurement is on the quality of maintenance services, corrective or preventive maintenance, conducted to the machinery equipment such as pumps.

### 2.7) Maintenance Performance Measurement Approaches

Measuring the efficiency and effectiveness of maintenance should be linked with performance measurements, all factors that affect performance should be reflected (Niebel, 1994; Jardine, 1970). Measurement can be defined as a method of knowing where an organization is now,

by utilizing the term of measurement will help the organization to plan where they want to be and when they will reach to their target (Amartunga and Baldry, 2002). The measurements provides the base to the entity whether or not they are moving towards their objectives, helps to identify the areas of strengths and weaknesses, and decision for future initiatives will be taken in order to improve the performance. Therefore the measurement of maintenance performance become an essential requirement for the industry of today (Parida and Kumar, 2006), because the efficiency and effectiveness of the maintenance system play a common role in the organization's success and survivability" (Parida and Kumar, 2006).

There are some approaches proposed for measuring maintenance performance that can help analyze maintenance organizations, they are discussed and described hereunder,

Ben-Daya et al. (2009) suggest some important factors as a framework for evaluating and measuring maintenance productivity. These factors should be incorporated with the strategy at different hierarchal levels in the organization in order to have comprehensive picture.

The framework contains six parts, value created by the maintenance; allocation of resources; health, safety and environment; knowledge management; new trends in operation and maintenance strategy; and change in organizational structure. These are covering most important parts of the maintenance productivity but not all aspects.

1) *Value created by the maintenance.* It is the most important factor because it is related to business, it is needed to create value in all business.
2) *Allocation of resources.* Resources are the heart of the maintenance, the focus here on the effectiveness of them. It is very important to evaluate if the right resources exist and they are used in the right way. Here either more investments are needed or wrong investments have been made.
3) *Health, safety and environment.* Any organization must look at health, safety and environment factors, it is essential to have low number of incidents and accidents to be an efficient organization.
4) *Knowledge management.* Business today use more technology, information and communication. To handle the change, the existing knowledge in the organization need to be taken care of, and there is a need for systematic approach for obtaining knowledge.
5) *New trends in operation and maintenance strategy.* For every company, the strategy must be adjusted with changes in the environment, the strategy should be revised continuously.

6) *Changes in the organizational level.* The productivity measurements need to reflect the focus of the organizational structure.

The above factors are important to be looked at, also the strategies at different levels of the organization must be considered. Ben-Daya et al. (2009) give some examples of some measurements that can be used at different levels in Figure 2 below.

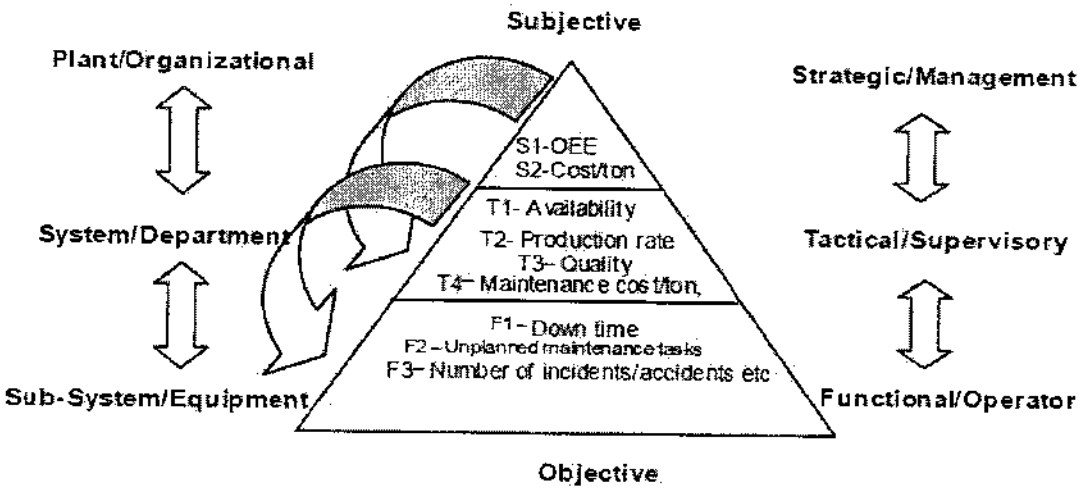



**Figure 2, The hierarchal levels (Ben-Daya, et al. 2009)**

The different hierarchal levels should be considered for designing measurements. Some examples of these measurements are unplanned maintenance tasks in functional level, availability at the tactical level, and the overall equipment effectiveness (OEE) at the strategic level. This model ensures the information flows smoothly within organization and create automatic evaluation of the measurements.

It is important to ensure an effective and efficient maintenance organization, it is possible to achieve this by using performance measures. There are many general performance measurement frameworks, but not much for the area of maintenance performance measurements (Parida, 2006). Parida suggests a framework which is based on factors influencing the maintenance effectiveness. Parida identified factors and divided them under seven criteria, the factors are presented in Figure 3 below with examples for each criteria, the hierarchical level is presented as well.

As per Parida (2006), "there is no standard reference for the performance measures proposed". It is part of the organization to set their goals and keep measuring the performance, this is a basis for organization continuous improvement. The framework in Figure 3 covers

maintenance as a whole, therefore some adaptation is required to fit the corrective maintenance specifically.

Campbell and Jardine (2001) propose a framework which express the most important categories that must be measured in order to achieve the overall goals of a maintenance departments. There are six main categories according to Campell and Jardine (2001):

1. *Maintenance productivity:* Some examples for measuring productivity is labour, materials, tools and equipments. These are different resources and productivity should measure the different resources.
2. *Maintenance organization:* This category measures the effectiveness of the organization and planning activities. ratio between planned and emergency work orders is an example of measures.
3. *Efficient maintenance work:* Different aspects of how the maintenance keeps up with the work load is measured in this category such as response time and work order turnover.
4. *Maintenance cost:* It is a common category in order to evaluate the maintenance, one example for this category is the total cost of corrective and preventive maintenance.
5. *Maintenance quality:* This category is often overlooked, the maintenance should put things right, any problem in maintenance quality could indicate a need of training or requirement of new skills. Repeated jobs and breakdowns can be used as a measure for this category.
6. *Overall maintenance results:* This category has more strategic focus and relates to measurements that are used in Ben-Daya et al.(2009) and Parida (2006) under strategic and tactical levels.

| Hierarchical LEVEL OF MPIs / MULTI-CRITERIA OF MPIs | Level I<br>*Strategic/Senior Manager/ Plant* | Level II<br>*Tactical/Middle manager/ system/ subsystem* | Level III<br>*Functional/ Operators/ Equipment/ item* |
|---|---|---|---|
| *Equipment/ Process related* | 1. OEE (Total production) | 1.Availability<br>2.Downtime(hours)<br>3.Performance speed<br>4.Impact of quality | 1.No of stop<br>2.Downtime(hours) |
| *Cost-related/ Financial* | 2.Maintenance cost per ton<br>3.Production cost per ton | 5.Maintenance cost<br>6.Production cost/ton | |
| *Maintenance Task-related* | | 7.Change over time<br>8.Planned maintenance tasks<br>9.Unplanned tasks | 3.Change over time<br>4.Planned maintenance tasks<br>5.Unplanned tasks |
| *Learning & Growth/ Innovation* | 4.Number of new ideas generated<br>5.Skill improvement & training | 10.Number of new ideas generated<br>11.Skill improvement & training | 6.Number of new ideas generated<br>7.Skill improvement & training |
| *Customer Satisfaction related* | 6.Quality complaint numbers<br>7.Quality return | 12.Quality complaint numbers<br>13.Quality return | 8.Quality complaint numbers<br>9.Quality return |
| Health, safety & environment (HSE) | 8.No of accidents<br>9.HSE complaints | 14.No of accidents or incidents<br>15.HSE complaints | 10.No of accidents or incidents<br>11.Environmental standards/ complaints |
| Employee/ Satisfaction | 10. Employee complaints | 16.Employee complaints | 12.Employee complaints |

**Figure 3, The maintenance performance measurement framework (Parida. 2006)**

Peter, Liliane, Ludu and Harry (2010) propose a conceptual framework that satisfy maintenance function towards performance demanded by manufacturing objectives. This framework which is shown in Figure 4 below directs the maintenance efforts to achieve the required performance as well as continuous improvements of the production equipments performance. The first section seeks to align the maintenance objective with manufacturing strategy, the performance requirements for the manufacturing system can be defined by reviewing stakeholders requirements, once these requirements is defined the maintenance objectives is derived also.

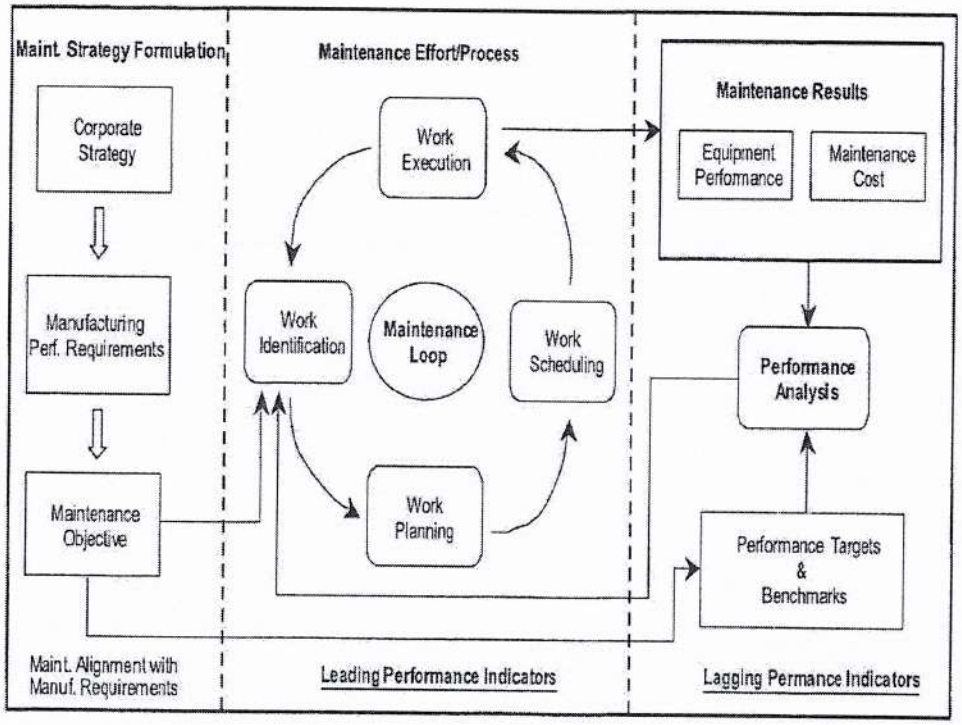



**Figure 4, The performance measurement framework for maintenance (Peter, Liliane, Ludu and Harry, 2010)**

The second section is the maintenance effort and processes, and there are four main key processes as follows,

1. *Work identification.* This process is to identify the right work to be performed at the right time by the maintenance team keeping in their mind meeting maintenance objectives.
2. *Work planning.* This process is to develop work orders and procedures for the maintenance activities identified, for example identification of resources and instructions required to handle the job.
3. *Work scheduling.* This process is responsible to evaluate the availability of all resources required to perform the job as well as the time required to perform the work.
4. *Work execution.* This process ensures that the scheduled activities above are executed within allocated resources and time. This process completes the loop of maintenance process and ensures the maintenance work done effectively.

The third section is for the monitoring of the maintenance results. The analysis of maintenance results is important, because it supports the identification of performance gaps,

the analysis should involve a comparison between the achieved and the target results, also the results must be compared with the historical data.

The authors proposed ***leading indicators*** for the maintenance process and ***lagging indicators*** for the maintenance results since they are known after the maintenance is done. The proposed leading indicators for the maintenance process section are shown in Figure 5 below.

| Category | Measures / Indicators | UNITS | Description | Recommended Targets |
|---|---|---|---|---|
| Work Identification | Percentage of Proactive work | % | Man-hours envisaged for proactive work/Total man hours available | 75% - 80% |
| | Percentage of Reactive work | % | Man-hours used for reactive work/Total man-hours available | 10% - 15% |
| | Percentage of Improvement work | % | Man-hours used for improvement & modification/Total man-hour available | 5% - 10% |
| | Work request response rate | % | Work requests remaining in 'request' status for <5days/Total work requests | 80% of requests |
| Work Planning | Planning Intensity/Rate | % | Planned work / Total work done | 95% of all work orders |
| | Quality of planning | % | Percentage of work orders requiring rework due to planning/All WO | < 3% of all WO |
| | Planning Responsiveness | % | Percentage of WO in planning status for <5days/ All WO | > 80% of all WO |
| Work Scheduling | Scheduling Intensity | % | Scheduled man-hours/ Total available man-hours | > 80% of available man-hours |
| | Quality of scheduling | % | Percentage of WO with delayed execution due to material or man-power | < 2% |
| | Schedule realization rate | % | WO with scheduled date earlier or equal to late finish date/All WO | > 95% of all WO |
| Work Execution | Schedule Compliance | % | Percentage of wok orders completed in scheduled period before late finish date | >90% |
| | Mean Time To Repair (MTTR) | Hours | Total Downtime/No. of failures | |
| | Manpower Utilization rate | % | Total Hours spent on tasks / Available Hours | > 80% |
| | Manpower Efficiency | % | Time Allocated to Tasks/Time spent on tasks | |
| | Work order turnover | % | No. of completed tasks/ No. of received tasks | |
| | Backlog size | % | No. of overdue tasks/ No. of received tasks | |
| | Quality of Execution(Rework) | % | Percentage of maintenance work requiring rework | < 3% |

**Figure 5, Leading performance indicators (Peter, Liliane, Ludu and Harry, 2010)**

For work identification, maintenance should identify the potential failures and it should try to prevent the causes of failures. An example of the indicators for work identification is man-hours for the precautionary work over specified period. Planning and scheduling are important processes in order to maximize maintenance efficiency. For work planning, the percentage of planned work indicator and percentage of work orders requiring rework indicator are some of the important indicators. For the work scheduling, an important indicator for this process is scheduling intensity (percentage of scheduled man-hours to the total available man-hours). The execution work indicators help in monitoring the effectiveness such as quality of work and efficiency like manpower and resources utilization. Percentage of reworks and percentage of completed task over all received tasks are some indicators for measuring work execution process.

The lagging indicators are used to measure the maintenance results in terms of equipment performance and maintenance cost. The results of maintenance process such as reliability and availability are important elements that maintenance seeks to measure. It is important to note the maintenance crews trying their best to achieve their objectives at an optimal cost, so it is essential to measure cost effectiveness of the maintenance activities. A summary of lagging maintenance indicators are shown in Figure 6 below.

| CATEGORY | MEASURES / INDICATORS | UNITS | DESCRIPTION |
|---|---|---|---|
| Measures of Equipment Performance | No. of Failures | No. | No. of Failures classified by their consequences: Operational, Non-operational, safety etc |
| | Failure / Breakdown Frequency | No./ Unit Time | No. of failures per unit time (A measure of Reliability) |
| | MTBF | Hours | Mean Time Between Failure (A measure of Reliability) |
| | Availability | % | MTBF/(MTBF + MTTR) = Uptime/(Uptime + downtime) |
| | OEE | % | Availability * Performance Rate * Quality rate |
| Measures of Cost Performance | Direct Maintenance Cost | $ | Total corrective and Preventive Maint. cost |
| | Breakdown Severity | % | Breakdown cost / Direct Maint. Cost |
| | Maintenance Intensity | $ / Unit production | % of Maint. Cost per unit of products produced in a period |
| | % Maint. Cost component over Manufacturing cost | % | % Maint. Cost / Total Manufacturing cost |
| | ERV (Equipment Replacement Value) | % | Maint. Cost / New condition Value |
| | Maintenance Stock turnover | No. | Ratio of cost of materials used from stock within a period |
| | Percentage Cost of Personnel | % | Staff Cost / Total Maintenance Cost |
| | Percentage Cost of subcontractors | % | Expenditure of Subcontracting / Total Maintenance cost |
| | Percentage cost of Supplies | % | Cost of Supplies / Total Maintenance Cost |

**Figure 6, Lagging performance indicators (Peter, Liliane, Ludu and Harry, 2010)**

This thesis mainly follow Ben-Dyan et. Al (2009), Parida (2006) and Peter et al. (2010) frameworks. Whatever data available from these sources will be used to evaluate the performance of maintenance. Many data related to some of the measurements are not available from these sources.

## 2.8) Maintenance Performance Indicators (MPIs)

"An indicator is a product of several metrics (measures), when used for measurement of maintenance performance in an area or activity, they are called the maintenance performance indicators "(Wireman, 1998). MPIs are mainly used in order to evaluate the effectiveness of maintenance carried out (Wireman, 1998). It compares the actual conditions with a specific set of reference conditions (requirements/targets) (EEA, 1999). MPIs can also be defined as "the means to measure the efficiency and effectiveness of maintenance and related performance."

"A performance indicator is a measure capable of generating a quantified value to indicate the level of performance, taking into account single or multiple aspects. Performance indicators are applied in order to find ways to reduce downtimes, costs and wastes, operate more efficiently, and get more capacity from the operational lines" (Aditya Parida ,2006).

Developing maintenance performance indicators and implement them to the entire organization is a way to measure maintenance performance. MPIs are linked to the reduction of downtime, costs and wastes, and the enhancement of capacity utilization, productivity, quality, health and safety (Arts et al. 1998). The maintantence performance indicators can be used to monitor the performance of employees, health, rating of safety and environment (HSE), overall equipment effectiveness (OEE) and customer satisfaction when it is linked with financial reports.

(Campel, 1995) classifies the commonly used measures of maintenance performance into three categories based of their focus, the first category measures equipment performance such as availability, reliability and overall equipment effectiveness. The second category measures the cost of performance like operation and maintenance labor cost and maintenance cost. The third category measures process performance like the ratio of planned and unplanned work. The first and second category are the main measures utilized in this project in order to measure the maintenance performance of the Mechanical Section, the third category requires information which are not available.

Some examples of maintenance performance indicators are maintenance budget, system availability targets, meantime between failures (MTBF) and mean time to repair (MTTR), maintenance reliability and downtime. The establishment of a link between the lagging and the leading indicators helps to monitor and control the performance of the process, and the indicators to be linked are selected in line with the chosen maintenance strategy (Kumar and

Ellingsen, 2000). The selection of maintenance performance indicators depends on the way in which the maintenance performance measurement is developed. When designing MPIs, it is important to relate them to both the process inputs and the process outputs. If this is carried out properly, then MPIs can provide or identify resource allocation and control, problem areas, the maintenance contribution, benchmarking, personnel performance, and the contribution to maintenance and overall business objectives (Kumar and Ellingsen, 2000).

# CHAPTER THREE
# PROBLEM BACKGROUND

## 3.0) Introduction

This chapter is dedicated mainly for the Water Transmission Directorate (WTD) where this study is conducted, initially started with historical background of water including water transmission network and a small description about the different types of water. Also in this chapter there will be more elaboration about the Mechanical Maintenance Section, its structure, main responsibilities, and activities implemented by the section including the corrective and preventive maintenance tasks.

## 3.1) Historical Background

The beginning of public water supply in Bahrain can be traced back to the year 1924 when the first mechanically drilled borehole was sunk for pumping ground water from aquifers for public supply. The responsibility for water supply in Bahrain was divided between Public Works and Rural Affairs Directorate till 1961 when it was entrusted to the newly established Water Supply Directorate. Nevertheless, the pipe water was brackish having total dissolved solids (TDS) content far above the acceptable levels of 1000 Parts Per Million (PPM). So for potable uses people preferred "sweet water" drawn by divers in sheepskin bags from sea bed springs which were known to have lower TDS content in the past. Later on tanker water from private water purification plants formed the bulk of the drinking water.

The first water desalination plant of five million gallons per day (MGD) capacity was established at Sitra Power & Water Station (SPWS) in 1976. By 1985 the SPWS capacity was raised to twenty five million gallons per day (MGD) and another ten MGD reverse osmosis plant at Ras Abu Jarjur came on stream. Thereby blended water was provided to the public in most of the areas.

A second reverse osmosis plant of ten MGD capacity at Al Dur and another Multi Stage Flash (MSF) plant of thirty MGD at Hidd Power & Water Company (HPWC) were commissioned in 1990 and 2000 respectively which boosted the availability of desalinated water meeting the rising demand. Potable water from ALBA coke calcinations plant too started flowing in to Sitra C station since February 2004. An expansion of Hidd Power Company took place in 2004 raising the production of water to ninety MGD by adding sixty MGD. The last project of water production is ALdurr Power and Water Company (AlDurr PWC), it is under private sector which should produce forty eight MGD of potable water to national network and it is under final stage of commissioning.

### 3.2) Water Transmission Directorate

The main goal of the Water Transmission directorate (WTD) is to provide an adequate, reliable and safe supply of water for distribution to the public. The Department is headed by Director, Water Transmission. There are 350 employees (excluding trainees) under WTD, and 210 of them (i.e. 60%) are working on shift to run the system round the clock. WTD network encompasses the piping mains water production plant boundaries and up to water distribution main take off valves. The water transmission network comprises of the following:

- Desalinated water forwarding stations.
- Borehole and ground water forwarding stations.
- Blending stations.
- Water transmission piping mains.
- Storage tanks and distribution towers.
- Water control center.
- Laboratory and corrosion control laboratory.
- Maintenance and workshop facilities.

Plants and equipment in the WTD network are scattered all over the island as shown in Figure 7. There are four main water production plants, Hidd Power Company, Alba Calcining Plant, Addur Sea Water Reverse Osmosis Plant, and Ras Abu Jarjur Plant. The area of study is concentrated on five stations as mentioned earlier, West Riff'a 1&2 Blending Stations, Hamad Town Blending Station, Hamad Town Distribution Station and Hamala A2 Station which is a forwarding station for ground water only.

Each block in Figure 7 represent a station which includes its name, the lines connecting the blocks represent water pipelines connecting the stations together. The red lines represent the distillate water while the green colored lines represent ground water, and the dark blue lines are for potable and blended water. The light blue colored lines represent the water supplied for consumers from the distribution station, and the dark blue circles represent the Elevated Storage Reservoirs (ESRs) which are used to store water and feed distribution network.

To easy understand the usage of this network diagram, an example is given, West Riff'a BS 1&2 receive distillate water from Ras Abu Jarjur Reverse Osmosis plant and Sitra distillate forwarding station, the ground water for both stations comes from Hamala A2 Ground Forwarding Station. Blending process is carried out inside the stations and then the blended water will be stored in the ESRs. Hamad Town BS also receives distillate water from West Riff'a 1 BS, ground water from Hamala A2 GFS, blending takes place within the station, and blended water is stored and supplied to consumers using the ESRs.

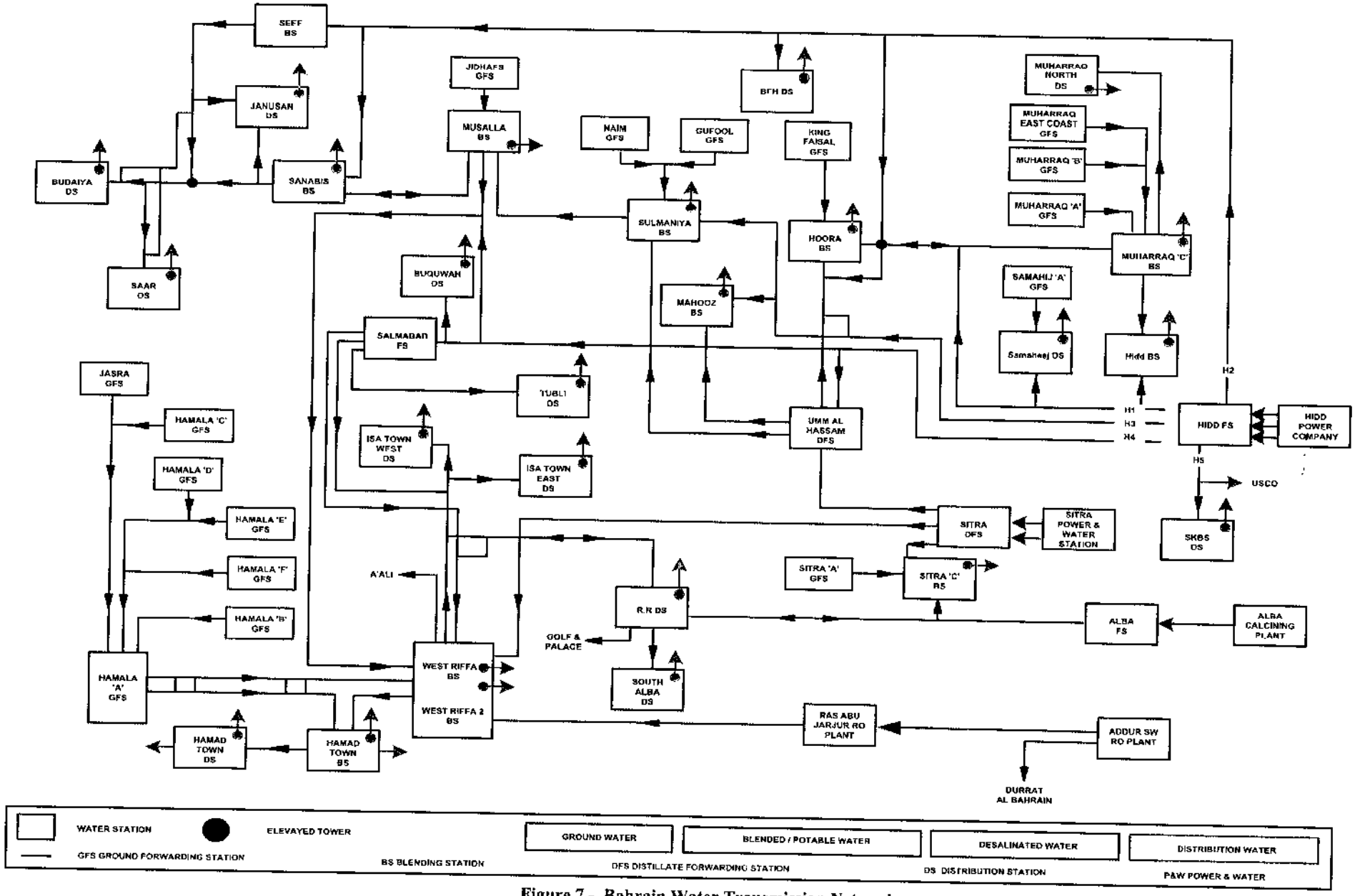



**Figure 7 - Bahrain Water Transmission Network**

WTD receives different types of water from different plant as shown in Table 3:

**Table 3 - Plants names and type of water for each plant**

| Plant Name | Type of Water |
|---|---|
| Hidd Power & Water Company | Potable Water (PW) |
| Sitra Power & Water Station | Distillate Water (DW) |
| Aldurr Reverse Osmosis Plant | Reverse Osmosis Water (ROW) |
| Ras Abu Jarjur Plant | Reverse Osmosis Water (ROW) |
| Alba Plant | Potable Water (PW) |
| Aldurr Power & Water Company | Potable Water (PW) |

The desalinated water (Distillate & RO) required post treatment for corrosion control, this water will transfer to various blending stations (BS) which are generally located near their associated distribution zones. All desalinated water at this stage is not fit for human consumption, it should have treatment either at production plant or at blending stations to make it drinkable and usable.

At production station the post treatment concentrate on the water ph & chemical parameters. At the blending stations, the desalinated water is blended with ground water which is abstracted from site borehole or nearby ground water complying to specifications set by GCC standards (GS 194/1993) and World Health Organization (WHO) Guidelines for Drinking water Quality. Blended water is then supplied to each distribution zone maintaining the pressure regime set for each area. WTD also receives potable water from Hidd Power and Water Company and ALBA water plant. This water is directly distributed to consumers since it is ready for drinking.

### 3.3) Types of Water

There are five main types of water within the network, these types of water are classified starting from production plants as follows:

a. **Distillate water (DW):** It is a desalinated water from multi stage flash evaporation process. This water mainly coming from Sitra Power and Water Station, the most important water quality parameters are :
    - Conductivity (µs/cm) : 160

- Turbidity (NTU) : 0.05
- PH : 9.5

b. **Potable Water (PW):** It is a desalinated water from multi stage flash evaporation process and it is processed within the production plant to be a drinkable water. This water mainly coming from Hidd Power & Water Company, the most important water quality parameters are :
   - Conductivity (µs/cm) : 430
   - Turbidity (NTU) : 0.1
   - PH : 7.5

c. **Reverse Osmosis Water (ROW):** It is a desalinated water from reverse osmosis water process. There are two production plants responsible for this type of water, the first one is called Al-Durr Reverse Osmosis Plant and it is producing water from the sea and the quality parameters are:
   - Conductivity (µs/cm) : 3100
   - Turbidity (NTU) : 2
   - PH : 7.5

   The second plant is Ras Abu Jarjur Reverse Osmosis Plant, and it is producing water from ground aquifer and the quality parameters are :
   - Conductivity (µs/cm) : 330
   - Turbidity (NTU) : 1
   - PH : 8.2

d. **Ground Water (GW):** It is the ground water which extracted from boreholes all around the kingdom, the main water for this thesis is extracted mainly from Hamala area. There are twenty boreholes available and this water is used mainly for blending process with either distillate water or reverse osmosis water. The quality parameters of this water are :
   - Conductivity (µs/cm) : 3000 to 6500
   - Turbidity (NTU) : 0.2
   - PH : 7 – 7.2

e. **Blended Water (BW):** it is the water generated from mixing ground water with either distillate or reverse osmosis water. This water is pumped to public network for drinking and general utilization. The water quality parameters (for stations covered in this thesis) are :

- Conductivity (μs/cm) : 1000 to 3000
- Turbidity (NTU) : 0.2
- PH : 7 - 8

### 3.4) Blending Process

Blending process take place at Blending Station (BS) which are generally located near their associated distribution zones, and often nearby ground water sources. These blending stations are supplied with groundwater and desalinated water through pipes network called transmission network. Each blending station consists of ground storage tanks, a pumping station and an elevated Tank. The Blending Process is executed at each individual Blending Station at a specified blending ratio of groundwater to desalinated water. This ratio varies from one location to another, depending on several different criteria.

Figure 8 explains how the blending process takes place at the blending stations. The ground water pump and distillate water pump will pump water through one header where the blending will take place between the two types of water, this water will be stored in the blended water tank.

Following the blending process, chlorine gas is added to the blended water for sterilization, and then pumped to the Elevated Towers, within the blending stations. From the elevated tower, the blended water is allowed to flow down into the distribution network by gravity. To maintain a certain pressure in the distribution network, it is being controlled by throttling of the elevated towers' outlet valve. All flows and quality parameters are measured locally by Water Control Center (WCC). The blending-ratio is controlled through the variable speed ground-water pumps, by means of pumps' speed adjustment.

An important issue should be mentioned here, for every set of pumps such as distillate, ground or blended water pumps and even potable pumps, standby pump should be available for every single type. As an example, if there are two pumps for certain type of water in a station, one should be running and the other must be standby and it will be used in emergency, and if there are three pumps, two must be running and the third one will be standby. The standby pumps will be used

weekly as an exercise done by Operation and System Control Department, and one of the running pumps will be stopped and it will be considered as a standby pump.

This means there will be no stoppage of supply facility towards consumers or towards other stations as well. Continuous supply of all types of water is done and controlled by Water Control Center (WCC).

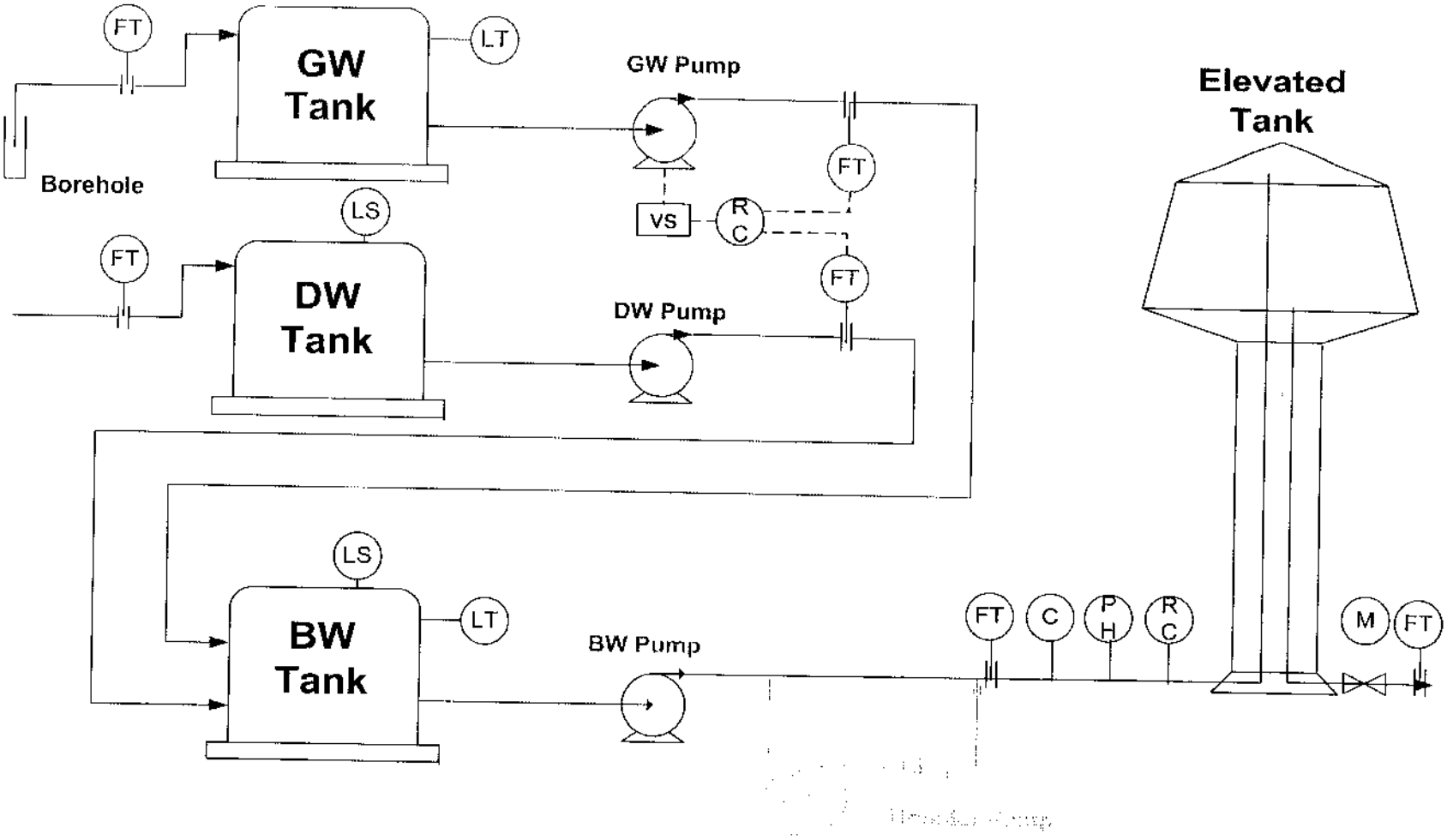



**Figure 8 – Blending process diagram**

### 3.5) Maintenance Department

The Maintenance Department under Water Transmission Directorate (WTD) undertakes the sole responsibility for up-keeping the water pumping stations, piping network & process control equipment, ensuring its failure-free operation all times at the maximum capacity with optimized efficiency by adopting cost-effective techniques. In line with this philosophy a systematic corrective, preventive maintenance and predictive maintenance programs were developed and put in practice using the available and limited resources of machinery and manpower. To cater for the urgent Off-site maintenance requirements, WTD utilizes the facilities available at its own workshop located at Salmabad premise.

WTD recognizes that the elements for achieving optimization in equipment reliability and maximization of asset availability are continual process of learning, reviewing, bench marking and adopting best practices in the field of maintenance. In line with this vision and to integrate with changing business philosophy of Electricity & Water Authority (EWA), the Maintenance Department has initiated various steps to "Deliver Operational Excellence" through various strategic measures, which were outlined in the Balance Score Card (BSC) Program. (Maintenance Handbook – 2012)

#### 3.5.1) Organization structure maintenance department

Water Transmission Directorate is headed by a director and there are two chiefs, the first one for Operation and System Control (OSC) and the second one is for maintenance. Under chief of maintenance there is head of tanks and trunks. The remaining structure is shown in the organization structure chart in Figure 9, the important structure for this research is highlighted in red color for easier understanding of whom are related to mechanical section.

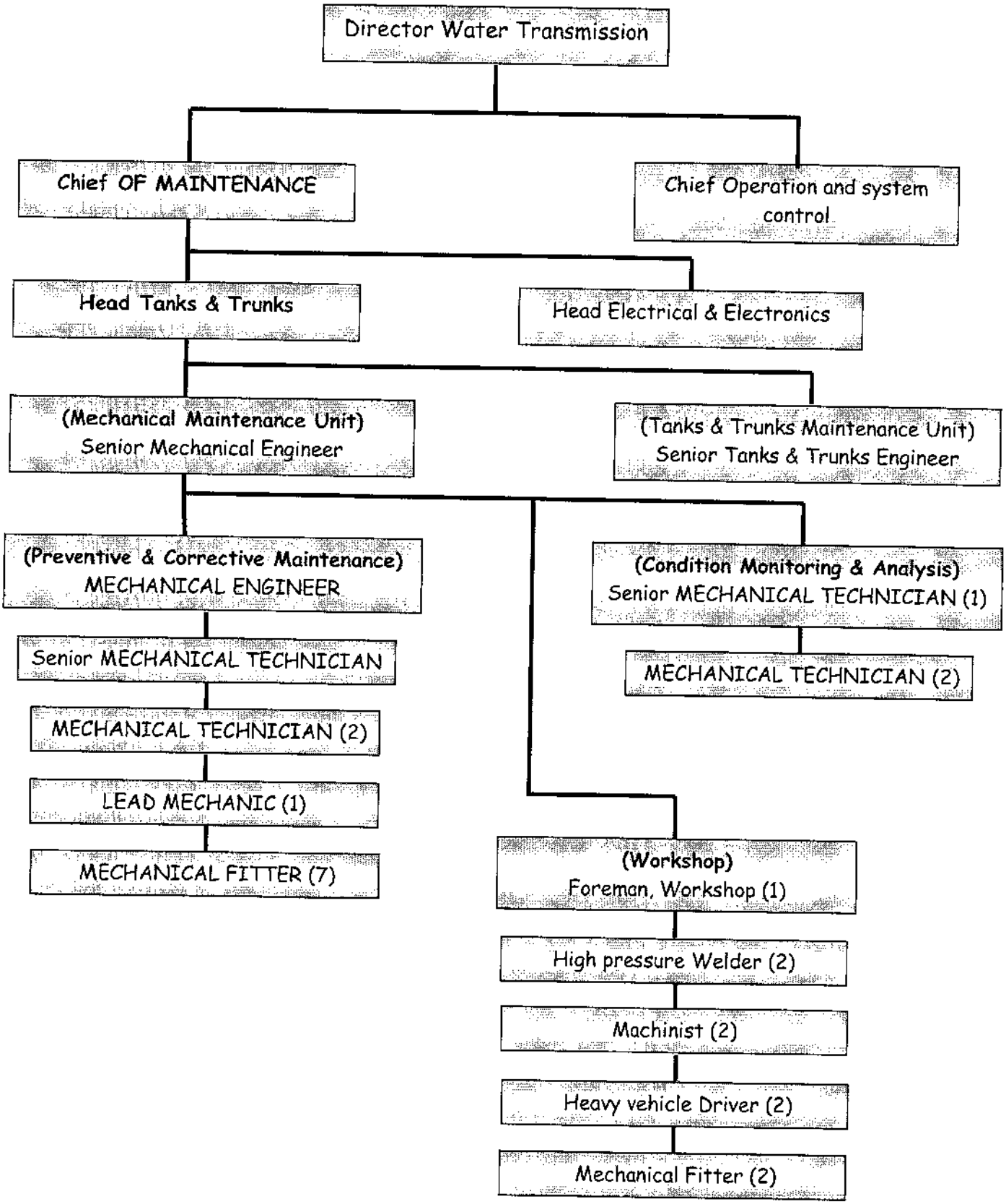



**Figure 9 – Organization structure of Water Transmission Directorate**

### 3.5.2) Mechanical maintenance section

Water Transmission Directorate has the capacity of pumping around 150 MGPD of water using more than 271 pumps and associated accessories installed at 40 different stations on the island. Out of these about 206 pumps of different capacities varying from 61 liters per second to 879 liters per second, installed at twenty two blending, pumping and forwarding stations at various parts of the island.

Maintenance of these pumps, associated equipment and accessories, keeping the plant at peak efficiency reducing the down time and increasing the life of the plant is the main objective of the Mechanical Maintenance Section. This section is located at Salmabad Workshop and it is one of major sections of the Maintenance Department.

**Major equipment**

Mechanical Maintenance Section is responsible for the maintenance of different types of equipment, such as:

1. Pumps (a wide variety of different types of pumps, depending on their usage such as: water forwarding pumps "ground, distillate, blended", submersible pumps, chlorine booster pumps, sump pumps…etc).
2. Valves (gate valves, check valves, butterfly valves, safety valves).
3. Air compressors, Overhead cranes, Ventilation fans and Diesel generators.

**Mechanical maintenance main activities**

Water Transmission Directorate has established a committee to document every single activity within the firm in one manual, the purpose of this document is to define and describe the WTD maintenance program and to provide general procedures for all activities that constitute various maintenance practices. This documentation provides guidance to engineers and technicians to achieve and sustain a productive and effective overall maintenance program. The manual is divided into chapters describing each maintenance elements or activities. The subsections in the handbook describe the procedures and code of practices for maintaining the WTD's water transmission system (See Appendix B for activity description example). This will ensure that maintenance policies are practiced perfectly to the extent possible, this maintenance handbook has been brought forth as the key source of learning and understanding, as well as, a reference document. Here under are some samples of the main activities handled by the Mechanical Maintenance Section from the maintenance handbook.

a. **Planned preventive maintenance (PPM) activities**

1. Preventive activities for pumps and their auxiliaries (routine).
2. Predictive activities for pumps (condition monitoring).
3. Preventive activities for air compressors and their auxiliaries (routine).
4. Preventive activities for stand-by diesel generator and their auxiliaries (routine).
5. Preventive activities for ventilation and their auxiliaries (routine).

b. **Corrective maintenance for work request card:**

1. Major and minor correction activities for pumps and their auxiliaries.
2. Major and minor correction activities for air compressors and their auxiliaries.
3. Major and minor correction activities for stand-by diesel generator and their auxiliaries
4. Major and minor correction activities for ventilation fans and their auxiliaries.
5. Major and minor machining activities.
6. Major and minor welding activities.

c. **Outsourcing jobs:**

1. Overhauling of pumps
2. Reconditioning of valves.
3. Replacement of headers, elbows, ventilation fans, ducts, etc.
4. Major overhaul for stand-by diesel generator.

### 3.5.3) Planned Preventive Maintenance (PPM)

Basically planned preventive maintenance defined as the periodic inspection of planned assets and equipment to uncover conditions leading to production breakdown. The PPM system consists of a checklist that intended to convey to the worker, what work is required to be done to a specific item or component. For equipment within water transmission system, the frequency of conducting planned preventive maintenance is decided by the concerned section based on several criteria, it will be discussed in the coming sections, based on these criteria the concerned section should decide whether the PPM should be conducted monthly, quarterly or half yearly.

Prime responsibility of mechanical maintenance section will be to execute the PPM program, including the following tasks:

- To coordinate with planning unit and operation section in preparing the yearly master schedule.

- To follow up on weekly basis for the implementation as per schedule.
- To analyze the PPM activities with corrective maintenance for improvement of equipment performance.
- To carry out study for replacement of equipment on the basis of PPM history.
- To return the completed PPM cards to planning unit as per due date and advise the status of all delayed and un-attended PPM jobs.

Reference can be made to PPM standard procedure no. WTD-S-06-1998 at Appendix C.

**Pump planned preventive maintenance**

There is a task sheet prepared by maintenance and planning section for recording every important item related to the pump during the PPM visit or inspection. In this sheet a lot of information and details are filled about every single devices and equipment related to the pump like flow rate, suction and discharge pressure, oil level, pump body condition, foundation bolts, leakage from suction and discharge valves, bearings grease and oil level, non-return valve condition, and other parameters about the alignment and temperature. (See Appendix D for full details of Pump Task Sheet)

**Pumps PPM criteria**

In any plant, there must be certain criteria to be taken under consideration when preparing PPM program for any equipment. The following points are the criteria considered for the PPM program.

a. Manufacturer recommendations:

Intervals and activities are identified by request for maintenance in order to run the equipment with high performance and availability.

b. Experiences:

By knowing the plant and have full appreciation of its equipment, which will give some confidence to the management staff to take an action for reducing the maintenance cost from either or both ways, the downtime and the shutdown activities.

c. Condition based monitoring technique:

This type of technique will give some guidance for such an action to be taken by recording parameters such as temperatures, vibration, leaks and other which called in terms of an objective condition monitoring. All these types will lead to know how far this equipment last and operate before its failing time. In addition, it will give some guidelines for keeping the

equipment in service or taking it out of service during its bad condition.

d. Aging:

Long term of operation of an equipment causing un expected failure, which leads to decrease its reliability. At the same time, it might affect other machine/s to be failed and so, the plant reliability will decrease even more. Because of that, plant experienced staff will make a decision to continue repairing or rehabilitate the equipment or scraped the old by a new one. In conclusion, aging of equipment will cause an increasing of down time, increasing maintenance cost and decreasing of the plant reliability.

**Overhauling program**

Mechanical Maintenance Section had made program to overhaul pumps and related equipment as part of planned program based on physical condition of the equipment, maintenance experience and manufacturers instruction. According to this program the schedule overhauling frequency is once every four years. To keep this frequency between 18 to 28 number of pumps of different capacities are planned to overhaul every year. The actual plan for pumps overhauling are shown in the table attached in Appendix E. which shows the year of overhauling of every individual pump.

### 3.5.4) Corrective maintenance

Corrective maintenance is defined as maintenance carried out to restore (including adjustment and repairs on items) machine from failure, which has raised to meet an acceptable condition. An average of seventy number of work request cards per month received to carry out corrective maintenance at different stations all over the country.

**Corrective maintenance procedure**

Mechanical Engineer will review the defect or job described in the Work Request Card (WRC) and will approve the WRC, and will forward it to senior engineering technician and technician for job scheduling. Mechanical engineer will discuss the defect and jobs with technicians as per the priority assigned, tasks involved, and availability of spare parts and material, as well as the manpower and time required for completion of the job.

Accordingly, the job schedule will be prepared and planned start time and planned completion will be entered on the work card and this will be given to the assigned crew. The assigned crew will carry out the work as scheduled, and after completion of the work, the original WRC will be returned to Planning Unit signed by the requester as "Accepted" and engineer or

senior technician tick as "Completed" with the required entries for man-hours spent, material used and actual period of work. See Appendix F for WRC procedure.

### 3.5.5) Condition monitoring program

Detection and diagnosis of machinery problems is obviously the most desirable way to maintain machinery. If a problem can be detected early, when defects are minor and do not affect machine operation, and if the nature of the problems can be diagnosed as the machine runs; then shut down for repairs can be scheduled for a convenient time. A work schedule, together with the requirements for manpower, tools and replacement parts can be prepared before the scheduled shutdown. Extensive damage to the machine resulting from forced failure can be minimized. Repair time can be kept to a minimum, resulting in less machinery down time. An effective condition monitoring program is a total program of detection, analysis & correction.

This is a logical sequence of steps. The program first helps to detects the onset of a problem. It then provides means for analyzing the problem in order to determine its cause. Finally it puts you in a position to correct the problem, effectively and efficiently, at a convenient time.

#### Detection

The first step in the program is the detection of the problem. This means for example keeping track of a machines' level of vibration and noting any increase that indicates developing of mechanical trouble. All machines in this program should be tested in this fashion, or monitored, according to a prescribed schedule. Some kinds of machines can be scheduled for monitoring one time every couple of months, some every several weeks, some daily and in the case of particularly critical machines, the monitoring can be done continuously.

#### Analysis

Vibration measurement with a meter, data collector or monitor is only the detection part of the total program to control machinery condition. Once trouble has been detected, the next step is to determine the nature of the problem, this is the purpose of analysis to pinpoint a specific machinery problem by identifying its unique vibration characteristics. The analysis of machinery vibration is done by a special instrument Data Pack Vibration Analyzer.

#### Correction

When the basic steps of a condition monitoring program been used, to detect and analyze a problem in its early stages, the work then can be scheduled for correction of any problems

raised. Machinery faults such as bad bearings, looseness or misalignment can be then corrected. Generally most of the problems being with following:

- ❖ Vibration: Each machine will have a vibration while it is in operation, so, limits of vibration should be specified to know "how much" for that particular machine considering the initial installation, rolling element bearings, gear teeth class of the machine, site conditions etc. So the vibration readings has to be checked and analyzed periodically to pin point the reason and predict the type of maintenance required.
- ❖ Bearing condition: Bearing replacement is an expensive proposition, and most bearings are replaced long before their designed life is reached. Using proper instruments bearing faults such as dry running, rubbing, slipping and other imperfections of rolling elements and raceway are identified and corrected.
- ❖ Cavitation: This occurs when the fluid forms bubbles in the pump, which results low efficiency and the impeller and housing damage. This cannot be heard or identified without the help of proper instrument.
- ❖ Unbalance: Unbalance can take place for the rotating assembly and this can be identified by proper monitoring instrument.
- ❖ Misalignment: This complain can be developed even within short time course and shall be identified and corrected in order to prevent leading to further defects and damages.

**Condition monitoring devices**

It is very important to show the main devices used for detection of any abnormal level of vibration, temperature and noise. Here are the main devices within condition monitoring group:

1. Vibration device: this device called SKF Microlog MCXA50, this device purchased in 2001. It is used for taking measurement of vibration for rotating machinery, it is supported by software PRISM4, which has the capability of data presentation, analysis, reporting, history & record keeping.
2. Temperature device (SKF TMD T2): it is digital device and used mainly to measure the bearing and body temperature.
3. Sound level device (Martel 325): it is used for measuring noise level around the rotating machinery to notice any abnormal noise.

# CHAPTER FOUR
# METHODOLOGY

## 4.0) Introduction

In this chapter the approach used throughout this research work is discussed. There are many steps that are implemented in order to reach final results and the analysis process. All of these steps are explained below.

## 4.1) Problem Definition

Some common types of mechanical defects are continuously occurring on a regular basis mainly on pumps, here are some examples of these defects:

- Leakage from gland packing of the pumps
- Leakage from discharge header
- Check valve is not working properly
- Inboard bearing is noisy
- Outboard bearing temperature is high
- Drain valve is blocked

The concern here for the above examples can be expressed by some questions like: why are these defects repeated? why do they occur continuously? what are the actions implemented to repair these defects? what are the actions implemented by Mechanical Section to prevent or to eliminate them from occurring? are these defects anticipated? is there any preventive maintenance for pumps and is it efficient?

## 4.2) Relevant Data Collection

There are two main sources of data for this research, the first one is the Planning Section and the second is the Mechanical Section and both of them are under the umbrella of Water Transmission Directorate. Planning Section is responsible to monitor all the Work Request Cards (WRCs). These WRCs for the defects are issued by the Field Operation Section on every individual equipment in pumping station. All of these defects are stored in the Computerized Maintenance Management System (CMMS). There are some basic information for each individual WRC, like the name of the equipment, description of the defect, date of reporting defect, the type of repair action by maintenance section, cost of material, date of repair completion and other information. All of these information are in Excel format.

The second source of data is the Mechanical Section. It provides the history of overhauling programs of the pumps, and the Planned Preventive Maintenance (PPM) task sheets, these hard sheets contain the date of PPM visits, and the number of people attending the visit including number of hours.

### 4.3) Data Validations and Verifications

There are two types of data collected, the first one as a soft copy collected in Excel format which contains the main information about each WRCs, and the second type is normal hard copies mainly related to preventive maintenance tasks which contains the date and time of each task and the number of people conducting this task.

The soft data consumes extra effort to validate and verify only the related data belonging to the system of each station. Any data not related to the individual station under consideration are removed to reduce its size. The data are also verified by the mechanical maintenance technicians and engineers.

### 4.4) Data Classification

This section will give a brief explanation of the steps taken to classify and segregate available data. It is important here to mention that there are two types of data, corrective maintenance data and preventive maintenance data. Corrective maintenance data include the WRCs and it will be explained first since it represent the major data collected.

1. Corrective maintenance data classification

   Data of corrective maintenance are in Excel format, it is mainly the WRCs raised by field operation staff to planning section, reporting certain types of defects on equipment, the classification process of these data are explained in the following steps:

   a. First process of classification is to segregate the data or the WRCs based on each individual station (this project includes five main stations). All data for each station are collected in one Excel sheet.
   b. The second step is to remove the WRCs which are not related to the pumps, fittings and other equipment connected with the pumps. All other data for example related to motors, tanks, and elevated storage reservoirs are removed from the lists.
   c. The third step is to segregate the data based on each individual pump, all WRCs that belongs to each pump kept in one Excel sheet.

d. Forth step is to classify all WRCs based on their date and year of issuance, each one has its own number and date. This process helps to know how many defects are reported in each year for every individual pump in each station.

e. New Excel sheets are generated for every station. These sheets contain mainly frequency of defects (all types of defects) for all pumps, time of repair actions for individual defects, and cost of repair actions. These formats are shown in Appendices H, I, J, K and L.

f. The final step of classification is to extract all the information of the mechanical defects for each individual pump in each station. All electrical, instrumentation and telecommunication defects for the pumps are removed since the study is for the Mechanical Section.

2. Preventive maintenance data classification

These data are available in hard format. Each individual pump has its own sheet which contains the date of PPM visit, duration of the visit, number of technicians and their grades. All of the data available in the task sheets are presented in tabular format, where the final format of tables can show the following data

- Number of PPM visits for each pump
- Total visit times for each pump
- Total man-hours of each pump
- Total cost of man-hours for each pump

### 4.5) Data Analysis and Results

The analysis of the available data for both the corrective and preventive maintenance is conducted in steps as well, the focus of analysis is based mainly on the frequency and time for repair. Because the budget allocated to Maintenance Department is huge compared with the cost of repairing, it is decided to concentrate the analysis of corrective maintenance data on their frequency not their cost. From a broader point of view, the common link for all stations is the Maintenance Section, since all stations have the same equipment and same types of water. Maintenance crews responsible to conduct repair or preventive works for all pumps in all stations are the same. If the maintenance crews manage to conduct proper corrective and preventive maintenance tasks, the frequency of defects, time and cost definitely will be reduced for all stations.

Initially the corrective maintenance analysis is conducted as follows:

- The data of all types of mechanical defects related to pumps only are summarized and presented in tables showing their frequencies, the time and cost of repair actions.
- Pareto chart (20/80 rule) is drawn for each station showing the major mechanical defects for the pumps, and comparative analysis is conducted among stations.
- From Pareto charts, a new table is generated showing the major types of defects for all pumps in all five chosen stations, this table is utilized for further analysis of the defects based on their frequencies.
- The first five major defects are analyzed thoroughly by calculating mean time between failures, failure rate, mean time to repair, availability and reliability of equipment. Also analysis is done based on the cost of repair actions.
- Analysis is conducted based on the defect, how it is being repaired, and how many times this type of repair is repeated. This analysis is conducted for major defects.

The preventive maintenance analysis is conducted as well based on the collected data. The analysis concentrates on the averages of PPM visits and the cost of visits for each pump, number and cost of technician man-hours conducted for PPM visits. Relationship analysis between the corrective and preventive is conducted also to have an indication about the effectiveness of the preventive maintenance and its reflection on the corrective maintenance. These are the main categories of preventive maintenance analyses.

### 4.6) Discussion Conclusion and Recommendations

The final step of the methodology is the discussion of the findings and possible explanations about the state of the corrective and preventive maintenance. Finally, conclusion and recommendations are drawn.

# CHAPTER FIVE
# DATA COLLECTION

## 5.0) Introduction

This chapter will cover the data collection for all stations covered in this project. The data are mainly covering the corrective maintenance represented by the defects cards and preventive maintenance represented by preventive maintenance task sheets containing all data related to this type of maintenance. Initially the corrective maintenance data collected cover all maintenance sections, it will be sorted out to have only the one related to mechanical maintenance. The preventive maintenance data belong to Mechanical Section.

## 5.1) History of Data

Since 2005 an integrated Computerized Maintenance Management System (CMMS) was introduced within WTD in order to reduce the huge paper work which was the normal practice before year 2005 for reporting defect, its number, priority, date of failure, location, equipment name, type of failure, time of failure, and reporter name. These initial information are significant and essential for maintenance sections to understand the nature of defect and plan for rectifying it.

After completion of work by maintenance section, many other information are added like defect repair date, time consumed, man-hours utilized, material consumed, cost of manpower, equipment utilized and approver name.

All the above information used to be recorded manually in papers, but after creating the CMMS all of the information fed to the system. The CMMS was created locally by one of the technicians who utilized Microsoft Access to create this system.

## 5.2) Sources for Data

A summary of the sources of data that will be used in the thesis is given below:

- All defects and failure data were collected from localized CMMS including all information from issuing the defects' cards until its clearing and cancelations.
- All PPM tasks data were collected from PPM cards, and the Planning Section keeps these cards in the documents' room.
- History of overhauling for the pumps were collected from Mechanical Maintenance Section.

### 5.2.1) Time span of data

The time span of the data collected for this work is from 2005 up to 2011, i.e. the data collected from CMMS since it was created. Data before year 2005 is not available because it was scraped (Data were on files only).

### 5.3) Reasons for Selecting Mechanical Maintenance Section

A question will be raised about the focus of this thesis on Mechanical Maintenance Section rather than other sections, the answer for this question can be summarized in the following paragraphs.

a. Summary of data from MMS:

The data collected from MMS for all the five stations covered in this thesis, shows that the majority of defects belong to the Mechanical Section, the summary of the different sections defects and their percentages are listed in Table 4 hereunder.

**Table 4 - Summary of defects for each maintenance section**

| Rank | Maintenance Section | No. of Defects | Percentage (%) |
|---|---|---|---|
| 1 | Mechanical | 1098 | 24.93 |
| 2 | Instrument | 1057 | 23.69 |
| 3 | Electrical | 967 | 21.95 |
| 4 | Civil | 618 | 14 |
| 5 | Process | 350 | 7.94 |
| 6 | Tanks | 241 | 5.5 |
| 7 | Operations | 63 | 1.43 |
| 8 | Trunk | 8 | 0.18 |
| 9 | Planning | 4 | 0.1 |
| **Total** | | **4406** | **100 %** |

The total number of defects for all stations are 4406, this covers all types of defects for all maintenance sections, almost 25% of defects is registered to mechanical only.

b. Analysis of pumps defects and its accessories:

Deep filtration is conducted to all data from MMS to extract the defects related to pumps and any defect for any equipment connected to pumps. Examples of some defects related to pumps are summarized in Table 5.

**Table 5 - Sample types of defects for maintenance sections**

| Type of Defect | Maintenance Section |
|---|---|
| Gland packing of pump is leaking | Mechanical |
| Shaft is jammed | Mechanical |
| Inboard bearing is noisy | Mechanical |
| Outboard bearing temperature is high | Electrical |
| Load breaker switch is not functioning | Electrical |
| Pump trip on under current | Electrical |
| Speed controller is not working | Instrument |
| Pump failed without alarm | Process |
| Pump is not working on remote | Process |
| RPM is not working | Instrument |

The above examples cover some of maintenance sections except Civil, Tanks and Trunk Sections, where there were no defects recorded linked with pumps. In Table 4 there are 4406 defects registered for all stations and all sections, but in Table 6 the total defects related to pumps only are 1139 for the main four maintenance sections.

In the process of filtration, main information related to each defect were recorded whether it is related to the pump itself or its accessories, information like,

i. Types of defects
ii. The concerned maintenance section
iii. Frequency of defects
iv. Cost of repair defects
v. Time to repair defects

Table 6 shows these data categories for the different maintenance sections

**Table 6 - Summary of frequency, time and repair cost for each maintenance section**

| Maintenance Section | Defects details | | | | | |
|---|---|---|---|---|---|---|
| | Frequency (Nos.) | Frequency (%) | Total Time (Hrs) | Time (%) | Total Cost (BD) | Cost (%) |
| **Mechanical Maintenance** | 660 | 57.95 | 10784.69 | 67.01 | 52,976.72 | 60.62 |
| **Electrical Maintenance** | 164 | 10.8 | 2250.55 | 4.63 | 19,575.00 | 3.36 |
| **Instrument Maintenance** | 123 | 14.4 | 745.92 | 13.98 | 2939.31 | 22.4 |
| **Electronics Maintenance** | 192 | 16.86 | 2313.78 | 14.38 | 11,899.44 | 13.62 |
| **Total** | **1139** | | **16094.94** | | **87,390.46** | |

Furthermore, the percentage of each category (Defect Frequency, Time and Cost) was plotted separately to show which category should have to be focused on. The above table and Chart 1 below show that most of defects, time and cost were mainly exercised by Mechanical Maintenance Section (MMS) only, and these evidences guide us to concentrate on Mechanical Section rather than other sections.

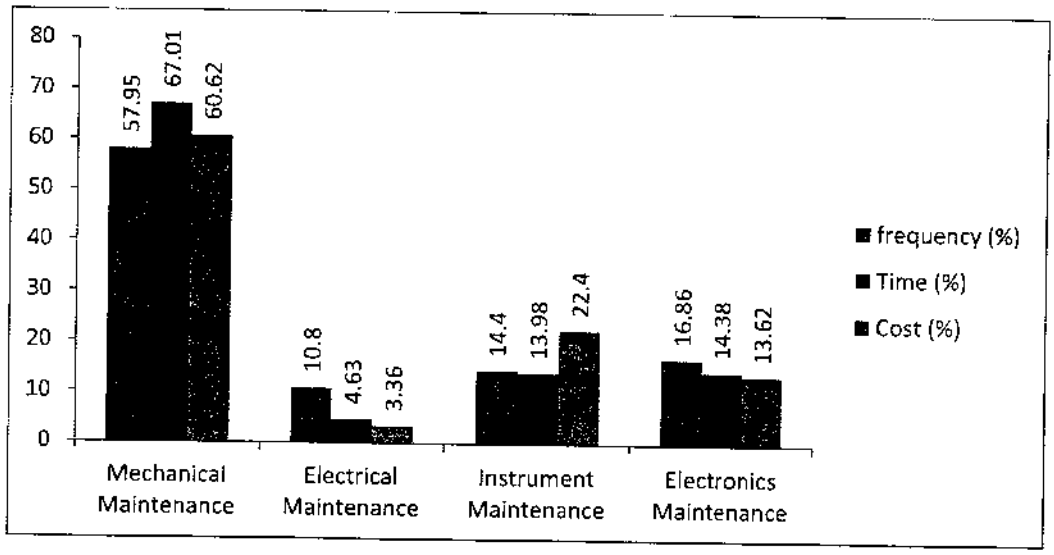



**Chart 1 - Percentage of pump's defect frequency, time and cost for each maintenance section**

### 5.4) Pumps' Defects Analysis by Station

This section covers the five stations under investigations, brief description is given for each station and some information about the incoming water from other stations and water supply to the network. Then more elaborations about the types of defects, their frequencies, time of maintenance and cost of repair are included.

#### 5.4.1) Hamala A2 Ground Forwarding Station (GFS)

**a. Station description**

Hamala A2 GFS is located in Hamala village, the station is designed to receive ground water from all ground water boreholes (Hamala A2, B, C, D, E, F, and Jasra). The received ground water is stored within three ground storage tanks (the capacity of each tank is one million gallon) and forwarded to West Riff'a-1&2 Blending Station and Hamad Town Blending Station.

**b. Ground water abstraction in year-2011**

- Hamala A2 has six Boreholes –Total abstraction of 1395.31 MG during year 2011.
- Hamala B, D, E and F have six Boreholes-Total abstraction of 1016.30 MG during year 2011.
- Hamala C has six Boreholes- Total abstractions of 1130.30 MG during year 2011.
- Jasra has two Boreholes-Total abstractions of 236.4 MG during year 2011.

**c. Average incoming supply**

The station received ground water from Hamala A2, B, C, D, E, F, and Jasra with an average of 10.34 MG/day, the total abstraction was 3778.18 MG in 2011. The station forwards ground water to Hamad Town Blending Station through 600 mm pipeline with an average of 5.99 MG/day in year 2011, and for West Riff'a no. 1&2 through another 600 mm pipeline with an average of 2.01 MG/day in year 2011.

**d. Station site layout**

Figure 10 shows the main details of the Hamala A2 GFS Station.

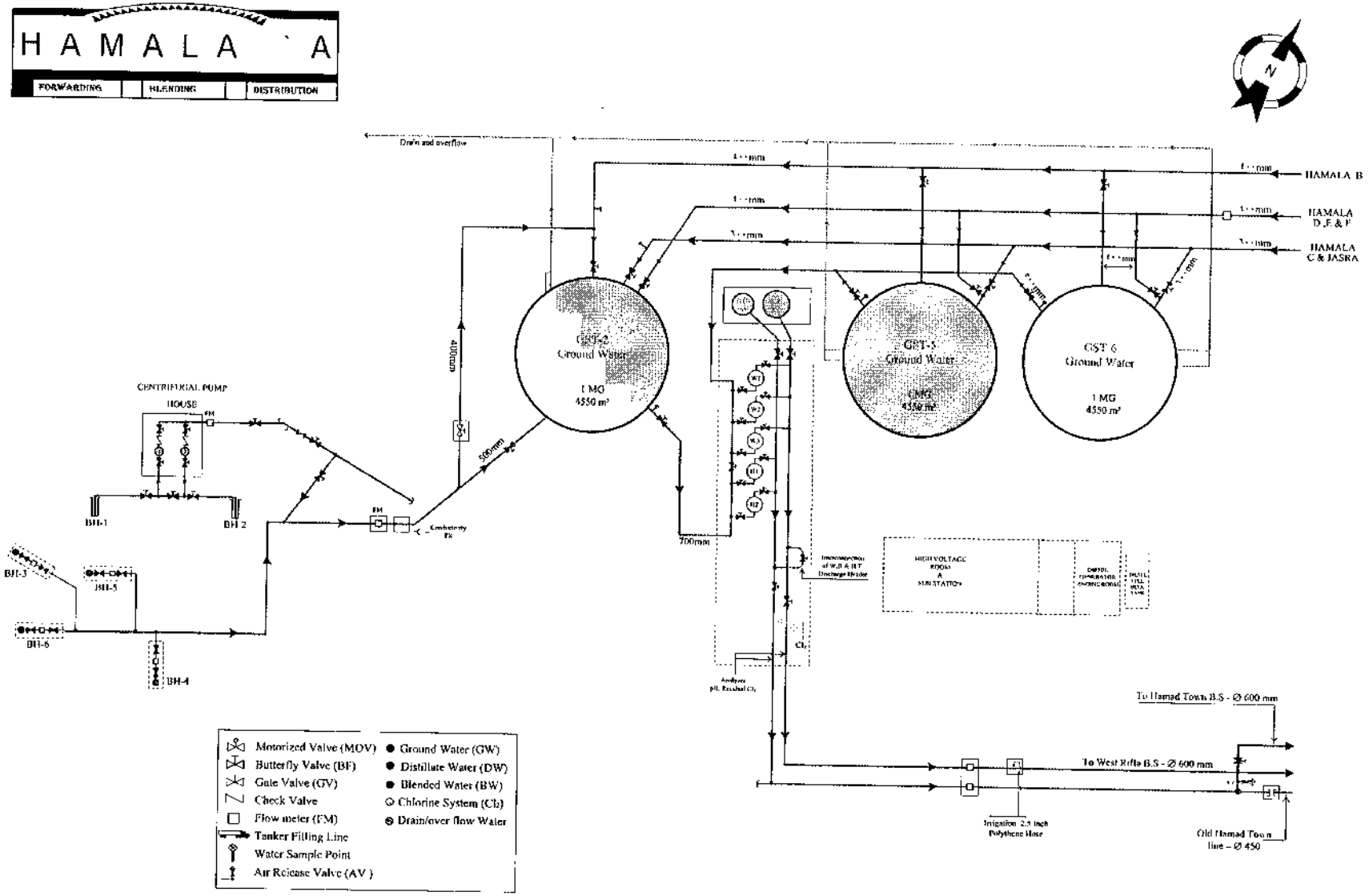





Figure 10 – Hamala A2 ground forwarding stations drawing

### e. Total defects reported for Hamala A2 GFS

The defects' data for the above mentioned station are summarized for each year from 2005 to 2011and for each individual pump as shown in Table 7

**Table 7- Details of number of defects for each individual pump at Hamala A2 GFS**

| Sr.No. | Pump Name | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1 | W.R. BS#1 | 6 | 9 | 9 | 12 | 7 | 5 | 2 | **50** |
| 2 | W.R BS#2 | 5 | 4 | 5 | 13 | 6 | 5 | 2 | **40** |
| 3 | W.R. BS#3 | 3 | 6 | 6 | 8 | 4 | 8 | 1 | **36** |
| 4 | HT BS #1 | 5 | 5 | 4 | 2 | 2 | 8 | 2 | **28** |
| 5 | HT BS #2 | 15 | 3 | 9 | 6 | 2 | 7 | 2 | **44** |
| **Total per 5 pumps** | | **34** | **27** | **33** | **41** | **21** | **33** | **9** | **198** |

The above table shows the numbers of defects raised from Field Operation Unit to all maintenance sections. So there were 198 defects raised from year 2005 up to 2011 in total.

### f. Analysis of defects

Initial analysis is done for all defects issued for every single pump at Hamala A2 station by extracting the information from these defects such as types of defects, frequency of each defect, time spent for repair, and finally the cost of repair. All of these details are tabulated and shown in Appendix H. Table 8 below shows the types of defects, total frequency, time and cost for all Hamala A2 pumps and maintenance sections.

As a summary, 198 defects recorded for all pumps took 3731.38 hours to repair with a total maintenance cost of 19313.59 BD .

**Table 8 - Summary of defects, frequency, time and cost for all Hamala A2 pumps**

| No. | Types of defects | Total Summary | | |
|---|---|---|---|---|
| | | Frequency (No.) | Total Time (Hrs) | Total Cost (BD) |
| 1 | Leakage from discharge line | 12 | 177.70 | 675.10 |
| 2 | Gland packing of the pump is leaking | 81 | 1,577.53 | 8,354.39 |
| 3 | Gland packing of the pump is smoking | 6 | 57.50 | 155.65 |
| 4 | Gland packing of the suction valve is leaking | 1 | 20.49 | 38.27 |

| | | | | |
|---|---|---|---|---|
| 5 | Gland packing of the discharge valve is leaking | 0 | 0.00 | 0.00 |
| 6 | Check valve is passing | 5 | 127.50 | 382.93 |
| 7 | Check valve is hammering / not working properly | 4 | 174.00 | 500.30 |
| 8 | Drain valve is blocked /leaking/broken | 11 | 138.66 | 330.81 |
| 9 | Suction pressure gauge is not working | 14 | 44.00 | 194.55 |
| 10 | Discharge pressure gauge is not working | 8 | 28.75 | 278.60 |
| 11 | Casing is leaking from pin hole | 2 | 208.00 | 2,091.50 |
| 12 | Inboard bearing is noisy | 13 | 347.25 | 3,702.06 |
| 13 | Outboard bearing is noisy | 3 | 94.50 | 394.91 |
| 14 | Inboard bearing temperature is high | 2 | 11.00 | 35.20 |
| 15 | Outboard bearing temperature is high | 4 | 105.50 | 292.30 |
| 16 | Inboard bearing grease is coming out | 3 | 35.00 | 93.46 |
| 17 | Outboard bearing grease is coming out | 0 | 0.00 | 0.00 |
| 18 | Problem in load breaker switch | 10 | 409.00 | 1,148.73 |
| 19 | Problem in power supply | 2 | 43.00 | 134.90 |
| 20 | Tripping due to under current | 4 | 11.00 | 29.00 |
| 21 | Tripping due to over current | 1 | 4.00 | 11.20 |
| 22 | Tripping due to over load | 1 | 8.00 | 22.80 |
| 23 | Pump not working on remote | 7 | 85.00 | 340.95 |
| 24 | Motor inboard bearing is noisy | 2 | 11.00 | 50.30 |
| 25 | Motor outboard bearing is noisy | 0 | 0.00 | 0.00 |
| 26 | Pressure switch is not functioning / tripping pump | 2 | 13.00 | 55.70 |
| | **Total** | **198** | **3,731.38** | **19,313.59** |

### 5.4.2) Hamad Town Blending Station (HTBS)

#### a. Station description

Hamad Town blending station is located in Hamad Town area. The station is designed to receive reverse osmosis water and distillate water from West Riff'a #1 Blending Station, as well as ground water from Hamala A2 GFS, blending process will take place utilizing ground and distillate water pumps. The blended water will be stored in the tanks and then will be supplied to consumers and Hamad Town Distribution Station.

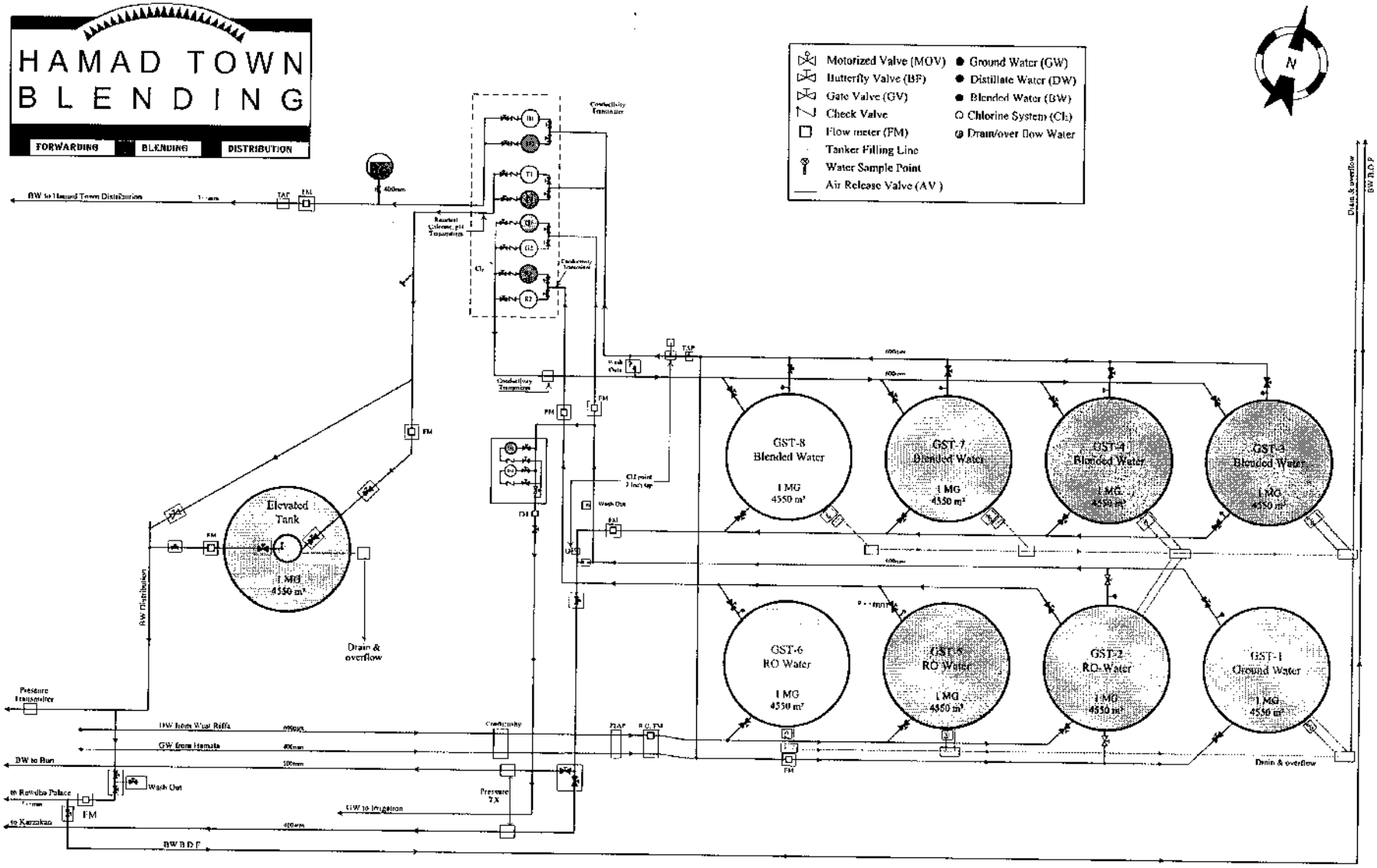
#### b. Incoming and outgoing water supply

The station receives ground water from Hamala A2 GFS , with an average of 5.99MG/day during year 2011. In addition, the station received reverse osmosis desalinated water from West Riff'a #1 BS with an average of 14.35 MG/day during year 2011.

The station forwards blended water to Hamad town distribution station, with an average of 7.65 MG/day during year 2011, the elevated storage reservoir supplies Hamad town area with an average of 4.42 MG/day in year 2011 and the ground storage tanks supplies customers using gravity with an average of 7.34 MG/day in year 2011. The average total dissolved solids of the supplied water was 1521 PPM with PH of 7.42.

**c. Station site layout**

Figure 11 shows the main details of the Hamad Town Blending Station.




51

Figure 11 – Hamad Town Blending Station drawing

### d. Total defects reported for HTBS

The defects' data for the above mentioned station are summarized for each year from 2005 to 2011, and for each individual pump as shown in Table 9.

**Table 9 - Details of number of defects for each individual pump at HTBS**

| No | Pump Name | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Distillate Water #1 | 7 | 6 | 9 | 1 | 4 | 2 | 3 | **32** |
| 2 | Distillate Water #2 | 5 | 6 | 3 | 7 | 7 | 2 | 7 | **37** |
| 3 | Ground Water #1 | 5 | 7 | 1 | 6 | 4 | 4 | 2 | **29** |
| 4 | Ground Water #2 | 7 | 3 | 3 | 3 | 10 | 7 | 3 | **36** |
| 5 | Tower Pump #1 | 2 | 3 | 5 | 0 | 2 | 7 | 1 | **20** |
| 6 | Tower Pump #2 | 0 | 6 | 3 | 5 | 11 | 0 | 4 | **29** |
| 7 | Hamad Town DS #1 | 6 | 11 | 10 | 1 | 2 | 3 | 2 | **35** |
| 8 | Hamad Town DS #2 | 9 | 12 | 6 | 8 | 4 | 6 | 7 | **52** |
| **Total per 8 pumps** | | **45** | **56** | **40** | **32** | **45** | **31** | **31** | **278** |

The above table shows the numbers of defects raised from Field Operation Unit to all maintenance sections. So there were 278 defects raised from 2005 up to 2011 in total.

### e. Analysis of defects

Initial analysis is done for all defects issued for every single pump at Hamad Town Blending Station, by extracting the information from these defects such as types of defects, frequency of each defect, time spent for repair, and finally the cost of repair. All of these details are tabulated and shown in the Appendix I. Table 10 below shows the types of defects, total frequency, time and cost for all HTB pumps and all maintenance sections.

In summary, 278 defects recorded for all pumps took 3619 hours to repair with a total maintenance cost of 22795 BD to repair the defects.

**Table 10 - Summary of defects, frequency, time and cost for all HTB pumps**

| No. | Types of defects | Total no. of Defects | | |
|---|---|---|---|---|
| | | Frequency (Nos) | Total Time (Hrs) | Total Cost (BD) |
| 1 | leakage from discharge line | 25 | 399.5 | 1103.89 |
| 2 | Gland packing of the pump is leaking | 49 | 608.58 | 2099.39 |
| 3 | Gland packing of the pump is smoking | 11 | 148.5 | 497.6 |
| 4 | Gland packing of the suction valve is leaking | 0 | 0 | 0 |
| 5 | Gland packing of the discharge valve is leaking | 0 | 0 | 0 |
| 6 | Shaft is jammed | 3 | 56.5 | 153.54 |
| 7 | Coupling is damaged | 4 | 95 | 1023.61 |
| 8 | Pump is not sucking water | 2 | 13 | 46 |
| 9 | Relieve valve is blocked | 8 | 61 | 144.6 |
| 10 | Check valve is passing | 10 | 172.66 | 401.1 |
| 11 | Check valve is hammering / not working properly | 3 | 42 | 112.2 |
| 12 | Drain valve is blocked /leaking/broken | 12 | 103.66 | 672.95 |
| 13 | Suction pressure gauge is not working | 14 | 61.16 | 145.25 |
| 14 | Discharge pressure gauge is not working | 16 | 85.42 | 266.23 |
| 15 | Casing is leaking from pin hole | 2 | 18 | 27.3 |
| 16 | Inboard bearing is noisy | 13 | 382.83 | 1215.69 |
| 17 | Outboard bearing is noisy | 2 | 16 | 49.4 |
| 18 | Inboard bearing temperature is high | 1 | 5 | 26.25 |
| 19 | Outboard bearing temperature is high | 1 | 10 | 33.1 |
| 20 | Inboard bearing grease is coming out | 0 | 0 | 0 |
| 21 | Outboard bearing grease is coming out | 0 | 0 | 0 |
| 22 | Problem in load breaker switch | 0 | 0 | 0 |
| 23 | Problem in power supply | 7 | 44 | 159.16 |
| 24 | Tripping due to under current | 0 | 0 | 0 |
| 25 | Tripping due to over current | 0 | 0 | 0 |
| 26 | Tripping due to over load | 0 | 0 | 0 |
| 27 | Pump not working on remote | 15 | 129 | 389 |
| 28 | Motor inboard bearing is noisy | 9 | 249.5 | 839.32 |
| 29 | Motor outboard bearing is noisy | 5 | 165 | 550.51 |
| 30 | Pressure switch is not functioning / tripping pump | 0 | 0 | 0 |
| 31 | Ampere meter is hunting/not giving correct reading/not working | 33 | 382 | 8059.00 |
| 32 | Capacitor is burnt out | 8 | 96 | 386.05 |
| 33 | Display screen is not working/no reading | 6 | 69 | 220.08 |
| 34 | Speed controller is not working | 8 | 111 | 874.97 |
| 35 | RPM is not working | 4 | 28 | 92.7 |
| 36 | Cooling fan is not working | 2 | 11 | 36.45 |
| 37 | failed without alarm | 5 | 56 | 3170.1 |
| | **Total** | **278** | **3619** | **22795** |

### 5.4.3) Hamad Town Distribution Station (HTDS)

#### a. Station description

Hamad Town Distribution Station is located in Southern area. The station is designed to receive blended water from Hamad Town Blending Station, the blended water is stored within three ground storage tanks and one elevated tank with one million gallon capacity of each.

#### b. Average incoming and outgoing supply

The station receives blended water from Hamad Town Blending Station through 600 mm pipe line. Average incoming blended water from HTBS was 7.65 MG/day during year 2011. The station distributes blended water to Southern villages with an average of 2.59 MG/day during year 2011 using gravity flow from the ground storage tanks. The elevated storage reservoir supplies distribution network with an average of 5.23 MG/day during year 2011. The average TDS of the supplied water is 1521 PPM.

#### c. Station site layout

Figure 12 shows the main details of the Hamad Town Blending Station.

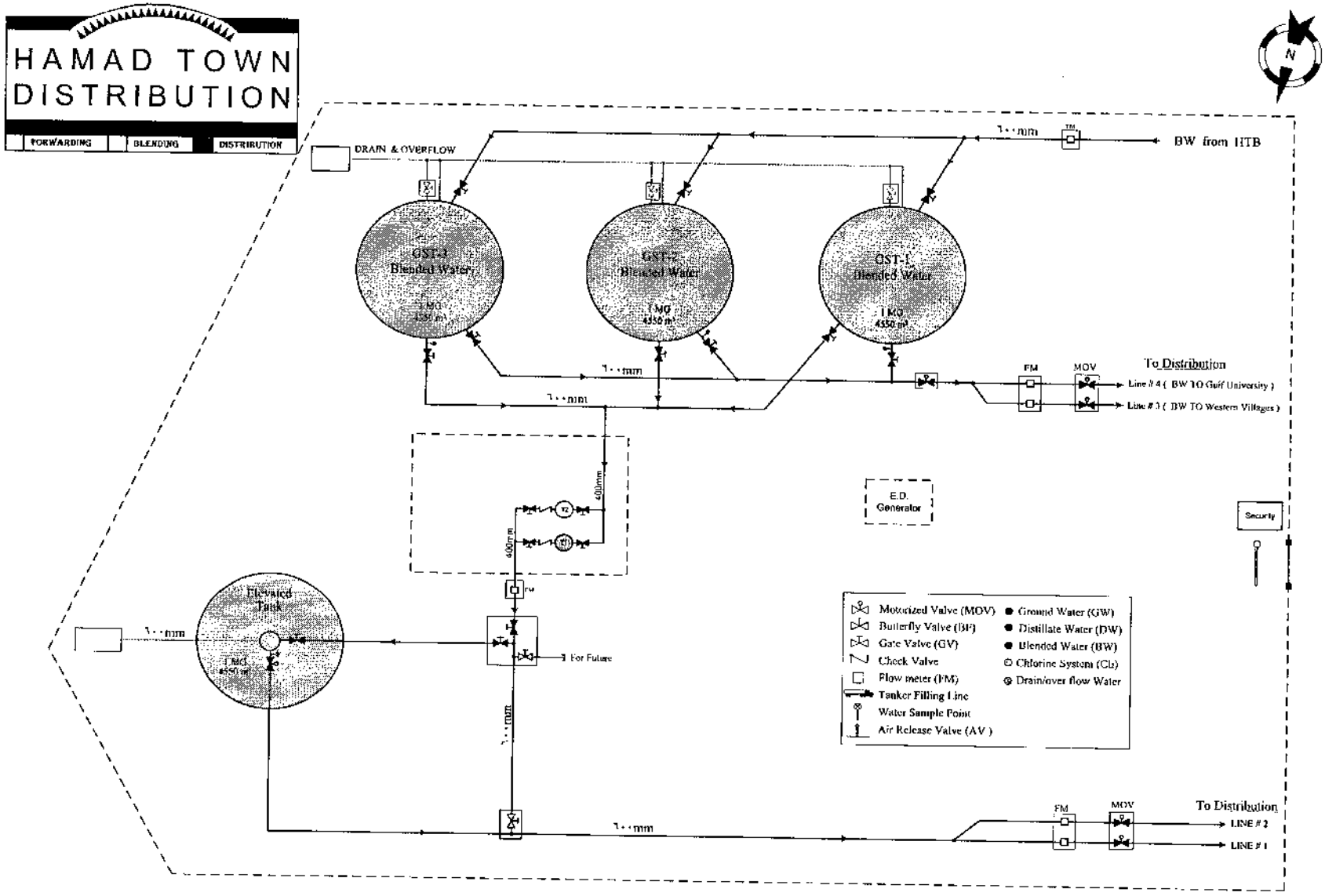





Figure 12 – Hamad Town Distribution Station drawing

### d. Total defects reported for HTDS

The defects' data for the above mentioned station are summarized for each year and for each individual pump as shown in the Table 11.

**Table 11 - Details of defects for each individual pump at HTDS**

| No | Pump Name | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Tower Pump #1 | 4 | 6 | 7 | 2 | 1 | 1 | 4 | **25** |
| 2 | Tower Pump #2 | 2 | 9 | 0 | 2 | 1 | 2 | 3 | **18** |
| **Total per 2 pumps** | | **6** | **15** | **7** | **4** | **2** | **3** | **7** | **44** |

The above table shows the numbers of defects raised from Field Operation Unit to all maintenance sections. So there were 44 defects raised from 2005 up to 2011 in total.

### e. Analysis of defects

Initial analysis is done for all defects issued for every single pump at Hamad Town Distribution Station, by extracting the information from these defects such as types of defects, frequency of each defect, time spent for repair, and finally the cost of repair. All of these details are tabulated and shown in the Appendix J. Table #12 below shows the types of defects, total frequency, time and cost for all HTDS pumps and all maintenance sections.

In summary, 44 defects recorded for all pumps took 357.533 hours to repair with a total maintenance cost of 2972.43 BD.

**Table 12 - Summary of defects, frequency, time and cost for all pumps at HTDS**

| No. | Types of defects | Total no. of Defects | | |
|---|---|---|---|---|
| | | Frequency (Nos.) | Total Time (Hrs) | Total Cost (BD) |
| 1 | leakage from discharge line (Header) from Pin hole | 1 | 16 | 50.6 |
| 2 | Gland packing of the pump is leaking | 2 | 17 | 72 |
| 3 | Gland packing of the pump is smoking | 1 | 13 | 52.7 |
| 4 | Gland packing of the suction valve is leaking | 0 | 0 | 0 |
| 5 | Gland packing of the discharge valve is leaking | 3 | 36 | 89.65 |
| 6 | Suction / discharge valve is jammed | 0 | 0 | 0 |
| 7 | Coupling cove to be re-fixed | 0 | 0 | 0 |
| 8 | Problem in discharge MOV /Actuator/stuck in position | 0 | 0 | 0 |

| | | | | |
|---|---|---|---|---|
| 9 | Problem in suction MOV /Actuator/stuck in position | 0 | 0 | 0 |
| 10 | Check valve is leaking | 3 | 23 | 55.2 |
| 11 | Check valve is hammering / not working properly / Passing | 3 | 56 | 124.9 |
| 12 | Drain valve is blocked /leaking/broken | 7 | 53 | 101.6 |
| 13 | Suction pressure gauge is not working | 1 | 3 | 7.2 |
| 14 | Discharge pressure gauge is not working | 3 | 12 | 32 |
| 15 | Actuator is leaking water from gear box | 0 | 0 | 0 |
| 16 | Inboard bearing is noisy | 1 | 15 | 30 |
| 17 | Outboard bearing is noisy | 1 | 0 | 0 |
| 18 | Inboard bearing temperature is high | 0 | 0 | 0 |
| 19 | Outboard bearing temperature is high | 0 | 0 | 0 |
| 20 | Inboard bearing grease is coming out | 0 | 0 | 0 |
| 21 | Outboard bearing grease is coming out | 0 | 0 | 0 |
| 22 | Vibration sensor is not reading / Tripping on high vibration | 0 | 0 | 0 |
| 23 | Problem in power supply | 4 | 30 | 102.5 |
| 24 | Tripping on LCP | 0 | 0 | 0 |
| 25 | Tripping on phase unbalance | 0 | 0 | 0 |
| 26 | Problem in DCS / data is stuck in display screen | 0 | 0 | 0 |
| 27 | Pump not working on sequence | 3 | 16 | 52.4 |
| 28 | Motor inboard bearing is noisy | 5 | 20.53 | 42.68 |
| 29 | Motor outboard bearing is noisy | 2 | 18 | 2036.2 |
| 30 | Level switch is not functioning / alarm standing | 0 | 0 | 0 |
| 31 | Motor current reading is low | 0 | 0 | 0 |
| 32 | Capacitor is is giving low readings | 0 | 0 | 0 |
| 33 | Smell is coming from Resistance box | 0 | 0 | 0 |
| 34 | Motor is tripping frequently | 2 | 13.5 | 80 |
| 35 | Motor is heating / high winding temperature | 1 | 5 | 12 |
| 36 | Speed cannot be controlled | 0 | 0 | 0 |
| 37 | Filed to start | 1 | 10.5 | 30.8 |
| | **Total** | **44** | **357.533** | **2972.43** |

### 5.4.4) West Riff'a #1 Blending Station (WR #1 BS)

#### a. Station description

West Riffa #1 Blending Station is located in West Riffa area. The station is designed to receive reverse osmosis water and distillate water from Ras Abu Jarjur Plant and Sitra Power and Water Station, respectively, also ground water. from Hamala A2 G.F.S., in addition the station receives potable water from Salmabad Forwarding Station.

**b. Storage capacity**

The station has six ground storage tanks: three blended tanks, one for ground water tank and two for distillate storage tank. All tanks are with one million gallon capacity, also, there are two elevated storage reservoirs with capacity of one MG for each one.

**c. Incoming and outgoing water supply**

The station receives ground water from Hamala A2 GFS with an average of 2.54MG/day in year 2011. Also, it receives reverse osmosis with an average of 21 MG in year 2011 from Ras Abu Jarjur and distillate water from Sitra DFS with an average of 12 MG/day in year 2011. The station forwards R.O. and distillate water to HTB Station with an average of 14.35 MG/day in year 2011. In addition, it forwards blended water to Isa Town towers utilizing gravity flow with an average of 8.47 MG/day in year 2011, and it forwards blended water to A'ali with an average of 2.52 MG/day in year 2011. All blended water is supplied with TDS of 1159 PPM.

**d. Station site layout**

Figure 13 shows the main details of the West Riffa #1 Blending Station.

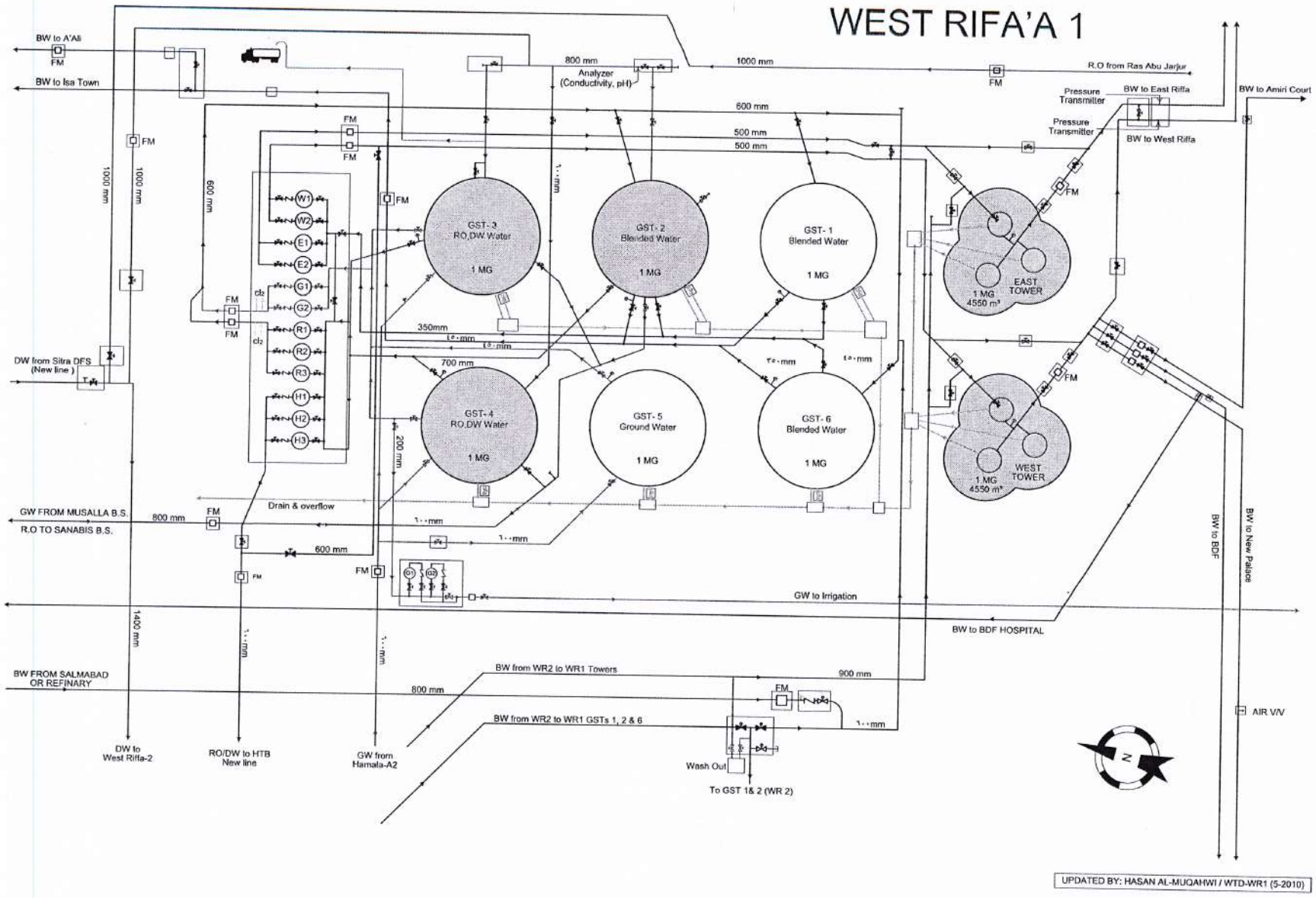





Figure 13 – West Riffa #1 Blending Station drawing

### e. Total defects reported for West Riff'a #1 BS

The defects' data for the above mentioned station for each year from 2005 to 2011 and for each individual pump is shown in Table 13.

**Table 13 - Details of defects for each individual pump at WR#1 BS**

| No. | Pump Name | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Distillate Water #1 | 5 | 7 | 6 | 4 | 4 | 1 | 5 | **32** |
| 2 | Distillate Water #2 | 1 | 6 | 1 | 1 | 3 | 6 | 4 | **22** |
| 3 | Distillate Water #3 | 4 | 5 | 2 | 4 | 3 | 3 | 1 | **22** |
| 4 | Ground Water #1 | 2 | 2 | 3 | 2 | 4 | 2 | 1 | **16** |
| 5 | Ground Water #2 | 3 | 1 | 0 | 1 | 6 | 2 | 4 | **17** |
| 6 | Hamad Town BS #1 | 4 | 4 | 2 | 4 | 2 | 2 | 1 | **16** |
| 7 | Hamad Town BS #2 | 3 | 3 | 4 | 2 | 2 | 0 | 1 | **15** |
| 8 | Hamad Town BS #3 | 6 | 3 | 3 | 1 | 2 | 2 | 2 | **19** |
| 9 | East Tower #1 | 2 | 6 | 2 | 9 | 6 | 3 | 2 | **30** |
| 10 | East Tower #2 | 0 | 4 | 2 | 4 | 11 | 12 | 5 | **38** |
| 11 | West Tower #1 | 0 | 2 | 2 | 3 | 5 | 2 | 0 | **14** |
| 12 | West Tower #2 | 6 | 2 | 0 | 2 | 10 | 3 | 0 | **23** |
| **Total per 12 pumps** | | **35** | **43** | **25** | **35** | **52** | **37** | **22** | **264** |

The above table shows the numbers of defects raised from Field Operation Unit to all maintenance sections. So there were 264 defects raised from 2005 up to 2011 in total.

### f. Analysis of defects

Initial analysis is done for all defects issued for every single pump at West Riff'a BS #1, by extracting the information from these defects such as types of defects, frequency of each defect, time spent for repair, and finally the cost of repair. All of these details are tabulated and shown in the Appendix K. Table 14 below shows the types of defects, total frequency, time and cost for WR#1 BS and all maintenance sections.

In summary, 264 defects recorded for all pumps took 3853 hours to repair with a total maintenance cost of 25708 BD.

**Table 14 - Summary of defects, frequency, time and cost for all pumps at W.R#1 BS**

| No. | Types of defects | Total no. of Defects | | |
|---|---|---|---|---|
| | | Frequency (Nos.) | Total Time (Hrs) | Total Cost (BD) |
| 1 | Leakage from discharge line (Header) from Pin hole | 38 | 867.74 | 2,984.32 |
| 2 | Gland packing of the pump is leaking | 49 | 569 | 6,935.43 |
| 3 | Gland packing of the pump is smoking | 11 | 73.74 | 596.67 |
| 4 | Gland packing of the suction valve is leaking | 7 | 74.5 | 195.61 |
| 5 | Gland packing of the discharge valve is leaking | 3 | 22 | 56.50 |
| 6 | Shaft is jammed | 0 | 0 | 0.00 |
| 7 | Coupling is damaged | 0 | 0 | 0.00 |
| 8 | Pump is not sucking water | 0 | 0 | 0.00 |
| 9 | Relieve valve is blocked | 0 | 0 | 0.00 |
| 10 | Check valve is leaking | 22 | 227 | 584.50 |
| 11 | Check valve is hammering / not working properly / Passing | 20 | 540.42 | 4,923.24 |
| 12 | Drain valve is blocked /leaking/broken | 10 | 81 | 167.80 |
| 13 | Suction pressure gauge is not working | 4 | 33.33 | 110.40 |
| 14 | Discharge pressure gauge is not working | 10 | 43.25 | 104.03 |
| 15 | Casing is leaking from pin hole | 0 | 0 | 0.00 |
| 16 | Inboard bearing is noisy | 7 | 104 | 518.91 |
| 17 | Outboard bearing is noisy | 2 | 49.5 | 95.89 |
| 18 | Inboard bearing temperature is high | 0 | 0 | 0.00 |
| 19 | Outboard bearing temperature is high | 0 | 0 | 0.00 |
| 20 | Inboard bearing grease is coming out | 0 | 0 | 0.00 |
| 21 | Outboard bearing grease is coming out | 0 | 0 | 0.00 |
| 22 | Problem in load breaker switch | 0 | 0 | 0.00 |
| 23 | Problem in power supply | 2 | 8.5 | 26.70 |
| 24 | Tripping due to under current | 0 | 0 | 0.00 |
| 25 | Tripping due to over current | 0 | 0 | 0.00 |
| 26 | Tripping due to over load | 1 | 20 | 118.95 |
| 27 | Pump not working on Auto mode / Remote | 16 | 251.55 | 493.95 |
| 28 | Motor inboard bearing is noisy | 6 | 70.5 | 239.82 |
| 29 | Motor outboard bearing is noisy | 5 | 46 | 155.92 |
| 30 | Pressure switch is not functioning / tripping pump | 0 | 0 | 0.00 |
| 31 | Ampere meter is hunting/not giving correct reading/not working | 14 | 171 | 5,105.34 |
| 32 | Capacitor is giving low readings | 7 | 144 | 765.69 |
| 33 | Smell is coming from Resistance box | 15 | 328.5 | 1,111.20 |
| 34 | Motor is tripping frequently | 2 | 51.5 | 160.10 |

| | | | | |
|---|---|---|---|---|
| 35 | Motor is heating | 4 | 11.5 | 42.40 |
| 36 | Cooling fan is not working | 3 | 17 | 57.20 |
| 37 | Failed without alarm | 6 | 47.73 | 157.27 |
| | **Total** | **264** | **3853** | **25708** |

### 5.4.5) West Riff'a #2 Blending Station

#### a. Station description

The West Riff'a #2 Blending Station is located in West Riffa area. The station is designed to receive R.O. water from Ras Abu Jarjur Plant and distillate water from Sitra Power and Water Station (SPWS), and G.W. from Hamala A2 GFS. The station has five ground storage tanks, two blended tanks with capacity of 5 M.G. each, one ground tank with capacity of 2 M.G. and two distillate tanks with capacity of 2 M.G. for each one.

#### b. Incoming and Outgoing water supply

The station receives ground water from Hamala A2 GFS with an average of 2.02 MG/day in year 2011. In addition, it receives R.O. water and distillate water from Ras Abu Jarjur and Sitra DFS with a total average of 20 MG/day in the year 2011. The station forwards blended water to WR-1 East and West towers, with an average of 17.96 MG/day in year 2011. The average TDS of blended water supplied is 1003 PPM.

#### c. Station site layout

Figure 14 shows the main details of the West Riff'a #2 Blending Station.

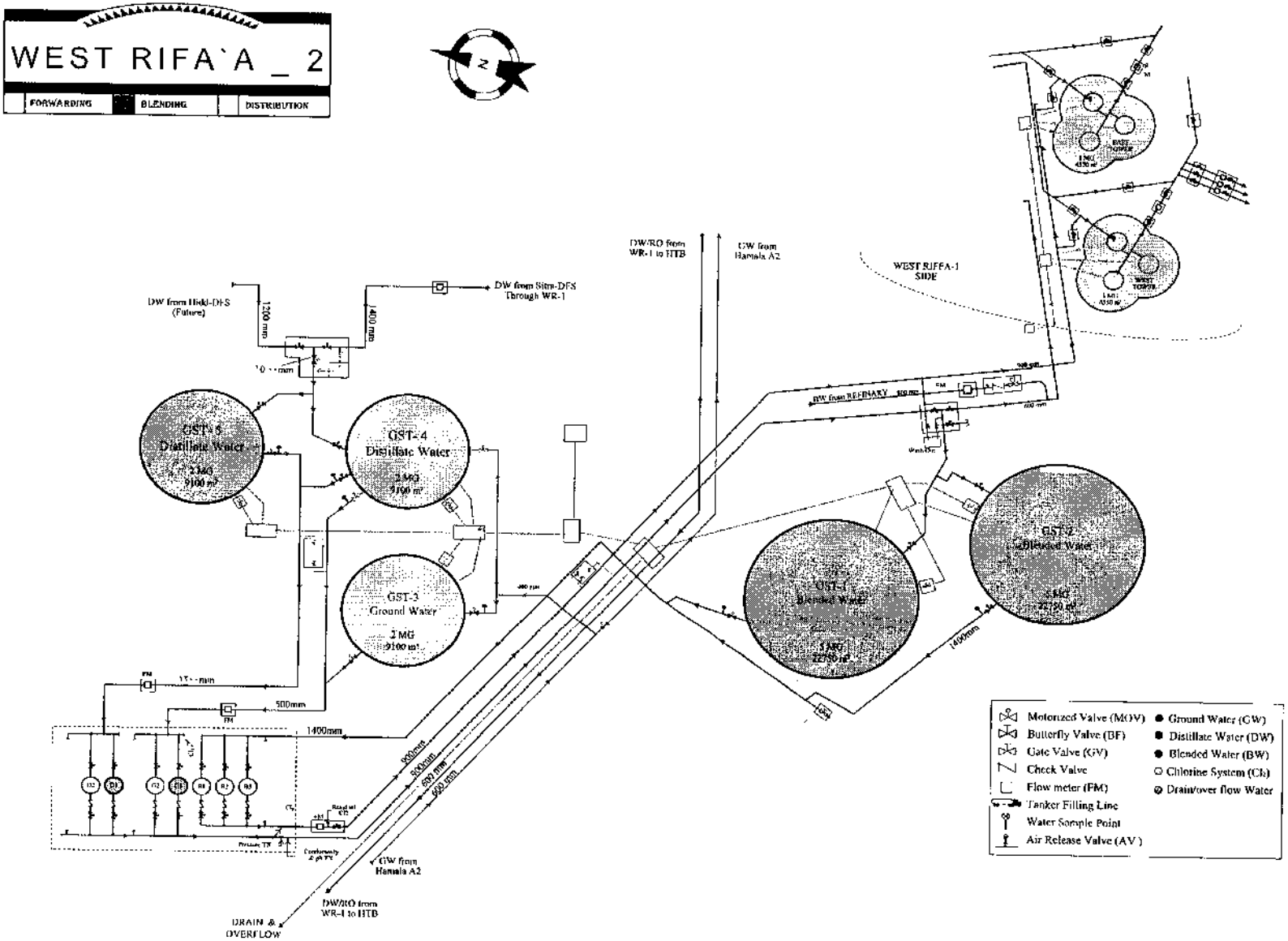





Figure 14 – West Riff'a #2 Blending Station drawing

### d. Total defects reported for WR#2 BS

The defects' data for the above mentioned station are summarized for each year from 2005 to 2011 and for each individual pump as shown in Table 15.

**Table 15- Details of defects for each individual pump at WR#2 BS**

| No. | Pump Name | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | **Total** |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Distillate Water #1 | 10 | 11 | 13 | 11 | 8 | 5 | 7 | **65** |
| 2 | Distillate Water #2 | 3 | 9 | 17 | 7 | 7 | 5 | 10 | **58** |
| 3 | Ground Water #1 | 3 | 4 | 4 | 0 | 8 | 17 | 0 | **36** |
| 4 | Ground Water #2 | 7 | 2 | 6 | 2 | 8 | 8 | 10 | **43** |
| 5 | Tower Pump #1 | 6 | 12 | 9 | 14 | 8 | 6 | 6 | **61** |
| 6 | Tower Pump #2 | 4 | 5 | 7 | 5 | 11 | 6 | 5 | **42** |
| 7 | Tower Pump #3 | 11 | 9 | 8 | 7 | 4 | 7 | 4 | **50** |
| **Total per 7 pumps** | | **44** | **53** | **64** | **47** | **51** | **55** | **41** | **355** |

The above table shows the numbers of defects raised from Field Operation Unit to all maintenance sections. So there were 355 defects raised from 2005 up to 2011 in total.

### e. Analysis of defects:

Initial analysis is done for all defects issued for every single pump at West Riff'a BS #2, by extracting the information from these defects such as types of defects, frequency of each defect, time spent for repair, and finally the cost of repair. All of these details are tabulated and shown in the Appendix L. Table 16 below shows the types of defects, total frequency, time and cost for all maintenance sections.

In summary, 355 defects recorded for all pumps took 4533.45 hours with a total maintenance cost of 16601.13 BD .

**Table 16 - Summary of defects, frequency, time and cost for all pumps at WR#2 BS**

| No | Types of defects | Total Summary | | |
|---|---|---|---|---|
| | | Frequency (Nos.) | Total Time (Hrs) | Total Cost (BD) |
| 1 | leakage from discharge line (Header) from Pin hole | 0 | 0 | 0.00 |
| 2 | Gland packing of the pump is leaking | 57 | 649.17 | 2,356.81 |
| 3 | Gland packing of the pump is smoking | 0 | 0 | 0.00 |
| 4 | Gland packing of the suction valve is leaking | 1 | 4 | 9.60 |
| 5 | Gland packing of the discharge valve is leaking | 1 | 120 | 359.12 |
| 6 | Suction / discharge valve is jammed | 1 | 35 | 101.73 |
| 7 | Coupling cove to be re-fixed | 1 | 14 | 29.00 |
| 8 | Problem in discharge MOV /Actuator/stuck in position | 35 | 420.5 | 1,208.88 |
| 9 | Problem in suction MOV /Actuator/stuck in position | 12 | 114.25 | 364.75 |
| 10 | Check valve is leaking | 20 | 360.42 | 913.85 |
| 11 | Check valve is hammering / not working properly / Passing | 13 | 223 | 573.35 |
| 12 | Drain valve is blocked /leaking/broken | 23 | 136.5 | 257.40 |
| 13 | Suction pressure gauge is not working | 1 | 4 | 10.80 |
| 14 | Discharge pressure gauge is not working | 0 | 0 | 0.00 |
| 15 | Actuator is leaking water from gear box | 8 | 483 | 2,259.57 |
| 16 | Inboard bearing is noisy | 11 | 287.31 | 1,263.71 |
| 17 | Outboard bearing is noisy | 1 | 0 | 0.00 |
| 18 | Inboard bearing temperature is high | 3 | 25 | 84.70 |
| 19 | Outboard bearing temperature is high | 1 | 75.5 | 272.91 |
| 20 | Inboard bearing grease is coming out | 0 | 0 | 0.00 |
| 21 | Outboard bearing grease is coming out | 0 | 0 | 0.00 |
| 22 | Vibration sensor is not reading / Tripping on high vibration | 37 | 289 | 1,353.45 |
| 23 | Problem in power supply | 6 | 62.5 | 201.45 |
| 24 | Tripping on LCP | 20 | 174 | 1,091.20 |
| 25 | Tripping on phase unbalance | 5 | 64 | 167.60 |
| 26 | Problem in DCS / data is stuck in display screen | 30 | 179.75 | 591.74 |
| 27 | Pump not working on Auto mode / Remote | 19 | 165 | 642.87 |
| 28 | Motor inboard bearing is noisy | 7 | 165.5 | 417.98 |
| 29 | Motor outboard bearing is noisy | 2 | 64 | 132.80 |
| 30 | Level switch is not functioning / alarm standing | 2 | 14 | 49.70 |
| 31 | Motor current reading is low | 1 | 7.8 | 19.11 |
| 32 | Capacitor is giving low readings | 0 | 0 | 0.00 |
| 33 | Smell is coming from Resistance box | 1 | 6 | 14.40 |
| 34 | Motor is tripping frequently | 2 | 19 | 50.30 |
| 35 | Motor is heating / high winding temperature | 10 | 110 | 319.40 |
| 36 | Speed cannot be controlled | 2 | 12 | 41.70 |
| 37 | Filed to start | 22 | 249.25 | 1,441.28 |
| | **Total** | **355** | **4533.45** | **16,601.13** |

### 5.4.6) Summary of defects, time and cost for stations

Further effort carried out to classify all the above mentioned information according to maintenance section within the station itself, this will help to identify which section has the majority of defects. Each defect is reviewed thoroughly for classification, and the whole exercise is summarized into the following table which shows total defects frequency, total time to repair these defects and finally the total cost of all repairs for each maintenance section.

**Table 17 – Summary of Defects, time and cost for each maintenance section for all stations**

| Hamala A2 GFS | | | |
|---|---|---|---|
| **Section** | **Frequency (Nos.)** | **Total Time (Hrs)** | **Total Cost (BD)** |
| **Mechanical** | 149 | 3085.63 | 17097.17 |
| **Electrical** | 18 | 475 | 1346.63 |
| **Instrument** | 24 | 85.75 | 528.85 |
| **Process control** | 7 | 85 | 340.95 |
| **Total** | **198** | **3731** | **19314** |
| **Hamad Town BS** | | | |
| **Section** | **Frequency (Nos.)** | **Total Time (Hrs)** | **Total Cost (BD)** |
| **Mechanical** | 160 | 2546.74 | 8996.47 |
| **Electrical** | 54 | 561 | 8733.37 |
| **Instrument** | 30 | 146.58 | 411.48 |
| **Process control** | 34 | 365 | 4654.16 |
| **Total** | **278** | **3619** | **22795** |
| **Hamad Town DS** | | | |
| **Section** | **Frequency (Nos.)** | **Total Time (Hrs)** | **Total Cost (BD)** |
| **Mechanical** | 29 | 267.53 | 2655.53 |
| **Electrical** | 7 | 54 | 213.3 |
| **Instrument** | 5 | 20 | 51.2 |
| **Process control** | 3 | 16 | 52.4 |
| **Total** | **44** | **357.5** | **2972** |
| **West Riff'a #1 BS** | | | |
| **Section** | **Frequency (Nos.)** | **Total Time (Hrs)** | **Total Cost (BD)** |
| **Mechanical** | 180 | 2725.39 | 17454.61 |
| **Electrical** | 48 | 752 | 7387.57 |
| **Instrument** | 14 | 76.58 | 214.43 |
| **Process control** | 22 | 299.28 | 651.22 |
| **Total** | **264** | **3853** | **25708** |
| **West Riff'a #2 BS** | | | |

| Section | Frequency (Nos.) | Total Time (Hrs) | Total Cost (BD) |
|---|---|---|---|
| **Mechanical** | 142 | 2159.39 | 6772.95 |
| **Electrical** | 37 | 408.55 | 1894.14 |
| **Instrument** | 50 | 417 | 1733.35 |
| **Process control** | 126 | 1548.5 | 6200.69 |
| **Total** | **355** | **4533** | **16601** |

Table 18 shows an overall summary of the data collected and classified based on the specialty of the maintenance section

**Table 18 - Total summary for frequency, time and cost of defects for each maintenance section**

| Section | Frequency (Nos.) | Total Time (Hrs) | Total Cost (BD) |
|---|---|---|---|
| **Mechanical** | 660 | 10784.69 | 52976.72 |
| **Electrical** | 164 | 2250.55 | 19575.00 |
| **Instrument** | 123 | 745.92 | 2939.31 |
| **Process control** | 192 | 2313.78 | 11899.44 |
| **Total** | **1139** | **16094.94** | **87390.46** |

As was discussed earlier the Mechanical Section is chosen to be the main section this work should focus on, because it's frequency, time and cost have the highest values. Furthermore, to be more specific the mechanical defects on pumps only will be considered since they are the heart of the Transmission Directorate.

From here onwards the discussion, analysis and penetration on every single defect belong to the Mechanical Section which has been chosen, in order to find the main reasons, factors or problems behind the increase in frequency, the time and the cost of pumps' maintenance.

### 5.5) Preventive Maintenance of WTD Pumps

Preventive maintenance activities generally consist of inspection, cleaning, lubrication, adjustment, alignment, painting, and replacement of some parts if required. Obviously, preventive maintenance involves a basic trade-off between the costs of conducting maintenance and replacement activities and the cost savings achieved by reducing the overall rate of occurrence of system failures. Designers of preventive maintenance schedules must weigh these individual costs in an attempt to minimize the overall cost of system operation. They may also be interested in maximizing the system reliability, subject to some sort of budgetary constraint.

### 5.5.1) Preventive maintenance data collection

Maintenance Department at Water Transmission Directorate is doing planned preventive maintenance (PPM) for all pumps at all stations, they are doing the task based on different principles like aging or manufacturer recommendations. For every pump there is a PPM Task sheet which contain the main details of the pump, the dates of PPM, people who did the task and the time for each task.

The frequency of PPM for each station is common, every 4 months PPM must be conducted for each pump except Hamala A2 pumps which is decided to be monthly due to their importance and due to high conductivity of the ground water, the time of decision for conducting monthly preventive maintenance for Hamala A2 pumps is not known and it is not documented.

All information is tabulated for every pump, and a sample example for one pump is shown in the Table 19 (Ground water pump #1 at West Riff'a #1 BS ) hereunder. Table 19 shows that there are 24 PPM visits for this pump from beginning of 2006 till end of 2011, with a total cost of BD 357.15 for all technicians attended for the PPM visits and the total man hours are 108.5 hours. The average duration between the PPM tasks is around 3 months, therefore each pump must have four preventive maintenance tasks to be conducted every year. Every individual pump has its sheet similar to the above table.

### 5.5.2) Summary of PPM cost and duration of visits for all stations

Every individual pumps PPM data is collected from the planned preventive maintenance sheets and tabulated in Table 20, the total number of PPM visits, duration of visits, number of man hours, cost of man hours for individual pumps or individual stations. These are very important data to monitor the PPM activities, it shows if the preventive maintenance task is done in an effective, correct way and within planned schedule and proper timing or not. The tables below cover the conducted PPM tasks, unfortunately most of the data collected from the task sheets are not started from 2005 for this study because most of the old task sheets were scraped, they are started from year 2006 for all stations except for Hamala A2 GFS which started from 2008.

**Table 19 - Basic information from PPM Task Sheets from 2006 to 2011 for ground water pump #1 at WR#1 BS**

| PPM visit No. | Pump Name | Date | Duration of visit (Hrs) | No of persons attended, grades with total hours of visits & man hours of technicians | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | No. of G8 staff | No. of Man hours for G8 (Hrs) | No of G7 staff | No. of Man hours for G7 (Hrs) | No. of G6 staff | No. of Man hours for G6 (Hrs) | No of G5 staff | No. of Man hours for G5 (Hrs) |
| 1 | Ground Water Pump # 1 | 25/10/2011 | 1 | 0 | 0 | 2 | 2 | 2 | 2 | 0 | 0 |
| 2 | | 21/7/2011 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| 3 | | 23/4/2011 | 1.5 | 0 | 0 | 1 | 1.5 | 1 | 1.5 | 0 | 0 |
| 4 | | 10/1/2011 | 1 | 0 | 0 | 1 | 1 | 2 | 2 | 0 | 0 |
| 5 | | 20/10/2010 | 1 | 0 | 0 | 1 | 1 | 2 | 2 | 0 | 0 |
| 6 | | 7/7/2010 | 1.5 | 0 | 0 | 1 | 1.5 | 2 | 3 | 0 | 0 |
| 7 | | 12/4/2010 | 1 | 0 | 0 | 2 | 2 | 1 | 1 | 0 | 0 |
| 8 | | 14/1/2010 | 1.5 | 0 | 0 | 2 | 3 | 2 | 3 | 0 | 0 |
| 9 | | 26/10/2009 | 2 | 0 | 0 | 1 | 2 | 2 | 4 | 0 | 0 |
| 10 | | 12/7/2009 | 1.5 | 0 | 0 | 1 | 1.5 | 3 | 4.5 | 0 | 0 |
| 11 | | 25/4/2009 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 |
| 12 | | 3/2/2009 | 2.5 | 0 | 0 | 2 | 5 | 1 | 2.5 | 0 | 0 |
| 13 | | 25/10/2008 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 14 | | 23/6/2008 | 1 | 0 | 0 | 3 | 3 | 2 | 2 | 0 | 0 |
| 15 | | 20/4/2008 | 2 | 1 | 2 | 0 | 0 | 1 | 2 | 0 | 0 |
| 16 | | 6/2/2008 | 1.5 | 0 | 0 | 1 | 1.5 | 1 | 1.5 | 1 | 1.5 |
| 17 | | 21/10/2007 | 1.5 | 0 | 0 | 1 | 1.5 | 2 | 3 | 0 | 0 |
| 18 | | 16/7/2007 | 2 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 4 |
| 19 | | 5/4/2007 | 2 | 0 | 0 | 0 | 0 | 2 | 4 | 1 | 2 |
| 20 | | 18/1/2007 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 |
| 21 | | 30/10/2006 | 2.5 | 0 | 0 | 0 | 0 | 1 | 2.5 | 2 | 5 |
| 22 | | 6/8/2006 | 2 | 0 | 0 | 0 | 0 | 2 | 4 | 0 | 0 |
| 23 | | 22/4/2006 | 1.5 | 0 | 0 | 0 | 0 | 1 | 1.5 | 1 | 1.5 |
| 24 | | 2/1/2006 | 2 | 0 | 0 | 0 | 0 | 2 | 4 | 0 | 0 |
| **Total hours of visits (Hrs)** | | | **37.5** | **3** | | **23** | | **36** | | **8** | |
| **Total man hours of technicians (Hrs)** | | | | | **5** | | **31.5** | | **56** | | **16** |
| **Rate: BD / Hr** | | | | | 4.2 | | 3.7 | | 3.3 | | 3 |
| **Total cost of technicians (BD)** | | | | | **21** | | **116.55** | | **171.6** | | **48** |

Where G8: Mechanical Technician
G7: Lead Mechanic
G6: Mechanical Fitter
G5: Trade Worker

**Table 20 - Number PPM visits, duration of visits, man hours and man hours cost for individual stations & pumps**

| Station | Serial | Pumps Names | No. of PPM Tasks done | Total visit time for PPM (Hrs) | Total man hours (Hrs) | Total cost for man hours (BD) |
|---|---|---|---|---|---|---|
| Hamala A2 GFS (2008 – 2011) | 1 | West Riff'a Pump #1 | 24 | 48.5 | 138 | 481.55 |
| | 2 | West Riff'a Pump #2 | 27 | 59 | 189.5 | 662.6 |
| | 3 | West Riff'a Pump #3 | 27 | 54 | 158 | 550.1 |
| | 4 | Hamad Town Pump #1 | 26 | 46.5 | 135 | 471.65 |
| | 5 | Hamad Town Pump #2 | 28 | 54 | 161.5 | 564.3 |
| | **Total** | | **132** | **262** | **782** | **2730.2** |
| **Station** | **Serial** | **Pumps Names** | **No. of PPM Tasks done** | **Total visit time for PPM (Hrs)** | **Total man hours (Hrs)** | **Total cost for man hours (BD)** |
| Hamad Town BS (2006 – 2011) | 1 | Hamad Town DS pump #1 | 23 | 33 | 107 | 364.2 |
| | 2 | Hamad Town DS pump #2 | 24 | 37 | 112.5 | 381.9 |
| | 3 | Tower Pump #1 | 23 | 36.5 | 123 | 421.1 |
| | 4 | Tower Pump #2 | 26 | 39 | 113 | 384.15 |
| | 5 | Ground Water Pump #1 | 25 | 33.5 | 101.5 | 346.15 |
| | 6 | Ground Water Pump #2 | 25 | 34.5 | 110 | 375.45 |
| | 7 | Distillate Water Pump#1 | 27 | 41 | 113 | 387.6 |
| | 8 | Distillate Water Pump#2 | 28 | 39.5 | 106 | 467.2 |
| | **Total** | | **201** | **294** | **886** | **3127.75** |
| **Station** | **Serial** | **Pumps Names** | **No. of PPM Tasks done** | **Total visit time for PPM (Hrs)** | **Total man hours (Hrs)** | **Total cost for man hours (BD)** |
| HT DS(2006 – 21011) | 1 | Tower Pump #1 | 23 | 33 | 107 | 364.85 |
| | 2 | Tower Pump #2 | 24 | 37 | 103 | 350.15 |
| | **Total** | | **47** | **70** | **210** | **715** |
| **Station** | **Serial** | **Pumps Names** | **No. of PPM Tasks done** | **Total visit time for PPM (Hrs)** | **Total man hours (Hrs)** | **Total cost for man hours (BD)** |
| West Riff'a #1 BS (2006 – 2011) | 1 | Ground Water Pump #1 | 24 | 37.5 | 108.5 | 357.15 |
| | 2 | Ground Water Pump #2 | 22 | 39 | 117.5 | 396.85 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 3 | Distillate Water Pump#1 | 23 | 36.5 | 111.5 | 377.55 |
| | 4 | Distillate Water Pump#2 | 24 | 33 | 87 | 292.85 |
| | 5 | Distillate Water Pump#3 | 24 | 34 | 100 | 341.35 |
| | 6 | Hamad Town BS pump #1 | 22 | 34 | 101 | 338.95 |
| | 7 | Hamad Town BS pump #2 | 21 | 30.5 | 83.5 | 278.55 |
| | 8 | Hamad Town BS pump #3 | 21 | 34 | 96.5 | 330.7 |
| | 9 | East Tower Pump # 1 | 23 | 32.5 | 91 | 310 |
| | 10 | East Tower Pump # 2 | 23 | 32.5 | 91 | 310 |
| | 11 | West Tower Pump # 1 | 22 | 32 | 89.5 | 301.3 |
| | 12 | West Tower Pump # 2 | 22 | 29.5 | 83 | 280.8 |
| | **Total** | | **271** | **405** | **1156** | **3916.05** |
| **Station** | **Serial** | **Pumps Names** | **No. of PPM Tasks done** | **Total visit time for PPM (Hrs)** | **Total man hours (Hrs)** | **Total cost for man hours (BD)** |
| **West Riffa # 2 BS ( 2006 – 2011)** | 1 | Ground Water Pump #1 | 22 | 41 | 120 | 406.1 |
| | 2 | Ground Water Pump #2 | 24 | 48 | 147 | 493.3 |
| | 3 | Distillate Water Pump#1 | 23 | 45 | 131.5 | 443.4 |
| | 4 | Distillate Water Pump#2 | 20 | 40 | 121 | 405.85 |
| | 5 | Tower Pump # 1 | 21 | 37.5 | 121 | 407.15 |
| | 6 | Tower Pump # 2 | 22 | 41 | 132.5 | 446.1 |
| | 7 | Tower Pump # 3 | 22 | 43 | 130.5 | 440.7 |
| | **Total** | | **154** | **295.5** | **903.5** | **3042.6** |

### 5.5.3) Average cost and time of planned preventive maintenance for pumps

The average number of tasks, time and cost of each pump is calculated for each station yearly based on data collected from Table 20, the average data can give clear picture of the distribution of tasks, time and cost per year for each pump. Table 21 shows the averages of tasks, time and cost.

Note: The number of PPM years for Hamala A2 is 4 years, while for other stations is 6 years based on information's available from WTD.

**Table 21 - Average number of visits, cost and time per year for each individual pump**

| Station | No. of Pumps | No. of PPM visits | Avg. no. of visits/ pump / Year | Total man hours cost (BD) | Avg. cost (BD) per pump / Year | Total visits time for PPM (Hrs) | Avg. hours per pump / Year (Hrs) | Avg. cost / visit (BD) |
|---|---|---|---|---|---|---|---|---|
| Hamala A2 GFS | **5** | **132** | **6.6** | **2730.2** | **136.51** | **262** | **13.1** | **20.68** |
| Hamad Town BS | **8** | **201** | **4.18** | **3127.75** | **65.16** | **294** | **6.13** | **15.58** |
| Hamad Town DS | **2** | **47** | **3.92** | **715** | **59.58** | **70** | **5.8** | **15.19** |
| West Riffa #1 BS | **12** | **271** | **3.76** | **3916.05** | **54.39** | **405** | **5.63** | **14.46** |
| West Riffa # 2 BS | **7** | **154** | **3.66** | **3042.6** | **72.44** | **295.5** | **7** | **19.79** |
| **Total** | **34** | **805** | | **13531.6** | | **1326.5** | | |

Hereunder are samples for basic calculations for the averages shown above.

Average number of PPM tasks for Hamala A2 pumps = 132 / (5 pumps x 4 years of PPM)

**= 6.6 tasks per year**

Average cost of man hours for PPM for Hamala A2 pumps = 2730.2 / (5 pumps x 4 years )

**= BD 136.51 per pump per year**

Average number of PPM hours for Hamala A2 pumps = 262 / (5 pumps x 4 years)

**= 13.1 hours per pump per year**

Average cost per task for Hamala A2 pumps = 2730.2 / 132

**= BD 20.68**

Pumps at Hamala A2 GFS have the highest average number of visits, cost and time because the PPM visits of pumps are done on monthly basis, but generally most of the numbers are close and the difference or variation in figures is limited.

# CHAPTER SIX
# DATA ANALYSIS OF MECHANICAL DEFECTS

## 6.0) Introduction

The purpose of this chapter is to analyze the mechanical defects, all defects that are mainly related to pumps and its accessories will be covered. Initially the analysis will be based on individual stations and then it will be based on individual defects.

## 6.1) Data Analysis of Mechanical Defects for Stations

This section concentrates on mechanical defects that are directly related to the pumps and the equipment related to it. The figure below shows the main pumping system related to this study which consists of main centrifugal pump (3), suction and discharge valves (2&5), non-return(Check) valve (4) and finally both suction and discharge header (1&6).

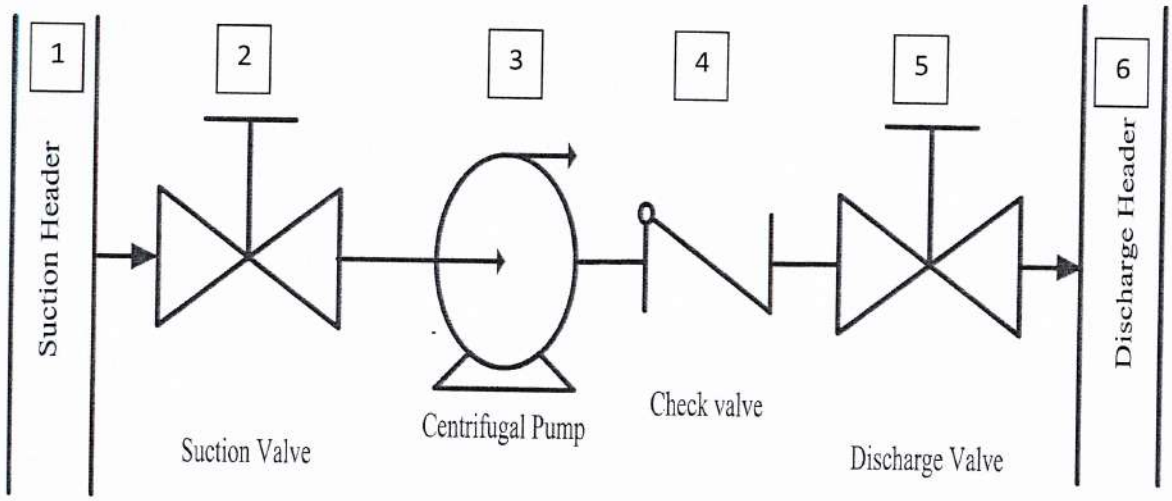



**Figure 15 – Main pumping system within Water Transmission Directorate**

There are some other components related to the above pumping system but cannot be shown because they are built within the pump itself such as bearings, shaft, stuffing box and drain valve or air valve. Valves also have small components like gland packing. It is important to mention that motor's bearings monitoring is part of mechanical maintenance task, if there is any deviation in vibration and temperature from normal limits, Electrical Maintenance must be notified to take necessary action either to repair or to overhaul the motor. All data related to mechanical defects only is collected from the previous chapter and summarized in Table 22 below showing all mechanical defects, the real repair time and cost of repair.

## Table 22- Mechanical defects, their time and cost for all stations for 7 years

| No. | Description of Defects | HTD | | | Hamala A2 | | | WR2 | | | HTB | | | WRI | | | Total Summary | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Frequency (Count) | Time (Hrs) | Cost (BD) | Frequency (Count) | Time (Hrs) | Cost (BD) | Frequency (Count) | Time (Hrs) | Cost (BD) | Frequency (Count) | Time (Hrs) | Cost (BD) | Frequency (Count) | Time (Hrs) | Cost (BD) | Frequency (Count) | Time (Hrs) | Cost (BD) |
| 1 | leakage from discharge line | 1 | 16 | 50.60 | 12 | 177.6967 | 675.10 | 0 | 0 | 0.00 | 25 | 399.5 | 1103.89 | 38 | 867.74 | 2984.32 | 76 | 1460.94 | 4813.92 |
| 2 | Gland packing of the pump is leaking | 2 | 17 | 72.00 | 81 | 1577.53 | 8354.39 | 57 | 649.17 | 2356.81 | 49 | 608.58 | 2099.40 | 49 | 569 | 6935.43 | 238 | 3421.28 | 19818.03 |
| 3 | Gland packing of the pump is smoking | 1 | 13 | 52.70 | 6 | 57.5 | 155.65 | 0 | 0 | 0.00 | 11 | 148.5 | 497.60 | 11 | 73.74 | 596.67 | 29 | 292.74 | 1302.62 |
| 4 | Gland packing of the suction valve is leaking | 0 | 0 | 0.00 | 1 | 20.49 | 38.27 | 1 | 4 | 9.60 | 0 | 0 | 0.00 | 7 | 74.5 | 195.61 | 9 | 98.99 | 243.48 |
| 5 | Gland packing of the discharge valve is leaking | 3 | 36 | 89.65 | 0 | 0 | 0.00 | 1 | 120 | 359.12 | 0 | 0 | 0.00 | 3 | 22 | 56.50 | 7 | 178 | 505.27 |
| 6 | Shaft is jammed | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 3 | 56.5 | 153.54 | 0 | 0 | 0.00 | 3 | 56.5 | 153.54 |
| 7 | Suction / discharge valve is jammed | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 1 | 35 | 101.73 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 1 | 35 | 101.725 |
| 8 | Coupling is damaged | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 4 | 95 | 1023.61 | 0 | 0 | 0.00 | 4 | 95 | 1023.61 |
| 9 | Coupling cove to be refixed | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 1 | 14 | 29.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 1 | 14 | 29 |
| 10 | Check valve is not working properly (Passing or Hummering) | 3 | 56 | 124.90 | 9 | 301.5 | 883.23 | 13 | 223 | 573.35 | 13 | 214.66 | 513.30 | 20 | 540.42 | 4923.24 | 58 | 1335.58 | 7018.02 |
| 11 | Check valve is leaking | 3 | 23 | 55.20 | 0 | 0 | 0.00 | 20 | 360.42 | 913.85 | 0 | 0 | 0.00 | 22 | 227 | 584.50 | 45 | 610.42 | 1553.55 |
| 12 | Relieve valve is blocked | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 8 | 61 | 144.60 | 0 | 0 | 0.00 | 8 | 61 | 144.6 |
| 13 | Drain valve is blocked /leaking/broken | 7 | 53 | 101.60 | 11 | 138.66 | 330.81 | 23 | 136.5 | 257.40 | 12 | 103.67 | 672.95 | 10 | 81 | 167.80 | 63 | 512.83 | 1530.56 |
| 14 | Casing is leaking from pin hole | 0 | 0 | 0.00 | 2 | 208 | 2091.50 | 0 | 0 | 0.00 | 2 | 18 | 27.30 | 0 | 0 | 0.00 | 4 | 226 | 2118.8 |
| 15 | Inboard bearing is noisy | 1 | 15 | 30.00 | 13 | 347.25 | 3702.06 | 11 | 287.31 | 1263.71 | 13 | 382.83 | 1215.69 | 7 | 104 | 518.91 | 45 | 1136.39 | 6730.37 |
| 16 | Outboard bearing is noisy | 1 | 0 | 0.00 | 3 | 94.5 | 394.91 | 1 | 0 | 0.00 | 2 | 16 | 49.40 | 2 | 49.5 | 95.89 | 9 | 160 | 540.19 |
| 17 | Inboard bearing temperature is high | 0 | 0 | 0.00 | 2 | 11 | 35.20 | 3 | 25 | 84.70 | 1 | 5 | 26.25 | 0 | 0 | 0.00 | 6 | 41 | 146.15 |
| 18 | Outboard bearing temperature is high | 0 | 0 | 0.00 | 4 | 105.5 | 292.30 | 1 | 75.5 | 272.91 | 1 | 10 | 33.10 | 0 | 0 | 0.00 | 6 | 191 | 598.31 |
| 19 | Inboard bearing grease is coming out | 0 | 0 | 0.00 | 3 | 35 | 93.46 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 3 | 35 | 93.46 |
| 20 | Motor inboard bearing is noisy | 5 | 20.53 | 42.68 | 2 | 11 | 50.30 | 7 | 165.5 | 417.98 | 9 | 249.5 | 839.32 | 6 | 70.5 | 239.82 | 29 | 517.03 | 1590.09 |
| 21 | Motor outboard bearing is noisy | 2 | 18 | 2036.20 | 0 | 0 | 0.00 | 2 | 64 | 132.80 | 5 | 165 | 550.51 | 5 | 46 | 155.92 | 14 | 293 | 2875.43 |
| 22 | Pump is not sucking water | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 2 | 13 | 46.00 | 0 | 0 | 0.00 | 2 | 13 | 46 |
| Total Summary | | 29 | 267.533 | 2655.53 | 149 | 3085.63 | 17097.17 | 142 | 2159.4 | 6772.95 | 160 | 2546.74 | 8996.47 | 180 | 2725.4 | 17454.60 | 660 | 10784.69 | 52976.72 |
| Percentages of frequency, time & cost | | 4.39 | 2.48 | 5.01 | 22.58 | 28.6112 | 32.27 | 21.52 | 20.0228 | 12.78 | 24.24 | 23.6144 | 16.98 | 27.27 | 25.271 | 32.95 | 100.00 | 100.00 | 100.00 |
| Number of pumps | | 2 | | | 5 | | | 7 | | | 8 | | | 12 | | | 34 | | |
| Percentage of pumps (%) | | 5.88 | | | 14.71 | | | 20.59 | | | 23.53 | | | 35.29 | | | 100.00 | | |
| Production capacity (Million gallons per year)* | | 946.1 | | | 3842.91 | | | 6247.37 | | | 7108.73 | | | 8328.73 | | | 26473.84 | | |
| Percentage of production (%) | | 3.57 | | | 14.52 | | | 23.60 | | | 26.85 | | | 31.46 | | | 100.00 | | |

* The data is based on 2011 statistical report

There are some important outcomes and relationships that can be extracted from the above table. There is a direct proportional relationship between the number of pumps and the number of defects, time for repair and cost of repair. As the number of pumps increases, the other parameters such as the cost of repair and time of repair also increase. There are two pumps at HTDS and only 29 defects recorded, but for West Riff'a #1 BS there are 12 pumps and there are 180 defects for this station. Also the number of defects is directly proportional to the production capacity, as the production capacity increases the number of defects also increases.

The most important observations from the table above is related to Hamala A2 GFS, this station contains only five pumps but the percentage of frequency (22.58%) {Defect frequency of Hamala over total number of defect frequency X100} is higher than West Riff'a 2 BS (21.52%) which contains 7 pumps, and almost the same percentage as for HTBS (24.24%). The percentage of time for the same station (28.62%) is higher than the other ones {West Riff'a # 1 BS (25.27%), West Riff'a # 2 BS (20.02%) and HTBS (23.62%)}, and its percentage of cost (32.27%) is high as that from both West Riff'a#2 BS (12.78%)and HTBS (16.98%), but similar to the percentage of cost for West Riff'a #1 (32.95%) which contains 12 pumps. This indicates that Hamala A2 station must be treated differently, by increasing the preventive maintenance tasks and using special types of materials that can withstand the salty water, such treatment reduce or eliminate the causes of the frequent defects.

The three main categories for analyses is the frequency of defects, the time of repair and the cost of repair. The analysis of each category is covered hereunder.

a. Analysis of repairing cost

The cost of repairing all mechanical defects is related to the manpower and material cost, the total cost for corrective maintenance is BD 52976.725, and the total cost of preventive maintenance is BD13531.6, both types of cost cover the period from year 2005 up to year 2011. The analysis which based on the cost will be limited in the coming sections since the budget allocated to Mechanical Maintenance Section (for both corrective and preventive maintenance) is large compared to the actual cost of corrective and preventive maintenance. The budget allocated to the Mechanical Maintenance Section is BD 242,000 for year 2011 only. The actual corrective maintenance cost for the seven years is representing around 22% only of the allocated budget for year 2011, and the actual preventive maintenance cost for the seven years also is representing 5.6% (the total

percentage of both costs for both types of maintenances is 27.6 %). Pareto chart of mechanical defects and their cost is shown in Chart 2 below.

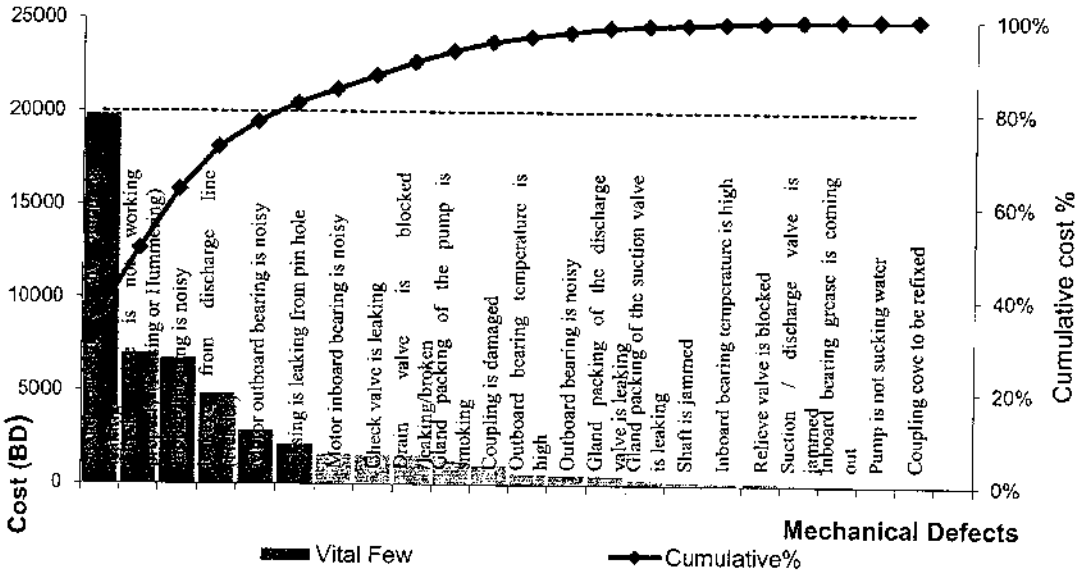



**Chart 2 – Pareto chart for the types of mechanical defects and their cost**

The first six types of defects are costing 81.87 % from the total repairing cost, the major repairing cost is for the repairing of leakage from the gland packing which represent 37.4% from the total cost, this defect has the highest number of frequency as well.

b. Analysis of repairing time

The repair time here is defined as "the time consumed by technicians to restore the equipment to their operating conditions", the total repair time of mechanical defects for all stations is 10784.69 hours and this is only the real repair time consumed to conduct actual repair works. The indirect time, which is the time taken by the technicians to reach the stations from their office, is not considered in our data, but it can be assumed that an average of 0.5 hour is needed to reach any station and also 0.5 hour to return back to office, therefore one hour can be added to each repair time for any defect. For example for the first defect, which is the leak from discharge header, the frequency is 76, which means that 76 hours can be added to the actual repair time, which is 1460.94 hours. So the total time to repair the leak in discharge header is 1536.94 hours combining the trip time with actual repair time.

Repairing time of defects will be addressed since it is related to the mechanical maintenance team which is common for all stations. Each station can be considered as an independent system, each one has its own pumps and operators, but all stations defects are repaired by the same maintenance team. Focusing on repair times can lead to know which main defects consume more time and how it can be reduced. Pareto chart of mechanical defects and their repair time is shown in Chart 3 below.

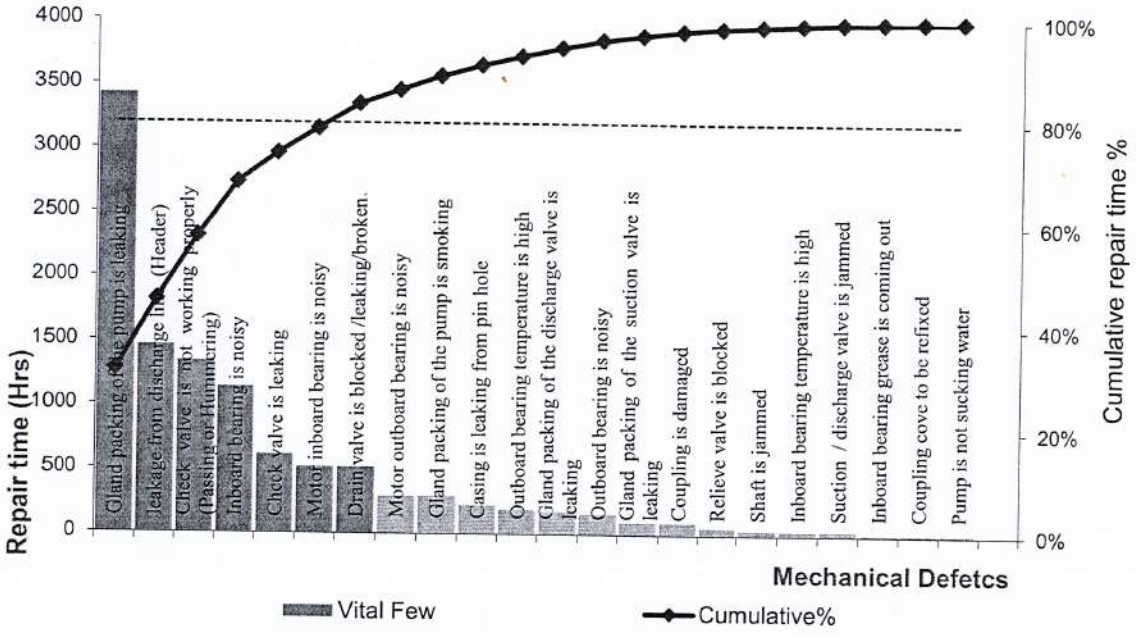



**Chart 3 – Pareto chart for the types of mechanical defects and their repair time**

The first seven defects are representing 83.73% from the total repair time of all defects, here again the leakage from gland packing of pumps is the major defect with a value of 31.8 % of the total time, and the second one is the leakage from discharge header.

c. Analysis of frequency of defects

The frequency of defects is the most important factor for analysis of all stations, the mechanical team is the common link for all stations and they are responsible to repair the mechanical defects in all stations, if the number of defects reduced the number of visits will be reduced as well as the time and cost of repair. The main question is how to reduce the number of defects or how to eliminate them from occurring in order to reduce their effects. There are 660 defects distributed over all stations, Pareto chart below shows the main defects that has major frequencies.

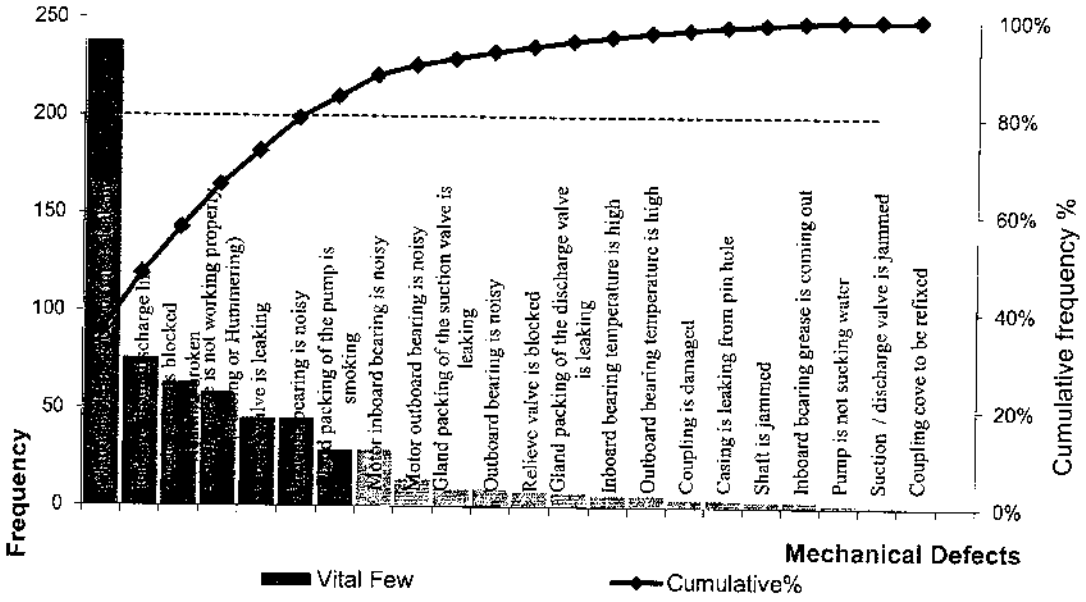



**Chart 4 – Pareto chart for the types of mechanical defects and their frequencies**

The first seven defects covers around 83.94 % of the total defects, the major defects is the leakage from gland packing of the pumps with a value of 36.1%, and the second one is the leakage from the discharge header. More analyses for the defects and their frequencies will be conducted in the coming sections.

In the coming sections, the analysis will be initially on individual stations focusing on main and major defects' occurrence based on their frequencies. These analyses will help to extract the major common defects for all stations, which will be analyzed individually.

### 6.1.1) Hamad Town DS

This station is small compared to other ones, it includes only two pumps. Only eleven defects related to mechanical section are experienced in this station. Frequency, time and cost for each defect are recorded in Table 23 and plotted in Chart 5

**Table 23 - Mechanical defects data for HTDS pumps**

| No. | Defects | | | Corrective maintenance | | |
|---|---|---|---|---|---|---|
| | Type | Frequency | | Time (Hrs.) | Cost | |
| | | Count | % | | BD | % |
| 1 | Drain valve is blocked /leaking/broken | 7 | 24.14 | 53 | 101.6 | 3.83 |
| 2 | Motor inboard bearing is noisy | 5 | 17.24 | 20.53 | 42.68 | 1.61 |
| 3 | Gland packing of the discharge valve is leaking | 3 | 10.34 | 36 | 89.65 | 3.38 |
| 4 | Check valve is leaking | 3 | 10.34 | 23 | 55.2 | 2.08 |
| 5 | Check valve is hammering / not working properly / Passing | 3 | 10.34 | 56 | 124.9 | 4.70 |
| 6 | Gland packing of the pump is leaking | 2 | 6.90 | 17 | 72 | 2.71 |
| 7 | Motor outboard bearing is noisy | 2 | 6.90 | 18 | 2036.2 | 76.68 |
| 8 | leakage from discharge line (Header) from Pin hole | 1 | 3.45 | 16 | 50.6 | 1.91 |
| 9 | Gland packing of the pump is smoking | 1 | 3.45 | 13 | 52.7 | 1.98 |
| 10 | Inboard bearing is noisy | 1 | 3.45 | 15 | 30 | 1.13 |
| 11 | Outboard bearing is noisy | 1 | 3.45 | 0 | 0 | 0.00 |
| **Total** | | **29.00** | **100** | **267.53** | **2655.53** | **100** |

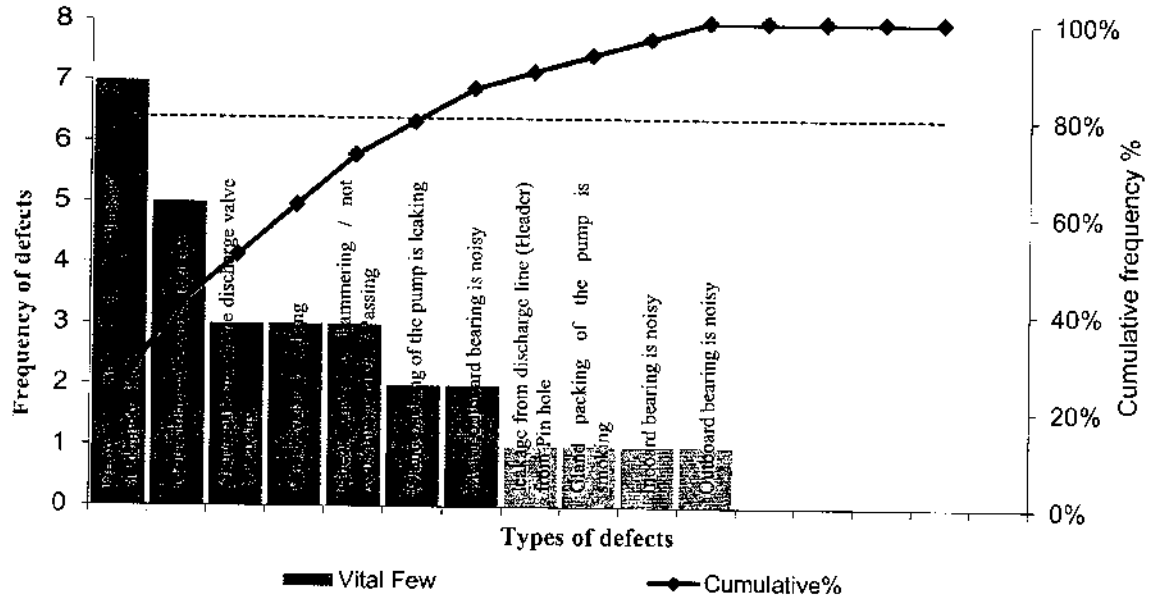



**Chart 5 - Mechanical defects at HT DS**

The above chart shows that The first seven defects (64% of the defects) cover 86.21% of the total failures. The major defect is due to "malfunction of the drain valve of the pump" and the second one is the "noise in the inboard bearing". In this station, there is no blending process, the blended water comes from HTBS directly to the ground storage tanks and by using tower pumps water is forwarded to the distribution network. The average TDS of blended water is similar to that of HTBS which is between 1600 to 2000 PPM. The average number of planned preventive maintenance visits is 3.92 per pump per year with an average of 5.8 hours per year for each pump.

### 6.1.2) Hamala A2 GFS

The station contains five pumps as mentioned earlier only for ground water, the main defects collected which are directly related to mechanical section are listed in Table 24 below. Fourteen different types of defects are identified for the pump and its main equipment like discharge valve, check valve, casing, bearings, gland packing and other accessories. The data is plotted in Chart 6 to bring up the major defects that affect reliability and availability of the pumps.

**Table 24 - Mechanical defects data for Hamala GFS pumps**

| Defect | | | | Corrective Maintenance | | |
|---|---|---|---|---|---|---|
| No. | Type | Frequency | | Time (Hrs.) | Cost | |
| | | Count | % | | BD | % |
| 1 | Gland packing of the pump is leaking | 81 | 54.36 | 1577.53 | 8354.39 | 48.86 |
| 2 | Inboard bearing is noisy | 13 | 8.72 | 347.25 | 3702.06 | 21.65 |
| 3 | leakage from discharge line | 12 | 8.05 | 177.70 | 675.10 | 3.95 |
| 4 | Drain valve is blocked /leaking/broken | 11 | 7.38 | 138.66 | 330.81 | 1.93 |
| 5 | Gland packing of the pump is smoking | 6 | 4.03 | 57.50 | 155.65 | 0.91 |
| 6 | Check valve is passing | 5 | 3.36 | 127.50 | 382.93 | 2.24 |
| 7 | Check valve is hammering / not working properly | 4 | 2.68 | 174.00 | 500.30 | 2.93 |
| 8 | Outboard bearing temperature is high | 4 | 2.68 | 105.50 | 292.30 | 1.71 |
| 9 | Outboard bearing is noisy | 3 | 2.01 | 94.50 | 394.91 | 2.31 |
| 10 | Inboard bearing grease is coming out | 3 | 2.01 | 35.00 | 93.46 | 0.55 |
| 11 | Casing is leaking from pin hole | 2 | 1.34 | 208.00 | 2091.50 | 12.23 |
| 12 | Inboard bearing temperature is high | 2 | 1.34 | 11.00 | 35.20 | 0.21 |
| 13 | Motor inboard bearing is noisy | 2 | 1.34 | 11.00 | 50.30 | 0.29 |
| 14 | Gland packing of the suction valve is leaking | 1 | 0.67 | 20.49 | 38.27 | 0.22 |
| **Total** | | **149.00** | **100** | **3085.63** | **17097.17** | **100** |

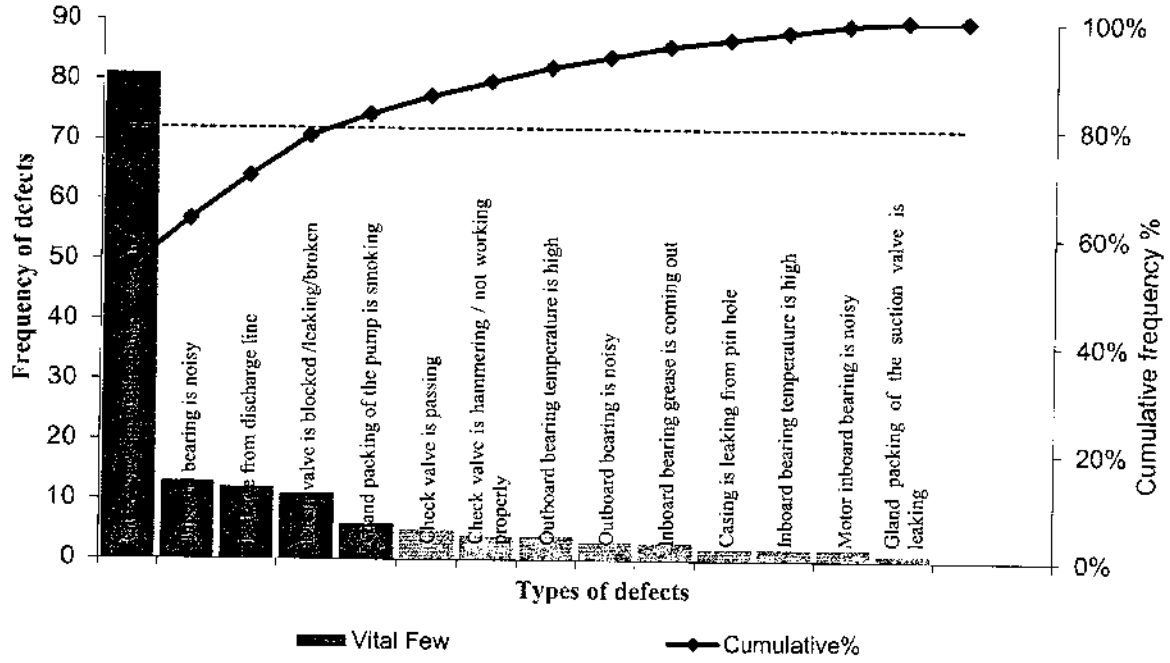



**Chart 6 - Mechanical defects at Hamala A2 GFS**

Chart 6 shows that the first 5 Defects (i.e.36% of the total defects) cover 82.55% of the total frequency of the failures. The major problem for the station's pumps is "the leaking of gland packing of the pumps" and the second major defect is "the noise in the inboard bearings".

The major five defects are mainly due to two main reasons, the first one is due to the ground water, this station forwards only ground water to other stations, the conductivity of the water is high compared with other types of water like potable and distillate water (as per the statistical report of 2011, the average TDS was between 3200 to 7100 PPM). This type of water affect other equipment like the discharge header, valves and the drain valves. Generally, TDS above 1000 PPM indicate ability to conduct electric current, which is enough to cause serious electrolytic corrosion (USACE, 1994). It is important to mention that the dosing of chlorine gas is high (1Kg/Hr) at this station for disinfection due to availability of Total Coliform Bacteria, higher concentration of chloride (more than 1 PPM) increases the rate of corrosion. The presence of chloride in water promotes corrosion and pitting of iron and copper (Seneviratne, 2007). Because chloride ions form strong acid, this tend to increase the acidity of water.

The second reason is due to the workforce, the level of experience of the work force is not adequate to do the corrective and preventive maintenance in a perfect way. Continuous

repetition of repairing gland packing defect using one technique which is mainly the adjusting and tightening of the packing is a good indication of low level of work force.

The average planned preventive maintenance visits for each pump at this station is 6.6 visits per year with an average of 13.1 hours per year (Table 21). Each pump visited at least six times a year and two hours per visit for inspection, lubrication and taking vibration readings. The time and frequency of PPM task should minimize the number of failures that may occur yearly since the task must ensure that the equipment is working properly. Any malfunctioning in the running of a pump such as high vibration or excessive leakage from gland packing must be rectified at the time of preventive maintenance.

### 6.1.3) West Riff'a #2 BS:

Seven pumps are located in this station, data collected about the frequency, time and cost for every failure recorded for mechanical section is tabulated in Table 25, and plotted in Chart 7.

**Table 25 - Mechanical defects data for WR#2 BS pumps**

| No. | Defects | | | Corrective maintenance | | |
|---|---|---|---|---|---|---|
| | Type | Frequency | | Time (Hrs.) | Cost | |
| | | Count | % | | BD | % |
| 1 | Gland packing of the pump is leaking | 57 | 40.14 | 649.17 | 2,356.81 | 34.80 |
| 2 | Drain valve is blocked /leaking/broken | 23 | 16.20 | 136.5 | 257.40 | 3.80 |
| 3 | Check valve is leaking | 20 | 14.08 | 360.42 | 913.85 | 13.49 |
| 4 | Check valve is hammering / not working properly / Passing | 13 | 9.15 | 223 | 573.35 | 8.47 |
| 5 | Inboard bearing is noisy | 11 | 7.75 | 287.31 | 1,263.71 | 18.66 |
| 6 | Motor inboard bearing is noisy | 7 | 4.93 | 165.5 | 417.98 | 6.17 |
| 7 | Inboard bearing temperature is high | 3 | 2.11 | 25 | 84.70 | 1.25 |
| 8 | Motor outboard bearing is noisy | 2 | 1.41 | 64 | 132.80 | 1.96 |
| 9 | Gland packing of the suction valve is leaking | 1 | 0.70 | 4 | 9.60 | 0.14 |
| 10 | Gland packing of the discharge valve is leaking | 1 | 0.70 | 120 | 359.12 | 5.30 |
| 11 | Suction / discharge valve is jammed | 1 | 0.70 | 35 | 101.73 | 1.50 |
| 12 | Coupling cove to be re-fixed | 1 | 0.70 | 14 | 29.00 | 0.43 |
| 13 | Outboard bearing is noisy | 1 | 0.70 | 0 | 0.00 | 0.00 |
| 14 | Outboard bearing temperature is high | 1 | 0.70 | 75.5 | 272.91 | 4.03 |
| **Total** | | **142.00** | **100** | **2159.4** | **6772.95** | **100** |

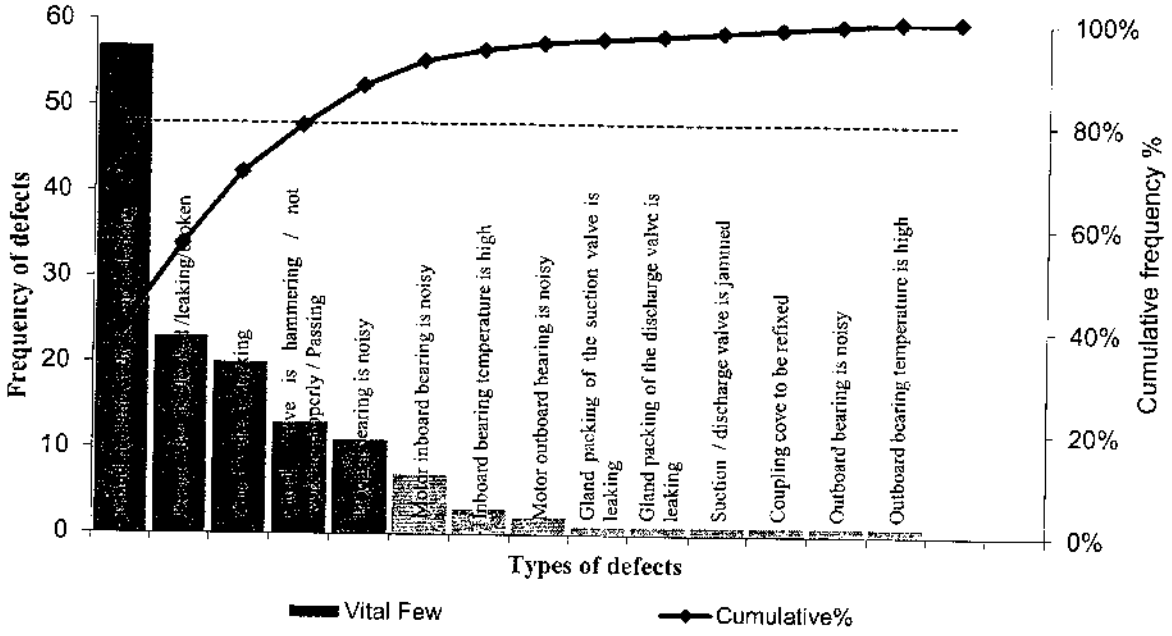



**Chart 7 - Mechanical defects at WR#2 BS**

The chart shows that the first five defects (i.e. 36% of defects) cover 87.32% of the total failures. The major one is the "leakage from gland packing of the pumps" and the second one is the "drain valve blocking". The average TDS of blended water is 1000 PPM and for the ground water it is similar to that of Hamala A2 GFS as per the statistical report of 2011. The average number of planned preventive maintenance visits is 3.66 per pump per year with an average of 7 hours per year for each pump.

### 6.1.4) Hamad Town BS

This station contains eight pumps that are used for different types of water. The same practice carried out in Section 6.1.1 is implemented here, seventeen different types of mechanical defects are identified and listed in Table 26 below, together with their frequency, time for repair and the cost of repair. The data is plotted in Chart 8.

**Table 26 - Mechanical defects data for HTBS pumps**

| No. | Types of Defects | | | Corrective Maintenance | | |
|---|---|---|---|---|---|---|
| | Type | Frequency | | Time (Hrs.) | Cost | |
| | | Count | (%) | | BD | % |
| 1 | Gland packing of the pump is leaking | 49 | 30.63 | 608.58 | 2099.39 | 23.34 |
| 2 | leakage from discharge line | 25 | 15.63 | 399.5 | 1103.89 | 12.27 |
| 3 | Inboard bearing is noisy | 13 | 8.13 | 382.82 | 1215.69 | 13.51 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 4 | Drain valve is blocked /leaking/broken | 12 | 7.50 | 103.66 | 672.95 | 7.48 |
| 5 | Gland packing of the pump is smoking | 11 | 6.88 | 148.5 | 497.6 | 5.53 |
| 6 | Check valve is passing | 10 | 6.25 | 172.66 | 401.1 | 4.46 |
| 7 | Motor inboard bearing is noisy | 9 | 5.63 | 249.5 | 839.32 | 9.33 |
| 8 | Relieve valve is blocked | 8 | 5.00 | 61 | 144.6 | 1.61 |
| 9 | Motor outboard bearing is noisy | 5 | 3.13 | 165 | 550.52 | 6.12 |
| 10 | Coupling is damaged | 4 | 2.50 | 95 | 1023.61 | 11.38 |
| 11 | Shaft is jammed | 3 | 1.88 | 56.5 | 153.54 | 1.71 |
| 12 | Check valve is hammering / not working properly | 3 | 1.88 | 42 | 112.2 | 1.25 |
| 13 | Pump is not sucking water | 2 | 1.25 | 13 | 46 | 0.51 |
| 14 | Casing is leaking from pin hole | 2 | 1.25 | 18 | 27.3 | 0.30 |
| 15 | Outboard bearing is noisy | 2 | 1.25 | 16 | 49.4 | 0.55 |
| 16 | Inboard bearing temperature is high | 1 | 0.63 | 5 | 26.25 | 0.29 |
| 17 | Outboard bearing temperature is high | 1 | 0.63 | 10 | 33.1 | 0.37 |
| **Total** | | **160.00** | **100** | **2546.74** | **8996.47** | **100** |

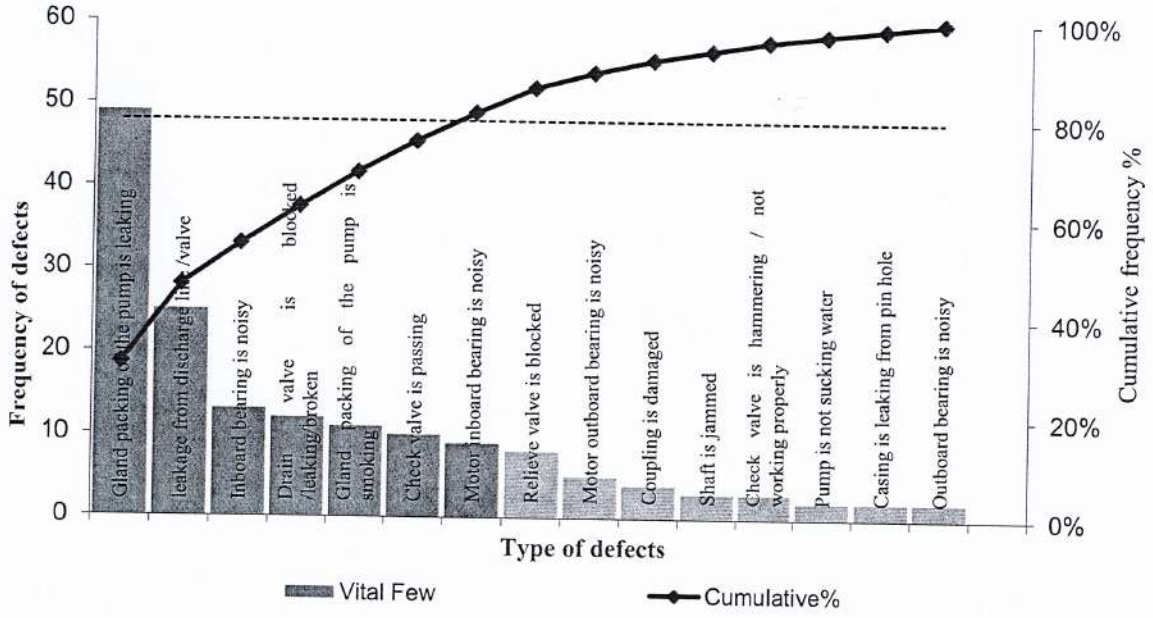



**Chart 8 - Mechanical defects at HT BS**

Chart 8 shows that the first seven Defects (i.e. 41 % of the defects) cover 81.65% of the total failures. The same defects are repeated in this station, "the gland packing leakage" is a major defect and the second one is the "leakage from discharge line or valves". The conductivity of the water here is the main factor that lead to all these defects. The ground water in HTBS comes from Hamala A2 GFS with high conductivity, and the blended water, which is a

mixture of ground water with distillate water and it is also of high conductivity (blended water conductivity between 1600 to 2000 PPM as per the statistical report of 2011).

The average planned maintenance for each pump is 4.18 visits every year with an average of 6.13 hours per year. The inadequate workforce experience factor will be valid in this station, the quality of the PPM tasks are not done in an efficient way that can reduce the failure rate. Most of the above failures must be discovered during the preventive maintenance. PPM task is done every 2.8 months and this type of maintenance cover most parts of the pumps as per planned preventive task sheet.

### 6.1.5) West Riff'a #1 BS:

There are twelve pumps in this station for diferent types of water. Only twelve defects are related to these pumps and issued for repairing to the Mechanical Section. Table 27 below and Chart 9 show the extracted data for the frequency, time and cost for every type of defect for West Riff'a BS.

**Table 27 - Mechanical defects data for WR#1 BS pumps**

| No. | Defects | | | Corrective maintenance | | |
|---|---|---|---|---|---|---|
| | Type | Frequency | | Time (Hrs.) | Cost | |
| | | Count | % | | BD | % |
| 1 | Gland packing of the pump is leaking | 49 | 27.22 | 569 | 6,935.43 | 39.73 |
| 2 | leakage from discharge line (Header) from Pin hole | 38 | 21.11 | 867.74 | 2,984.32 | 17.10 |
| 3 | Check valve is leaking | 22 | 12.22 | 227 | 584.50 | 3.35 |
| 4 | Check valve is hammering / not working properly / Passing | 20 | 11.11 | 540.42 | 4,923.24 | 28.21 |
| 5 | Gland packing of the pump is smoking | 11 | 6.11 | 73.74 | 596.67 | 3.42 |
| 6 | Drain valve is blocked /leaking/broken | 10 | 5.56 | 81 | 167.80 | 0.96 |
| 7 | Gland packing of the suction valve is leaking | 7 | 3.89 | 74.5 | 195.61 | 1.12 |
| 8 | Inboard bearing is noisy | 7 | 3.89 | 104 | 518.91 | 2.97 |
| 9 | Motor inboard bearing is noisy | 6 | 3.33 | 70.5 | 239.82 | 1.37 |
| 10 | Motor outboard bearing is noisy | 5 | 2.78 | 46 | 155.92 | 0.89 |
| 11 | Gland packing of the discharge valve is leaking | 3 | 1.67 | 22 | 56.50 | 0.32 |
| 12 | Outboard bearing is noisy | 2 | 1.11 | 49.5 | 95.89 | 0.55 |
| **Total** | | **180.00** | **100** | **2725.40** | **17454.6** | **100** |

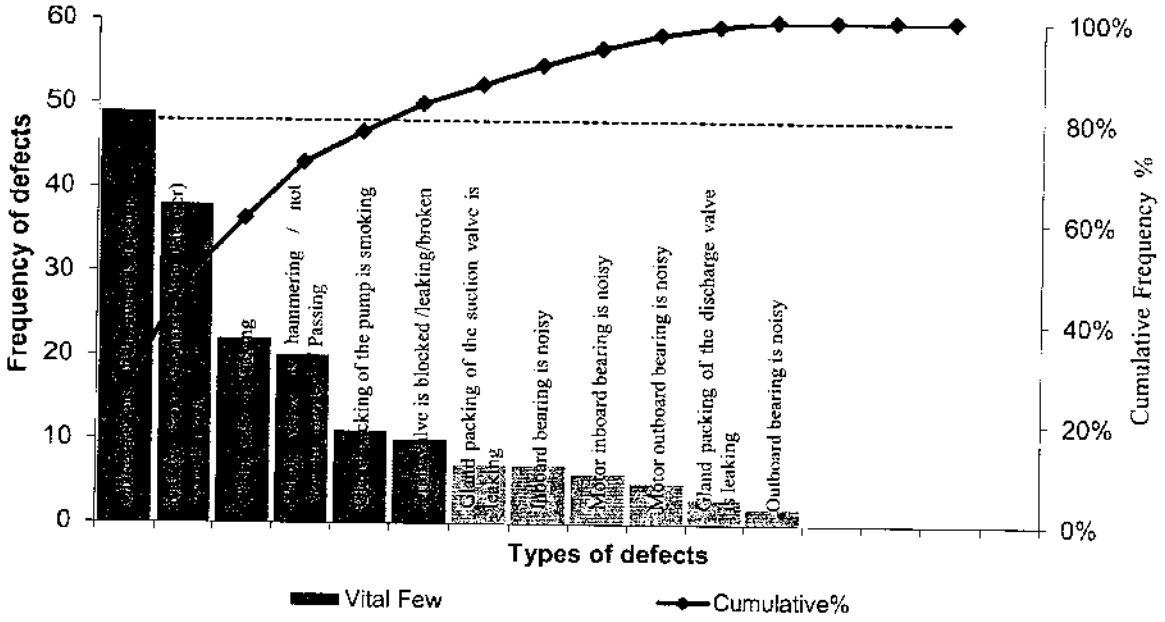



**Chart 9 - Mechanical defects at WR#1 BS**

The first six defects (50% of the total defects) cover 83.33% of the total frequency, and the major defect is the "leakage from gland packing of the pumps", and the second one is the "leakage from pin hole in the discharge header of the pumps". The average TDS of blended water is 1000 PPM and for the ground water it is similar to that of Hamala A2 GFS as per the statistical report of 2011. The average number of planned preventive maintenance visits is 3.76 per pump per year with an average of 5.63 hours per year for each pump.

### 6.2) Common Major Defects of Stations

Table 28 shows comparisons of the major defects among stations. In this table the first seven major defects are listed in descending order of their frequencies for each station. Each type of defect in the table is colored by the same color to compare its position in the defects list among the stations. The total percentage of frequency is shown at the bottom of the table for each station. Each station listed defects are representing more than 80 % of the total defects associated with that station. Some types of defects are common in all stations with different percentages. These common defects are discussed in the following paragraphs

- **Gland packing is leaking**

  Gland packing is part of stuffing box, this part is mainly used to prevent the high pressure of water from leaking to the suction or to the external environment. The packing used when leakage from pump is not costly, packing squeezes against the pump shaft and requires frequent adjustment to maintain proper amount of cooling and lubrication leakage. Packing life depends on service conditions, the quality of the packing material and the care during installation and adjustment.

  This defect occurs in all stations where it comes first with highest frequency percentage (the percentage ranges from 6.9 to 54.36 %) except at Hamad Town distribution station where it has low frequency. At this latter station specifically the pumps are not running continuously for 24 hours, they run only for couple of hours then stopped for the remaining day due to low demand. This is the reason behind the low frequency of the leaking of gland packing in this station. In the other stations the pumps are running continuously for 24 hours, even though there is a redundancy in these stations.

- **Leakage from discharge line**

  The function of discharge header or line is to deliver or supply water to the second point (either elevated storage reservoir or another station). All stations suffer from this defect except West Riffa # 2 blending station because it is new and provided with excellent internal and external coating and it is new compare to other stations, while other stations' headers are old and have no internal paint coating. For HTD there is no defects related to the discharge header because there is no ground water in the station, the water comes from HTBS is blended water and there is no blending process.

**Table 28 - Comparisons of major defects among stations**

| Order | Hamala A2 GFS | | | Hamad Town BS | | Hamad Town DS | | | West Riff'a 1 BS | | | West Riff'a 2 BS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Defects | Frequency (%) | | Defects | Frequency (%) | Defects | Frequency (%) | | Defects | Frequency (%) | | Defects | Frequency (%) | |
| 1 | Gland packing of the pump is leaking | 54.36 | | Gland packing of the pump is leaking | 30.63 | Drain valve is blocked /leaking/broken | 24.14 | | Gland packing of the pump is leaking | 27.22 | | Gland packing of the pump is leaking | 40.14 | |
| 2 | Inboard bearing is noisy | 8.72 | | leakage from discharge line | 15.63 | Motor inboard bearing is noisy | 17.24 | | leakage from discharge line (Header) from Pin hole | 21.11 | | Drain valve is blocked /leaking/broken | 16.20 | |
| 3 | leakage from discharge line | 8.05 | | Inboard bearing is noisy | 8.13 | Gland packing of the discharge valve is leaking | 10.34 | | Check valve is leaking | 12.22 | 23.33 | Check valve is leaking | 14.08 | 23.23 |
| 4 | Drain valve is blocked /leaking/broken | 7.38 | | Drain valve is blocked /leaking/broken | 7.50 | Check valve is leaking | 10.34 | 20.68 | Check valve is hammering / not working properly / Passing | 11.11 | | Check valve is hammering / not working properly / Passing | 9.15 | |
| 5 | Gland packing of the pump is smoking | 4.03 | | Gland packing of the pump is smoking | 6.88 | Check valve is hammering / not working properly / Passing | 10.34 | | Gland packing of the pump is smoking | 6.11 | | Inboard bearing is noisy | 7.75 | |
| 6 | Check valve is leaking | 3.36 | 6.04 | Check valve is hammering / not working properly | 6.25 | Gland packing of the pump is leaking | 6.90 | | Drain valve is blocked /leaking/broken | 5.56 | | Motor inboard bearing is noisy | 4.93 | |
| 7 | Check valve is hammering / not working properly | 2.68 | | Motor inboard bearing is noisy | 5.63 | Motor outboard bearing is noisy | 6.90 | | Gland packing of the suction valve is leaking | 3.89 | | Inboard bearing temperature is high | 2.11 | |
| **Total** | | **88.58** | | | **80.65** | | **86.2** | | | **87.22** | | | **94.36** | |

- **Drain valve is blocked, leaking or broken**

  This defect exists in all stations, it is the first defect at HTDS with frequency of 24.14%, second one at WR#2 BS with a frequency of 16.2%, for the other stations the defect ranges between 5.5 to 7.5 %. The main reason for this defect is the quality of water which most of the time have high conductivity resulting into corrosion scales and salt scales. These scales block the valve and the drain line. Also the type of material used for this drain line is galvanized pipes, this type of material cannot withstand the condition of water at these stations.

- **Check valve is hammering or not working properly and it is leaking**

  These two type of defects exist in all stations, at Hamala A2 GFS the percentage of frequency for these defects together is 6.04%, while it varies between 20 to 23 % for HTD, WR#1 BS and WR#2 BS. The reason behind these defects' occurrences in Hamala A2 GFS is due to the age of the check valves, they run for long period without replacement or even planned preventive maintenance, only corrective maintenance is applied in case of request raised from operation. while in West Riff'a #2 BS the main reason is due to poor quality of the valves as per mechanical maintenance group opinion.

- **Inboard bearing is noisy (pumps or motors) and temperature is high**

  These types of defect exist in all stations with different percentages, here it is important to mention that the operating conditions have large impact on these types of defects. There are some factors accelerating the bearing wear like high loads, poor lubrications, high operating temperature, and vibration. Preventive maintenance techniques such as vibration analysis, temperature checks and oil analysis can improve the effectiveness of scheduling bearings replacements.

- **Gland packing is smoking**

  This defect exists in three stations in Table 28 above, the real cause of this defect is the inadequate lubrication which will lead to overheat of the packing and will generate smokes.

### 6.3) Analysis of Common Types of Defects for all Stations

Tables 23 to 27 show that there are many mechanical defects raised for repairing, some types of these defects are common among stations and some others are not. Collection of all defects in one table is done in Table 29 for easy analysis and to have wider picture about the main causes that affect the reliability of these pumps. (all the defects are listed in descending order of their frequencies)

**Table 29 - Final list of defects for all stations including frequency, frequency percentage, time and cost**

| No. | Description of Defects | Total Summary | | | |
|---|---|---|---|---|---|
| | | Frequency (Nos.) | Frequency (%) | Time for repairing (Hrs.) | Cost of repairing (BD) |
| 1 | Gland packing of the pump is leaking | 238 | 36.06 | 3421.28 | 19818.03 |
| 2 | leakage from discharge line (Header) | 76 | 11.52 | 1460.94 | 4813.92 |
| 3 | Drain valve is blocked /leaking/broken | 63 | 9.55 | 512.83 | 1530.56 |
| 4 | Check valve is not working properly (Passing or Hammering) | 58 | 8.79 | 1335.58 | 7018.02 |
| 5 | Check valve is leaking | 45 | 6.82 | 610.42 | 1553.55 |
| 6 | Inboard bearing is noisy | 45 | 6.82 | 1136.39 | 6730.37 |
| 7 | Gland packing of the pump is smoking | 29 | 4.39 | 292.74 | 1302.62 |
| 8 | Motor inboard bearing is noisy | 29 | 4.39 | 517.03 | 1590.09 |
| 9 | Motor outboard bearing is noisy | 14 | 2.12 | 293 | 2875.43 |
| 10 | Gland packing of the suction valve is leaking | 9 | 1.36 | 98.99 | 243.48 |
| 11 | Outboard bearing is noisy | 9 | 1.36 | 160 | 540.19 |
| 12 | Relieve valve is blocked | 8 | 1.21 | 61 | 144.6 |
| 13 | Gland packing of the discharge valve is leaking | 7 | 1.06 | 178 | 505.27 |
| 14 | Inboard bearing temperature is high | 6 | 0.91 | 41 | 146.15 |
| 15 | Outboard bearing temperature is high | 6 | 0.91 | 191 | 598.31 |
| 16 | Coupling is damaged | 4 | 0.61 | 95 | 1023.61 |
| 17 | Casing is leaking from pin hole | 4 | 0.61 | 226 | 2118.8 |
| 18 | Shaft is jammed | 3 | 0.45 | 56.5 | 153.54 |
| 19 | Inboard bearing grease is coming out | 3 | 0.45 | 35 | 93.46 |
| 20 | Pump is not sucking water | 2 | 0.30 | 13 | 46 |
| 21 | Suction / discharge valve is jammed | 1 | 0.15 | 35 | 101.725 |
| 22 | Coupling cove to be re-fixed | 1 | 0.15 | 14 | 29 |
| **Total** | | **660** | **100 %** | **10784.7** | **52976.725** |

The above table shows the type of defects in descending order of their frequencies. The "gland packing leakage" is the most common and major defect with the highest frequency, time and cost, therefore it will be discussed and analyzed in details to know the cause behind this defect and the relationship between planned preventive maintenance and corrective of the gland packing.

The gland packing leakage has shown a frequency of 36.6 % of the total defects and percentages of repair time and cost of 31.73% and 37.41, respectively. Also the "leakage from discharge header" (12% frequency) and the "drain line leakage, blockage and breakage" (9.5% frequency) will be discussed, thus 57.5 % of the defects will be discussed, and most of the observations will be extracted from these three types of defects.

### 6.3.1) Gland packing leakage analysis

Gland packing as mentioned earlier is part of stuffing box, the main function is to protect the pump against leakage at the point where the shaft passes out through the pump pressure casing. It prevents air leakage into the pump and also prevents water leakage out of the pump. The gland is a very important part of stuffing box, it gives the packing the desired fit on the shaft. The main reasons behind using stuffing box because it's cheaper than mechanical seal and it is easy to replace, despite these advantages, there are some disadvantages of using the gland packing such as it needs frequent adjustment, it tends to wear the shaft or bush, and a slight leakage is always required for cooling purposes. It is important to mention that all the pumps covered in this study are provided with gland packing because of their age.

After focused discussion with the mechanical maintenance officials, they attribute repetition of this leakage from the gland packing to the following reasons and factors:

- Packing not properly installed
- Packing not properly adjusted
- Shaft or shaft sleeve worn
- Degradation of the packing
- Fear to change the type of gland packing
- Misalignment or excessive vibration of the pump
- Lantern ring improperly located in the stuffing box
- Water quality is damaging the packing

**Reliability of gland packing**

To measure the equipment performance there are many indicators used. For the gland packing mentioned above, the best indicators available are

- Number of failures for the period studied (7 years)
- Mean time between failures in hours (MTBF)
- Availability in percentage given by

  Availability = [ MTBF / ( MTBF + MTTR) ] x100 ---------- (1)

  where MTTR is the Mean Time to Restore.

These are the main indicators that help to identify the reliability of the packing used for the pump in water transmission assets. Three pumps are selected from each station which have high frequency of defect in gland packing, except for Hamad town distribution station where only one pump is selected. All data related to this type of defect is calculated such as, MTBF, MTTR, availability and failure rate for each pump. MTBF is extracted using Weibull distribution chart (J.S. Craver 1996). Summary of the data is shown in Table 30. **(Refer to Appendix M for more details).**

**Table 30 - MTBF, failure rate and availability for gland packing**

| Station | Pump name | Number of defects | No. of defects covered | MTBF Calculated (Hrs) | MTBF Weibull (Hrs) | Failure rate (failures/hour) | MTTR calculated (Hrs) | Availability (%) |
|---|---|---|---|---|---|---|---|---|
| Hamala A2 GFS (5 pumps) | WR pump #1 | 18 | 59 out of 81 | 3253.33 | 3400 | 0.0003 | 17.16 | 99.5 |
| | WR pump #2 | 22 | | 2605.09 | 2600 | 0.00038 | 9.82 | 99.6 |
| | WR pump #3 | 19 | | 2363.38 | 2200 | 0.00043 | 14.17 | 99.4 |
| HT BS (8 pumps) | DW pump #1 | 12 | 26 out of 49 | 3836 | 3600 | 0.00026 | 19.13 | 99.5 |
| | HTD pump#2 | 6 | | 5764.8 | 4000 | 0.00017 | 11.3 | 99.8 |
| | GW pump#2 | 8 | | 7176 | 6400 | 0.00014 | 9.87 | 99.8 |
| HTD (2 pumps) | Tower pump #1 | 2 | 2 out of 2 | 8844 | 5700 | 0.00011 | 8.5 | 99.9 |
| West Riff'a #1 BS (12 pumps) | DW Pump #1 | 4 | 33 out of 57 | 13740 | 7400 | 0.00072 | 8.5 | 99.9 |
| | East pump #2 | 19 | | 3124 | 2400 | 0.00032 | 7.74 | 99.7 |
| | East pump #1 | 10 | | 5191.2 | 5000 | 0.00019 | 7.03 | 99.8 |
| West Riff'a #2 BS (7 pumps) | DW Pump #1 | 11 | 30 out of 49 | 4898.2 | 5000 | 0.0002 | 6.03 | 99.8 |
| | Tower pump#2 | 11 | | 5085.8 | 5100 | 0.00019 | 17.55 | 0.996 |
| | Tower pump#3 | 8 | | 5697 | 5500 | 0.00017 | 10 | 0.998 |

**Sample calculations:**

A brief explanation is given hereunder for one pump (West Riff'a pump #1 at Hamala A2 GFS) to show how the MTBF, failure rate, MTTR and availability figures in Table 30 are calculated.

**Table 31 - Gland packing defects' information for WR pump #1 at Hamala A2 GFS**

| Serial no. | Date of failure | Time to failure (TTF) in Hrs | Time to repair (TTR) in Hrs | TTF (Hrs) in Ascending order | % Cumulative Percentage of failure (failure no. / Sample size) |
|---|---|---|---|---|---|
| 0 | 1-1-2005 | 0 | 0 | 0 | 0 |
| 1 | 26-1-2005 | 600 | 20 | 144 | 5.56 |
| 2 | 2-11-2005 | 6720 | 6 | 192 | 11.11 |
| 3 | 28-12-2005 | 1344 | 9.66 | 360 | 16.67 |
| 4 | 14-1-2006 | 408 | 6 | 408 | 22.22 |
| 5 | 8-4-2006 | 2016 | 24.5 | 408 | 27.78 |
| 6 | 14-11-2006 | 5280 | 95 | 576 | 33.33 |
| 7 | 26-12-2006 | 1008 | 1.5 | 576 | 38.89 |
| 8 | 12-3-2007 | 1824 | 6.34 | 600 | 44.44 |
| 9 | 29-3-2007 | 408 | 18 | 1008 | 50.00 |
| 10 | 4-9-2007 | 3816 | 33 | 1344 | 55.56 |
| 11 | 19-9-2007 | 360 | 6 | 1824 | 61.11 |
| 12 | 11-8-2008 | 7848 | 22 | 2016 | 66.67 |
| 13 | 4-9-2008 | 576 | 5.5 | 3816 | 72.22 |
| 14 | 28-9-2008 | 576 | 2.5 | 4464 | 77.78 |
| 15 | 6-10-2008 | 192 | 21 | 5280 | 83.33 |
| 16 | 12-10-2008 | 144 | 10 | 6720 | 88.89 |
| 17 | 16-4-2009 | 4464 | 12 | 7848 | 94.44 |
| 18 | 7-9-2011 | 20976 | 10 | 20976 | 100.00 |
| **Total** | | **58560** | **309** | | |

Table 31 above shows in the second column the date on which Field Operation reported the leakage of gland packing. The third column shows the time in hours between two consecutive gland packing defects, and the third column shows how many hours it took to repair the gland packing leakage defect. The fourth column shows ascending order of the second column and the last column is the percentage of cumulative percentage of failure. The last two columns data are used to plot Weilbull Chart (Cumulative percentage of failure v.s. time to failure). For example the second defect reported on 2 of November 2005 after 6720 hours from the first defect and it was repaired within 6 hours only.

**Note:** the defect number zero is an estimated one because there are no data available before year 2005, and the date mentioned is the starting date of the recorded data. Moreover, it is assumed that 1 month is equal to 30 days, and every month represent 720 Hours.

The parameters for Hamala A2 GFS WR pump #1 based on data of Table 31 are:

MTBF calculated $= \sum$ TTF / no. of defects ---------- (2)

$= 58560 / 18 = 3253.33$ Hrs - (4.52 months)

MTTR $= \sum$ TTR / no. of defects ---------- (3)

$= 309 / 18 = 17.16$ Hrs

Failure rate ( $\lambda$ ) = 1/ MTBF ---------- (4)

$= 1/ 3253.33 = 0.0003$ failures / hour

Availability (A) = MTBF / MTBF+MTTR ---------- (5)

$= 3253.33 / (3253.33+17.16) = 0.995$

Figure 16 below shows a sample of Weibull Chart drawn for WR pump #1 at Hamala A2 GFS. The horizontal axis of the Weibull Chart represent the age of failure which is the fifth column from Table 31 and the vertical axis represent the cumulative percent failures which is the sixth column from Table 31. After plotting the cumulative percent failures versus age of failures, best-fit straight line must be drawn through the plotted points. A perpendicular line drawn from an estimation point in the upper left corner of the chart to the original line. Where the perpendicular line intersects the *Pu* scale at the top of the chart, the value of the *Pu* to be located on the vertical axis, and the originally plotted line to be used to read the corresponding Mean Time Between Failure from the horizontal axis.

From the figure 16 below the value of the Mean Time Between failure for the WR pump#1 at Hamala A2 is 3200 hours. Every individual pump listed in the table 30 above has a Weibull Chart drawn for it and MTBF from the graph is extracted in order to compare the both values, the calculated and the graphed one.

**Lumped analysis of MTBF:**

From Table 30 it is noticed that the number of defects in gland packings for **Hamala A2** station is higher than the other stations because of the reasons mentioned earlier in the beginning of Section 6.3.1. The calculated average MTBF for the gland packings of the three pumps at Hamala A2 GFS is 2740.6 hours (3.8 months), while the average MTBF from Weibull distribution chart is 2733.33 hours (3.8 months). This means that the packings in this station should be attended every 3.8 months since both figures are identical to check its situation (for example to adjust, add extra packings, replace or apply more tightening).

For ***Hamad town blending*** the calculated average MTBF is 5592.26 hours (gland packings to be attended every 7.77 months) and the average MTBF from Weibull chart is 4733.33 hours (gland packings to be attended every 6.57 months), the lowest value must be taken which is 6.57 months.

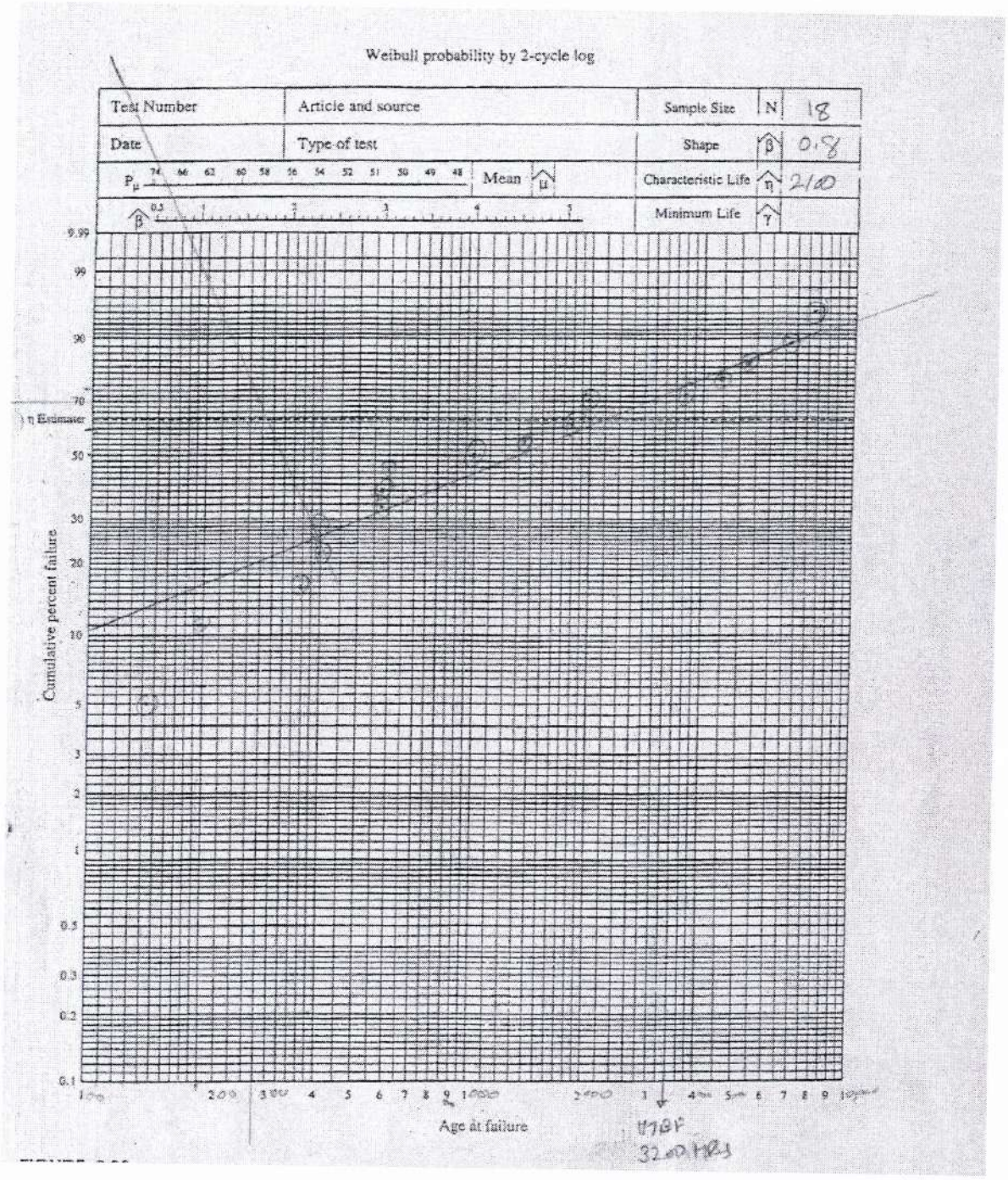



**Figure 16 – Weibull Chart for West Riff'a Pump # 1 at Hamala A2 GFS**

For ***West Riffa#1*** station the calculated average MTBF is 7351.73, so in average the gland packings should be visited every 10.2 months, while the MTBF from Weibull distribution charts is 4666.66 hours (6.5 months), this means that the gland packings should be visited every 6.5 months.

For ***West Riff'a #2*** station the calculated average MTBF is 5227 hours (7.26 months), and the MTBF from Weibull distribution charts is 5200 hours (7.22 months) , both of results are almost same. Therefore the gland packings should be visited every 7.22 months.

The last station is ***Hamad Town Distributio***n and the calculated average MTBF is 8844 hours, implying that gland packings should be visited every 12.28 months, while the MTBF from the Weibull chart is 5700 hours, indicating visits frequency of 7.9 months. **Thus, it is recommend to visit the gland packings every 7.9 months.**

- *Notice: In West Riff'a #1 BS, there is big difference between the calculated MTBF and the MTBF from the Weibull chart for Distillate Pump#1, this is due to the few number of defects (only 4 defects) that cannot give a good estimate of MTBF, and in the Weibull chart, it is difficult to draw best fit line for three or four points only. The same explanation is valid for Hamad Town Distribution, it has only two defects, these two will not give realistic MTBF neither for the calculated one nor from the graph.*
- *All Weibull plots show that the failure rate $\lambda$ is decreasing with time (except for HTDS, for this station there are only two defects, it is difficult to decide upon the behavior of the failure rate based on two values only.)*

From all the above it is noticed that each station has its own lumped mean time between failure for the gland packings, the value vary from 2740 to 8844 hours for the calculated MTBF, and 2733 to 5700 for the graphed MTBF.

All of the above results are obtained from calculations and by using Weibull distribution chart, but there are some data collected from the actual practices done by maintenance staff, and it is analyzed here under. (details are available in Appendix N)

***Further analysis of MTBF:***

This study covers 7 years from 2005 to 2011, this means 84 months, In Appendix N for each pump in the study the gland packing defects are shown with their dates and the dates of actual corrective maintenance done to repair the leakage. The dates of overhauling and the dates of preventive maintenance tasks are shown as well. Other details are shown and it will be mentioned whenever required but in this part the concentration is only on corrective maintenance to see the difference between the calculated and actual parameters. *(for the calculated parameters all defects will be considered whether they are correct or not, in the calculation of the durations between maintenance visits, as real defect, but for actual*

*parameters, the wrong defects will not be included in the calculation of the durations between maintenance visits to repair gland packing leakage, this is the main difference between calculated parameters and the actual parameters)*

Generally, the following corrective actions for the gland packing leakage will be considered for the actual parameters calculations as follows:

- Replace gland packing
- Adjust gland packing
- Tighten the gland packing
- Add packing
- Secure leak

These are the major corrective actions taken to repair the gland packing, the remaining actions like cancelled or duplicate will not be considered because it is part of error or wrong request from operation side.

In Hamala A2 GFS, for West Riff'a pump # 1 there are 18 defects raised from field operation section, 16 of these are real and correct requests for a maintenance action to be carried out and two of them are false requests i.e. wrong. To calculate the average visits of maintenance to repair the gland packing by dividing the total period of study (84 months) by the real number of requests (16 number) the answer will be 5.25 months, this means that the maintenance should visit this pump every 5.25 months to check and repair the gland packing not 4.5 months as calculated from Table 30. Table 32 below shows the values for remaining pumps selected from other stations.

**Table 32 - Average visits for repairing gland packing compared with calculated and graphed MTBF**

| Station | Pump name | No. of defects raised by field operation | No. of real correct corrective action | Average duration between visits by maintenance for individual pumps (months) | Calculated MTBF (Months) {Table 30} | Graphed MTBF (Months) |
|---|---|---|---|---|---|---|
| Hamala A2 GFS | WR pump #1 | 18 | 16 | 5.25 | 4.5 | 4.7 |
| | WR pump #2 | 22 | 19 | 4.42 | 5 | 3.7 |
| | WR pump #3 | 19 | 19 | 4.42 | 3.2 | 3 |
| HT BS | DW pump #1 | 12 | 12 | 7 | 5 | 5 |
| | HTD pump#2 | 5 | 5 | 16.8 | 8 | 5.5 |
| | GW pump#2 | 8 | 8 | 10.5 | 9.9 | 8.8 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **HTD** | Tower pump#1 | 2 | 2 | 42 | 12.2 | 7.9 |
| **West Riff'a #1 BS** | DW Pump #1 | 4 | 3 | 28 | 19 | 10.2 |
| | East pump #2 | 19 | 18 | 4.66 | 4.3 | 3.33 |
| | East pump #1 | 10 | 10 | 8.4 | 7.2 | 6.9 |
| **West Riff'a #2 BS** | DW Pump #1 | 11 | 11 | 7.63 | 6.8 | 6.9 |
| | Tower pump#2 | 11 | 9 | 9.33 | 7 | 7 |
| | Tower pump#3 | 8 | 8 | 10.5 | 7.9 | 7.6 |

Additional table is generated from Table 32, showing only the averages of the durations between each maintenance action, lumped calculated MTBF and lumped graphed MTBF for all pumps selected for all stations, this step will lead to concentrate on one value only which is the average.

**Table 33 - Average visits of maintenance, average calculated and graphed MTBF**

| Station | Pump name | Average duration between visits by maintenance for individual pumps (months) | Calculated MTBF (Lumped) (Months) | Graphed MTBF (Lumped) (Months) |
|---|---|---|---|---|
| **Hamala A2 GFS** | WR pump #1 | 5.25 | 4.5 | 4.7 |
| | WR pump #2 | 4.42 | 5 | 3.7 |
| | WR pump #3 | 4.42 | 3.2 | 3 |
| | Average | 4.7 | 4.2 | 3.8 |
| **HT BS** | DW pump #1 | 7 | 5 | 5 |
| | HTD pump#2 | 16.8 | 8 | 5.5 |
| | GW pump#2 | 10.5 | 9.9 | 8.8 |
| | Average | 11.4 | 7.6 | 6.4 |
| **HTD** | Tower pump #1 | 42 | 12.2 | 7.9 |
| **West Riff'a #1 BS** | DW Pump #1 | 28 | 19 | 10.2 |
| | East pump #2 | 4.66 | 4.3 | 3.33 |
| | East pump #1 | 8.4 | 7.2 | 6.9 |
| | Average | 13.6 | 10 | 6.81 |
| **West Riff'a #2 BS** | DW Pump #1 | 7.63 | 6.8 | 6.9 |
| | Tower pump#2 | 9.33 | 7 | 7 |
| | Tower pump#3 | 10.5 | 7.9 | 7.6 |
| | Average | 9.2 | 7.2 | 7.2 |

Tables 32 and 33 can help the Mechanical Maintenance Section to develop and modify planned preventive maintenance for each pump and for each station especially for the gland

packing maintenance since it is the major defect faced. For example, at Hamala A2 GFS, the actual average duration between visits for repairing the gland packing is 4.7 months, the average calculated MTBF of the pumps is 4.2 months, and average graphed MTBF is 3.8 months. These figures tells that the planned preventive maintenance must be conducted for these pumps every 3.8 months (minimum value), the gland packing must be inspected carefully during the PPM and rectified in case of any defect exists.

The other figures of averages from Table 33 are varying from 6.4 months to 13.6 months, but these values are large numbers, and it is not recommended to keep the pumps without planned preventive maintenance for more than 3 months which is the most common interval for the PPM. Therefore the best schedule for applying PPM is every 3 months which is already implemented for all stations except for Hamala A2 GFS where it is carried out monthly. *But this does not mean that the frequency of defects of the gland packing is acceptable with current maintenance practice, this mean that the PPM practices should be enhanced and improved to reduce the occurrences of defects.*

**Types and cost of repairs for the gland packing**

The types of repairing the gland packing were mentioned in previous section. The packing is either adjusted or replaced. These are the main actions carried out to fix any gland packing problem or leakage. These two repairing works may contain either improper installations or over tightening, packing typically requires some leakage in order to remain lubricated and cooled. If packing rings are over tightened, friction between the packing and the shaft will generate excessive heat which can destroy the packing and possibly the shaft. Since the packing is in direct contact with shaft, it wears over time and this leads to an increase in leakage rate. Improper packing installation leads to uneven compression of the rings or loose fit between the packing and the shaft and this results in excessive leakage .

More focus on these two actions in for each pump is elaborated in Appendices N & O, each pump is analyzed and full details about the time of defect, the action done and the cost of each action (Manpower and material) are represented in these two appendices. Table 34 is the summary of actions taken by the Mechanical Maintenance Section and the cost of each action for manpower and material.

Table 34 - **Summary of the cost related to replacement and adjustment of gland packing**

| Station | Pump name | No of replacement for gland packing | Cost of man-hours for replacement (BD) | Cost of material related to gland packing replacement (BD) | No of adjustment for gland packing | Cost of man-hours for adjustment (BD) | Cost of material related to gland packing adjustment (BD) |
|---|---|---|---|---|---|---|---|
| Hamala A2 GFS | WR pump #1 | 5 | 387.12 | 293 | 10 | 307.41 | - |
| | WR pump #2 | 5 | 130.76 | 20 | 10 | 465.32 | 86 |
| | WR pump #3 | 6 | 385.08 | 406.6 | 11 | 280.94 | - |
| Hamad Town BS | DW pump # 1 | 6 | 289.45 | 287 | 6 | 153.07 | - |
| | HTD pump # 2 | 2 | 12.15 | - | 3 | 109.03 | - |
| | GW pump # 2 | 4 | 129.63 | 439 | 3 | 71.25 | - |
| West Riffa #1 BS | DW pump # 1 | 1 | 42 | - | 2 | 28.3 | - |
| | East Tower Pump # 2 | 5 | 28.8 | 20 | 12 | 147.5 | - |
| | East Tower Pump # 1 | 1 | 81.3 | 161 | 9 | 272.53 | 25 |
| West Riffa #2 BS | DW pump # 1 | 1 | 21.6 | - | 9 | 147.8 | - |
| | Tower Pump # 2 | 4 | 426.51 | 448 | 4 | 70.38 | 64 |
| | Tower Pump #3 | 2 | 64.63 | 32 | 6 | 123.05 | - |
| **Total** | | **42** | **1999.03** | **2106.6** | **85** | **2176.58** | **236** |

- Information are not available

The above table contains samples of pumps from four stations which have the majority of defect related to gland packing, the number of adjustments (85 times) is almost double of replacements (42 times), but the cost of man-hours is almost same with very limited variation, the difference is only BD 177.55. the major difference mainly in the material which is more costly for the replacement of gland packing.

From Appendix N, it is recognized that there is no systematic approach or practice for replacing the gland packing, it is replaced after one, two, three or up to five times of adjustments. It means that the technician will start with adjustment only as a solution of the leakage, or add extra packing or remove one packing, finally if the leakage does not stop the packing will be replaced.

It is concluded that the replacement of gland packing is done if no other solution can be taken to stop leakage which means it is in worst conditions. Also it is concluded that it is not only the packing which is replaced, other parts also may be replaced due to its bad condition affected by the gland packing such as lantern rings, sleeve and /or even the shaft. All of this adds to the cost of replacing the gland packing. But in the case of adjustment, the cost of material is very low, nearly nil for some actions, while the cost of man hours is high exceeding that of replacements. This may be due to inadequacy of experience resulting into long time spent in trials to repair leakage and/or relaxation of maintenance crew in performing their duties.

*The Mechanical Maintenance Section must adopt a systematic approach to adjust or replace the packing periodically at certain intervals to avoid the extra cost that may result from damaging other parts in the pumps since the cost of packing material is cheaper than replacing other parts which are more costly.*

*A maximum number for adjustments before packing replacement must be established for each pump type or station. This upper bound on number of adjustments becomes a maintenance practice to be strictly followed.*

**Mean time to repair for gland packing defects**

Mean time to repair is calculated in Appendix M, the table below shows the calculated mean time to repair for selected individual pumps as well as the average time for MTTR.

**Table 35 - Corrective maintenance of gland packing (MTTR)**

| Station | Pump name | Number of defect | MTTR Calculated (Hrs) |
|---|---|---|---|
| Hamala A2 GFS | WR#1 | 18 | 17.16 |
| | WR#2 | 22 | 9.82 |
| | WR#3 | 19 | 14.7 |
| HT BS | DW pump #1 | 12 | 19.13 |
| | HTD pump#2 | 5 | 11.3 |
| | GW pump#2 | 8 | 9.87 |
| HTD | Tower pump #1 | 2 | 8.5 |
| West Riff'a #1 BS | DW Pump #1 | 4 | 8.5 |
| | East pump #2 | 19 | 7.74 |
| | East pump #1 | 10 | 7.03 |

| | | | |
|---|---|---|---|
| **West Riff'a #2 BS** | DW Pump #1 | 11 | 6.03 |
| | Tower pump#2 | 11 | 17.55 |
| | Tower pump#3 | 8 | 10 |
| **Total** | | **149** | **147.33** |
| **Average** | | | **11.33** |

The table above shows the MTTR for different stations and different pumps, the values are not similar even though the technicians are the same. The lowest MTTR is 6.03 hours and the highest is 19.13 hours, and the average is 11.33 hours. The reason behind the difference between the lowest and the highest is the conditions of the pumps, for example, if the pumps' bolts and nuts are in good conditions without rust or corrosion, the task can be done in a shorter time, but if the conditions are bad, it may take larger time to repair. Another main important issue is the availability of the spares if some items got damaged like bolts, nuts, gland follower.... etc. and if they are not available the time to repair the pumps will be longer.

The high MTTR figures shown in Table 35 are high, not reasonable and not acceptable. It is discussed with mechanical technicians about these values and they said that the normal adjustment time of packing will take around 15 to 30 minutes, and about 2 to 3 hours for replacement of the packing. The remaining time is for monitoring the packing performance, during the monitoring of the packing there should be no smoke or excessive water leak. The packing may require re-adjustment or re-fixing again based on the running conditions, the mechanical technician must not leave the site until the situation is acceptable for both maintenance and operation. *This means the monitoring time for the gland packing is around 10 hours if average MTTR is the reference value for an adjustment case and 8 hours for a replacement case. The monitoring time is more than ten times the corrective maintenance for the adjustment and about 3 times for replacement of gland packing, which are high and they need to be justified.*

To validate the timing of replacement and adjustment for the gland packing which is given by the mechanical technicians, Table 36 is generated to calculate the averages for both types of maintenance actions.

**Table 36 - Average MTTR for replacement and adjustment of gland packing**

| Station | Pump name | No of replacement for gland packing | Total time of replacement (Hrs) | Average time of replacement (Hrs) | No of adjustment of gland packing | Total time for adjustment (Hrs) | Average time of adjustment (Hrs) |
|---|---|---|---|---|---|---|---|
| Hamala A2 GFS | WR pump #1 | 5 | 155.25 | **31.05** | 10 | 100.49 | **10** |
| | WR pump #2 | 5 | 48.4 | **9.68** | 10 | 61.5 | **6.2** |
| | WR pump #3 | 6 | 195 | **32.5** | 11 | 82.5 | **7.5** |
| Hamad Town BS | DW pump # 1 | 6 | 162 | **27** | 6 | 57.5 | **9.6** |
| | HTD pump # 2 | 2 | 14.5 | **7.25** | 3 | 42 | **14** |
| | GW pump # 2 | 4 | 58 | **14.5** | 3 | 18 | **6** |
| West Riffa #1 BS | DW pump # 1 | 1 | 16 | **16** | 2 | 18 | **9** |
| | East Tower Pump # 2 | 5 | 97.33 | **19.46** | 12 | 36 | **3** |
| | East Tower Pump # 1 | 1 | 11 | **11** | 9 | 53.45 | **5.9** |
| West Riffa #2 BS | DW pump # 1 | 1 | 7.5 | **7.5** | 9 | 53.33 | **6.6** |
| | Tower Pump # 2 | 4 | 148.08 | **37.02** | 4 | 30 | **7.5** |
| | Tower Pump #3 | 2 | 20.5 | **10.25** | 6 | 55.5 | **9.25** |
| **Total** | | **42** | **933.56** | **223.21** | **85** | **608.27** | **94.55** |

The average time for replacing gland packing for all pumps is 5.3 hours (by dividing the total average time of replacement over the total number of replacement actions, 223.21 / 42), and the average time of adjustment is 1.1 hours (by dividing the total average time of adjustment over the total number of adjustment, 94.55 / 85).

***Therefore, it is recommended to establish a standard time for replacing and adjusting gland packing to keep a good monitoring system for the performance of the technicians.***

## Relationship between PPM and corrective maintenance of the gland packing

Relationship between the planned preventive maintenance and corrective maintenance (CM) is inversely proportional, this means that if the number of PPM is increased the number of corrective maintenance will decrease. In this section Appendix N is the reference where the block diagrams show the dates of the PPM and CM actions. Some sample PPM and CM dates are tabulated in Table 37 below to monitor the relationship between the two maintenance types. (This table mainly concentrates on gland packing since the leak is easy to be noticed)

**Table 37 - Relationship between PPM and CM of gland packing**

| Station | PPM frequency | Pump name | Date of PPM | Date of C.M. | Maintenance action |
|---|---|---|---|---|---|
| **Hamala A2 GFS** | **Monthly** | **WR pump # 1** | 7-8-2008 | 11-8-2008 | Replaced |
| | | | 31-8-2008 | 4-9-2008 | Tightened |
| | | | 8-4-2009 | 16-4-2009 | Adjusted |
| | | **WR pump # 2** | 27-2-2008 | 27-2-2008 | Adjusted |
| | | | 28-4-2008 | 1-5-2008 | Adjusted |
| | | | 26-5-2008 | 29-5-2008 | Replaced |
| | | | 2-6-2008 | 8-6-2008 | Completed |
| | | | 17-3-2009 | 24-3-2009 | Adjusted |
| | | | 8-4-2009 | 11-4-2009 | Adjusted |
| | | | 5-7-2009 | 10-7-2009 | Replaced |
| | | **WR pump # 3** | 4-6-2008 | 17-6-2008 | Add packing |
| | | | 10-8-2008 | 28-8-2008 | Adjusted |
| | | | 2-9-2008 | 14-9-2008 | Adjusted |
| | | | 16-10-2008 | 30-10-2008 | Add & adjusted |
| | | | 7-4-2009 | 7-4-2009 | Replaced |
| **HTBS** | **Every 3 months** | **DW pump #1** | 7-5-2006 | 7-5-2006 | Replaced |
| | | | 28-10-2006 | 28-10-2006 | Adjusted |
| | | | 3-5-2007 | 17-5-2007 | Adjusted |
| | | **GW pump # 2** | 12-10-2010 | 30-12-2010 | Replaced |
| | | | 14-7-2011 | 21-7-2011 | Adjusted |
| **WR # 1 BS** | **Every 3 months** | **East tower pump #2** | 29-4-2006 | 29-4-2006 | Replaced |
| | | | 5-11-2006 | 20-11-2006 | Replaced |
| | | | 4-2-2009 | 28-2-2009 | Adjusted |
| | | | 9-1-2011 | 16-1-2011 | Adjusted |
| | | **East tower pump #1** | 20-4-2008 | 23-4-2008 | Adjusted |
| | | | 25-10-2008 | 29-10-2008 | Adjusted |
| | | | 4-2-2009 | 28-2-2009 | Adjusted |
| | | **DW pump # 1** | 22-1-2007 | 24-1-2007 | Replaced |
| **WR # 2 BS** | **Every 3 months** | **DW pump # 1** | 25-5-2008 | 13-6-2008 | Adjusted |
| | | | 3-10-2010 | 4-10-2010 | Leak secured |
| | | **Tower pump # 2** | 29-5-2006 | 17-6-2006 | Adjusted |
| | | | 3-12-2007 | 17-12-2007 | Packing added |
| | | | 2-5-2011 | 21-5-2011 | Replace bearing sleeve and alignment done |

In the above table it is always noticed that there is gap between PPM and CM, many corrective actions take place after finishing the preventive one, the maximum duration between them is around 21 days. Four times only both dates are the same and this can be explained that the leak from gland packing is discovered during the PPM and it is being repaired at the same time with a request from maintenance to raise work request card. But for the remaining dates in the list, the work request card is raised after the PPM has been completed. The main explanation for this is the estimation of the condition of the gland packing situation will vary among technicians, one technician may consider the situation is good while another one may consider it bad, and based on the situation a decision will be taken, either to repair or to keep the packing as it is. The skill and experience of repairing the packing vary from technician to another, and this can lead to repetitive occurrence of this type of defects.

### 6.3.2) Analysis of leakage from discharge line defect

This defect has the second frequency after the gland packing, the discharge header is a large diameter pipe that accepts discharge from one or more pumps, the fluid in the discharge header will be delivered to another tank or another station. The main problem is the line itself, because line leakage means that the line is weak leading to reoccurrence of the defect. This line leakage occurs as a result of corrosion, which should be prevented by proper internal coating of the line. Table 38 below is extracted from **Appendix P** for MTBF, MTTR, and availability of the discharge line.

**Table 38 - MTBF, failure rate and availability of discharge line (from 2005 to 2011)**

| Station | Pump name | Number of defects | MTBF Calculated (Hrs) | MTTR (Hrs) | Failure rate (failure/hour) | Availability (%) | Cost of repair (BD) | Cost of material (BD) |
|---|---|---|---|---|---|---|---|---|
| Hamala A2 GFS | WR pump #1 | 3 | 16664 | 16.65 | 0.00006 | 0.999 | 189.65 | 35 |
| | WR pump #3 | 4 | 10944 | 18.75 | 0.000092 | 0.998 | 185.3 | 50 |
| HT BS | HTD pump #1 | 4 | 14220 | 12.37 | 0.00007 | 0.999 | 129.99 | 15.1 |
| | HTD pump #2 | 5 | 10761.6 | 10.5 | 0.000092 | 0.999 | 146.01 | 0 |
| West Riff'a #1 BS | DW Pump #1 | 4 | 14352 | 15.13 | 0.00069 | 0.998 | 153.01 | 70 |
| | West pump #1 | 6 | 8584 | 23.67 | 0.00011 | 0.997 | 411.23 | 0 |
| **Total** | | **26** | **75525.6** | **97.07** | **0.001114** | **5.99** | **1215.19** | **170.1** |
| **Average / pump** | | **4.33** | **12588 (17.5 months)** | **15.7** | **0.000185** | **0.998** | **202.53** | **28.35** |

The MTBF ranges between 8584 to 16664 hours for the pumps of Table 38 with an overall average of 12588 hrs (17.5 months). The overall MTBF of about 1.5 years for discharge line is not acceptable, this equipment is designed to have long life without failure because of its importance for delivery of water. The average availability of the discharge header is high (0.998), and this is a good indicator for such important equipment. The MTTR values are reasonable and there is an extremely high effort to repair the leaks as soon as possible.

Most of occurrences of this defect take place in the old stations where the lines have no internal protection. The frequency of this defect is small compared with that of the gland packing. However, it should be noticed from Appendix P that the occurrences of this defect took place from 2005 till 2011, this means no major action or major maintenance is considered to replace these headers since most of the repairs are not permanent. Seven years passed and no provision of budget to eliminate the problem and this indicates no concern or focus on such defect whose frequency is expected to increase with aging.

**Cost of repair of the discharge line leakage**

Referring to Appendix Q, the cost of manpower for Hamala A2 GFS is BD 374.95 and cost of material is only BD 85, for Hamad town blending the cost of manpower is BD 276 and for the material is BD 15 only, cost of manpower for West Riffa #1 blending station is BD 564.93 and the cost of material is BD 70 only. These figures are not high values because the repairs are only temporary repairs, most of the repairs are only welding of small plate on top of the line just to stop the leakage of water and sometimes if the leakage cannot be stopped by this type of solution due to deterioration of the pipe a clamp will be installed.

The main observation here is the type of repair being temporary not permanent one. One reason of this is due to lack of efficient communications between technicians who do the repair job and senior management like engineers and senior engineers, the situation must be clearly explained and analyzed, the consequences should be raised immediately to do the necessary arrangement to provide the required budget for replacement of the discharge lines that are of poor condition and not to keep it for seven years without complete and perfect solution. The failure frequency of such lines are expected to increase as result of aging. The second reason may be because of high availability of the line and low repair cost relative to the replacement cost which is normally high.

### 6.3.3) Analysis of drain line and valve leakage, blockage and breakage defect

The third major defect is the associated drain line and valve of the pump, this valve is mainly used to drain water from the casing of the pump when needed. The number of occurrences of this defect is 63 times and it represents 9.54% of the total number of mechanical defects. Three pumps are selected in order to analyze this defect, and the basic information are available in **Appendix R,** and the summary of the calculated data is in Table 39.

**Table 39 - MTBF, failure rate and availability for drain line and valve leakage, blockage and breakage (from 2005 to 2011)**

| Station | Pump name | Number of defects | MTBF Calculated (Hrs) | MTTR (Hrs) | Failure rate (failure/hour) | Availability (%) | Cost of repair (BD) | Cost of material (BD) |
|---|---|---|---|---|---|---|---|---|
| HT DS | Tower pump #2 | 7 | 8396.6 | 6.7 | 0.00012 | 0.999 | 98.5 | 3 |
| West Riff'a #2 BS | GW pump #2 | 5 | 4416 | 7.3 | 0.00022 | 0.998 | 73.05 | 0 |
| | Tower pump #2 | 5 | 7536 | 5.7 | 0.00013 | 0.999 | 50.2 | 0 |
| **Total** | | **17** | **20348.6** | **19.7** | **0.00047** | **2.996** | **221.75** | **3** |
| **Average / pump** | | **5.6** | **6782.8 (9.5 months)** | **6.6** | **0.00016** | **0.998** | **73.9** | **1** |

The calculated mean time between failures is high, i.e. this defect will not take place frequently, the failure rate is supporting this observation also, the value is very low. The availability is also high (0.99 %) is a good indication of the availability of the equipment.

In Appendix S which shows the cost of repairing the drain line leakage and blockage and breakage, the cost of manpower to repair the leak for HTDS tower pump # 2 is BD 98.5, and BD 3 only for the material. For West Riff'a #2 BS, the cost of manpower is BD 73.05 for ground water pump #2 and BD 50.2 for the tower pump #2. This shows that the cost for repairing this type of defect is not costly and the repairing works can be done during a short period of time.

Referring to Appendix S again for the maintenance action, there are different actions implemented to repair the defect, such as repaired, replaced with new one or cleaned. The best action here is to replace the drain line from carbon steel pipe to PVC pipes which is cheaper than stainless steel pipes, this type of pipes will not be corroded. Utilizing PVC material can reduce the leakage and blockage problems and it is easier to clean PVC pipes since the internal surfaces of the pipes are smooth.

### 6.4) Maintenance Corrective Actions (Repair Works)

In this section the ways or the real corrective actions for every defect are identified from the MMS, like how the gland packing or the leakage from discharge header is repaired?. Every individual repair for the whole 22 mechanical defects is extracted and added in one table in Appendix T. (Appendix T is obtained from the current corrective maintenance practices).

The first six defects which contain 525 occurrences and represent 79.95 % of the total number will be discussed in details. The main classification for this discussion will be based on the following:

- Type of repair is a permanent, this means that the action taken to repair the defect is final action that eliminate the problem from occurring and based on the best maintenance practices, for example, if excessive leakage from gland packing of the pump exists, the best maintenance practice is to replace the whole gland packing since it is not functioning its role efficiently.
- Type of repair is temporary, this means that the action taken to repair the defect is not according to the best maintenance practices and this action is only to keep the system running. This type is implemented due to lack of spares, lack of resources or due to criticality of the equipment, for example if a leak exist in the discharge header at midnight, the best solution is to weld small plate on top of the leakage area, but the best maintenance practices is to inspect the header and it may require to replace the whole header in order to eliminate this type of defect from occurring.
- some of the repair actions are not defined, because the maintenance technician has recorded some phrases like repaired or leakage secured, such undefined repairs will be considered as temporary ones.
- The defects reported by the field staff may not be genuine, sometimes they report incorrect defects, therefore, it will be classified either correct or incorrect defects.

The description of maintenance corrective actions will be as follows,

1. Gland packing of the pump is leaking,

   There are 238 work request cards raised for this type of defect, from the table mentioned in Appendix T, the packing was replaced 38 times which is permanent and perfect action, 5 times Slade packing replace (Slade is a type of packing), 4 times packing replaced with pump bearings (so total replacement actions are 47 times). The adjustment of gland packing implemented 147 times which temporary and was

tightened for 7 times and this can be considered as an adjustment also. There were 5 times of duplicate work request cards and 2 times of cancelations and this is mainly from field operation and can be considered as incorrect work request cards (incorrect defects). By combining the similar permanent and similar temporary the final outcome will be as follows,

- 47 times (19.7 %) the packing replaced completely and can be considered as permanent corrective action.
- 183 times (76.9 %) the packing either adjusted or tightened or repaired, and this is considered as temporary corrective action.
- 7 times (2.9 %) the packing was good and the field operation section was not correct when they raised the work request card.

2. Leak from discharge header,

   There are 76 number of work request cards raised for this defect, the permanent solution here is to replace the header, because if there is any leak this means the condition of the pipe most likely is bad since it is not protected. Some repair actions like welding, clamping or welding of metal plate are just temporary solutions. Therefore the outcomes are as follows,

   - 1 times (1.3 %) the repair were permanent.
   - 70 times (92.1 %) the repair were temporary
   - 5 times (6.6 %) the WRC's were not correct.

3. Drain valve is leaking, blocked, or broken

   There are 63 defects related to the drain valve, for the blockage it is enough to remove the blockage from the scales but it is important to eliminate the source of the blockage and thus cleaning will be considered as permanent solution. For the leaking and broken pipes the appropriate solution is to replace the pipes with PVC pipe, this will eliminate failure from taking place again since the quality of water will create this problem continually with galvanized pipes . Therefore the outcomes are hereunder,

   - For the blockage the actions are de-clogging and cleaning of the pipes as indicated by the first two actions of Appendix T, both are completely temporary actions (31 times) since the sources of the problems are not eliminated.

- For the leaking and broken drain pipes, 23 times (71.8 %) the repair actions are permanent by the replacement of the defective part.
- 7 times (21.8 %) the repairing was temporary by welding or by securing the leak.
- 2 times (6.3 %) of the WRC were not correct.

4. Check valve is not working properly (Passing or hammering),

   There are 58 defects raised complaining that the non-return valve is not functioning properly, it is very important to repair this valve because it is protecting pump set from backflow from the discharge line, if this valve is not working properly the pump and its main parts may be damaged from the back flow in case of power failure. The appropriate solution is to overhaul the valve or to replace it if it is beyond repair. So the outcomes based on our classifications are as follows.

   - 21 times of repair actions were permanent (36.2 %).
   - 28 times of the repair actions were temporary (48.3 %)
   - 9 times of the WRC were not correct which indicated as a normal situation of check valve.(15.5 %)

5. Check valve is leaking,

   45 defects are about the leakage from the check valve, by replacing the parts that responsible of the leakage or overhauling or even replacing the valve, such repairs are considered permanent. The final results for this type of defects are as follows,

   - 17 times the repair works are permanent (37.7 %).
   - 27 times the repairs are temporary (60 %)
   - 1 times the defects are not real (2.2 %)

6. Inboard bearing is noisy,

   45 related defects to the inboard bearing, normally once there is noise in the bearing the first action is to apply grease in bearing housing, if the noise does not stop, the bearing must be replaced. Sometimes the bearing's housing is cleaned and lubricated with new grease. Therefore greasing and replacing of bearing are proper repair actions for the noise. The results for this type are as follows,

   - 23 times the repair was properly applied (51.1 %)
   - 16 times the WRC were not correct (35.5%).

- 5 times the word "repaired" is mentioned ( 11.1%)

**Summary:**

The above discussion about the Mechanical Maintenance Section actions and Appendix T shows the following findings,

- ❖ Repairing works of the defects are good and reasonable in some types of defects like the bearings and drain lines defects, while for other types of defects they need revision like for the leakage from discharge header.
- ❖ Another findings which is very important is related to the field operation section, who is responsible of raising incorrect or inaccurate WRCs of defects specially the ones related to bearings, the section used to miss judge the bearings' condition from the noise, and it's staff must be trained and equipped with appropriate devices in order not to raise wrong work request cards.
- ❖ In total 73 incorrect WRCs were raised from field operation section which represent around 11.1 % of the total frequencies, 10 WRCs were duplicate, 6 WRCs were cancelled, 9 WRCs were raised for check valve while it was functioning well, and 37 WRCs were raised for either incorrect vibration or temperature for bearings. It is really worth to eliminate such practices in order to keep MMS to concentrate on real defects.
- ❖ Many times the mechanical maintenance Technicians are recording only the word "repaired" or "leak repaired, secured", 74 times these words are recorded as their action for solving defects, this cannot describe what is the real action being implemented. A simple, short, and proper description must be recorded for future analysis purposes.
- ❖ The Appendix T can help senior management to prepare the required budget and quantities of spares and tools for most types of defects, and also they can understand what are the defects faced and what are the real actions implemented at sites to enable them undertake certain analysis.

# CHAPTER SEVEN
# DISCUSSION, CONCLUSION AND RECOMMENDATIONS

## 7.0) Introduction

In this chapter more discussions will address many issues about the Mechanical Maintenance Section, each one will be discussed elaborated and then final conclusion with recommendation will be given based on analysis of data and results from this study. The first issue is the preventive maintenance.

## 7.1) Discussion

### a) Planned Preventive Maintenance

- The initial observation about the PPM is the unavailability of a specific preventive maintenance procedure for the main equipment of the system like pumps, a general PPM procedure for all maintenance sections is introduced in Appendix C which shows the role of each sections. There should be a preventive maintenance procedure for major equipment showing a detailed activities that must be carried out for each equipment based on best preventive maintenance practices, frequency of PPM based on the situation of equipment which should be identified from the condition monitoring group. The standard readings like vibrations and temperatures based on the manufacturer recommendation must be included in the maintenance procedure to know if the equipment running within the limits or beyond.
- Referring to Appendix D, the PPM task of the pumps shows most of items that should be covered during the PPM visit, it is a general sheet without basic design and manufacturer data of the pump like the allowable or recommended vibration readings, allowable or recommended bearings temperatures, and flow rate which can indicate that the pump is performing within the designed range or not. Not only the temperature and vibration can show the situation of the pump, the flow rates of the pump is an important indicator about the health of pumps. If the recommended data of the pumps is not included in the PPM task sheet, it is just only printing figures from the field to the sheet without knowing if the pump is running smoothly or not.
- Another observation is the description of the situation for parts of the pump, it is either "OK, Yes" or "No", and this cannot describe the reality, for example, the foundations of all Hamala A2 pumps are bad, they are cracked, nevertheless most of PPM sheets for the pumps show that it is "OK". The small details must be elaborated in better way like (good, bad, to be replaced) for the foundations.

- Condition monitoring team has good devices that can enable the team to do his duties efficiently, but there are some comments to be highlighted, the first one is the calibration activity of the devices, no calibration certificates for any of the monitoring devices except the thermometer device which was issued on 27 February 1998, it was valid for two years from issuance. Till the moment of this report no calibration done for any device (See Appendix G). Another comment is unavailability of a standard procedure explaining the importance of the calibration process of condition monitoring devices and specifying the frequency of this process based on the manufacturer recommendations.
- There is no assurance about the accuracy of temperature readings or vibrations readings since there is no third party certified the devices, and also there is no record for the date of purchasing of these devices, the dates are required to help senior management to decide whether they are coping with technology or not.
- Referring to Sections 5.5.1, and 5.5.2, about the planned preventive maintenance cost, Table 19 shows an example of PPM data sheet collected for one pump, there are 24 visits for conducting PPM task from 2006 to 2011 with total time of 37.5 hours. The average visit duration is 1.5 hours ( by dividing total visits hours {37.5} over total number of tasks {24}) which is acceptable. The average number of technicians attended can be obtained by dividing total number technicians over the number of tasks conducted (70 / 24) , the average is $2.9 \approx 3$ technicians for this pump only. And the average number of technicians for individual pumps for all stations is $2.99 \approx 3$ technicians, and this number is large compared to the task to be conducted.
- This practice is common for all other pumps in all stations, the minimum number of technicians is 2 and the maximum is 4 and sometimes reaches 5, the PPM task can be done by one qualified and trained technician to do the task. This practice should be reviewed and corrected to reduce the cost of PPM and also to utilize manpower effectively.
- Table 21 shows different averages related planned preventive maintenance, the PPM frequency for most of the pumps is 4 per year except for Hamala A2 GFS which 6.6 per year, the frequency is reasonable and acceptable and it is good practice. The reason behind increasing the PPM frequency at Hamala A2 GFS is due to their criticality and due to the conditions of water and it is changed to be monthly based on this.
- It was noticed during the PPM tasks for any pump, the technicians request field operation staff to raise WRC for any defect with the pump in order to rectify it later. The defect will

be repaired after one or two days not immediately because of the Maintenance Section other engagements and also on the priorities of defects.

- The overall PPM cost of man-hours is BD 13531.6 for 805 PPM task conducted, this cost is generated from 6 years of PPM man-hours cost for all stations except for Hamala GFS which covers 4 years of PPM man-hours cost. The cost of overhauling pumps is not included and it is not known.
- The overall corrective maintenance (CM) cost is BD 52976.725 for 660 defects attended.
- The CM cost is almost 3.9 times the PPM cost, for example if MMS spend BD 1 for PPM, they should spend BD 3.9 for CM, and this totally unacceptable, it should be in the other direction, because PM reduces the amount of corrective maintenance to certain level.
- This indication of preventive and corrective costs may tell that the PM is not efficient, effective and it is not doing its purpose of reducing corrective cost.
- One of reasons behind this is the manpower, most of the technicians have field experience without scientific background and they don't know why PPM is conducted, they trained to do the PPM task, fill the required information in the sheets and then file the information. People should be assessed and trained to understand importance of PPM and how to do it efficiently, also they should know its role to reduce the corrective maintenance cost and frequency.
- Mean preventive cost = Total PPM cost / number of PPM tasks, this formula gives an indication about the cost of each PPM task.
- Mean preventive cost = 13531.6 / 805 = BD 16.8, each PPM task which takes between 1 to 2 hours cost this amount. The PPM should be evaluated to identify its effectiveness, it is not worth to spend BD 16.8 to conduct PM, and then spend four times of this cost to do corrective maintenance.

**b) Corrective Maintenance**

Detailed analysis is conducted for the corrective maintenance in Chapter 6, and hereunder are the main findings and recommendations,

- There is no specific corrective maintenance procedure explaining how to repair certain types of defects based on best maintenance repair practices such as gland packing defects, high vibration of bearings, leakage from drain or discharge header.
- The Mechanical Maintenance Section must adopt a systematic approach to adjust or replace the packing periodically at certain intervals to avoid the extra cost that may result

from damaging other parts in the pumps since the cost of packing material is cheaper than replacing other parts which are more costly.

- ❖ Suction and discharge headers to be inspected at least once in a year, this can helps to assess the conditions of these pipes to take necessary measures.
- ❖ For the drain lines blockage, a special coating for the pump's drain area must be applied during the overhauling of the pumps, and this process must be included in the tender specification, this can eliminate scales creation that block the drain lines and valve. For the leakage, it is worth to make plan to replace the steel pipes with heavy duty PVC pipes since the cost will not be high. The replacement plan should be in batches distributed over a number of years.
- ❖ Mean corrective cost = Total CM cost / number defects, this formula gives an indication about the cost of each repair action.
  - ❖ Mean corrective cost = 52976.725 / 660 = BD 80.26, each CM task cost this amount, it is a high value and must be reduced.
  - ❖ Best Maintenance Repair Practices Manual should be generated as a reference for the MMS. The reasons why the Maintenance Section does not follow the best practices are
    - The Maintenance Section is totally reactive, they should be predictive to reduce and eliminate the failure occurrences.
    - Maintenance personnel do not have the maintenance skills to perform the work efficiently.
    - The maintenance work force lacks the discipline and directions to follow the best maintenance repair practices.
    - There is a lack of communication between the different levels within Maintenance Department. Communication between technicians who perform the maintenance and their engineers.

## 7.2) Conclusion and Recommendations

### a. Planned preventive maintenance

i. Standard planned preventive maintenance procedure to be introduced for every critical equipment (like pumps, check valves) based on best preventive maintenance practices. Detailed PPM task sheet to be created showing the recommended and allowable parameters for the equipment and better description of situation for the equipment parts.

ii. The overhauling program of pumps has to be planned based on the conditions of the pumps not based on the years (existing plan is once every four years), there is no need to overhaul pump if it is running smoothly. Condition monitoring is important here, there is no point to send a pump for overhauling because it is due after four years while another pump in bad situation and cannot be overhauled because it is not due for overhaul.

iii. Standard maintenance procedure to be introduced for the calibration process of condition monitoring devices indicating the importance of this process and the frequency of the calibration for each individual device based on the manufacturer recommendations.

iv. The average visit time for each pump is reasonable, the frequency of PPM task is also reasonable and acceptable, but every station should have its own frequency of PPM based on the situation of pumps and based on the recommendations from condition monitoring group. The average number of technicians attended for PPM is large and must be revised. The way of distributing technicians must be changed instead of three technicians conducting PPM task on one pump, each individual can do the task on separate pump. The duration of PPM visit and the number of technicians should be indicated in the preventive maintenance procedure.

v. During the PPM of the pumps, the manpower must be equipped and ready to rectify any malfunction in the pump and they should do it immediately without waiting for issuing of WRCs, attending defects after a period of time may create more problems and make the situation worst, and the manpower must be utilized effectively if they are available in the station.

**b. Corrective maintenance**

i. Corrective maintenance procedure explaining how to repair certain types of defects based on best maintenance repair practices must to introduced to enhance the capability of the technicians.

ii. A minimum number for adjustments before packing replacement must be established for each pump type or station including the standard time of replacement or adjusting the packing based on best practices and experiences, the monitoring time of the packing after maintenance task must be indicated as well. This upper bound on number of adjustments, repair times and monitoring time must become a maintenance practice to be strictly followed.

iii. There should be better integration between field operation staff and maintenance, all operational personnel should receive at least basic maintenance training. They should be trained to assess the defect before raising the WRCs, they should know if the leakage or

smoke from the packing is normal or excessive, they should also be equipped with required devices to measure some parameters like the vibrations of bearings rather than issuing wrong WRCs.

iv. To implement "Best Maintenance Repair Practices" some actions should be taken by the Mechanical Section with management support,

- Maintenance Section must identify the existing problems and track the repetitive equipment defects, their causes and losses. It is important to identify the true causes of defects and the best ways to eliminate them.
- Maintenance Section must perform skills' assessment to evaluate the technicians, the workforce must have the required technical and practical skills to do required maintenance actions.
- Maintenance Section should develop a plan to introduce a proactive maintenance program with planned preventive maintenance, this will provide more time for performing maintenance utilizing the best maintenance repair practices.

# List of References


- Amaratunga, D. and Baldry, D. (2002). Moving from performance measurement to performance management, Facilities, Vol. 20, No. 5/6, pp. 217-223.
- Arts, R.H.P.M., Knapp, G.M. and Mann, L. Jr (1998), "Some aspects of measuring maintenance performance in the process industry", Journal of Quality in Maintenance Engineering, Vol. 4 No. 1, pp. 6-11.
- Al-Najjar, B., 1997. Condition-based maintenance: Selection and improvement of a cost effective vibration-based policy for rolling element bearings. Doctoral Thesis, Lund University, Sweden.
- Al-Najjar, B., 1998. Improved effectiveness of vibration monitoring of rolling element bearings in paper mills. Journal of Engineering Tribology, Proceedings of Instrumentation Mechanical Engineers 212 (J), 111–120.
- Al-Najjar, B. and Alsyouf, I. (2000), "Improving effectiveness of manufacturing systems using total quality maintenance", Integrated Manufacturing Systems, Vol. 11 No. 4, pp. 267-76.
- Al-Najjar, B., 2000a. Impact of integrated vibration-based maintenance on plant-LCC: A case study. In: McNulty, G.J. (Ed.), Third International (Refereed) Conference Quality, Reliability and Maintenance, Oxford, England, Professional Engineering Publishing Limited, Bury St. Edmund, London UK, 30–31 March, pp. 105–110.
- Al-Najjar, B., 2002. Company's business and competitiveness enhancement: A model of integrated vibration-based maintenance impact on company's effectiveness. In: Proceedings of 15th International Congress COMADEM 2002, The University of Birmingham, Edgbaston, UK.
- Al-Najjar, B., Alsyouf, I., 2004. Enhancing a company's profitability and competitiveness using integrated vibration-based maintenance: a case study. European Journal of Operational Research 157, 643–657.
- Ben-Daya, M. and Duffuaa, S.O. (1995), "Maintenance and quality: the missing link", Journal of Quality in Maintenance Engineering, Vol. 1 No. 1, pp. 20-6.
- Ben-Daya, Mohammed, Salih O. Duffuaa, Abdul Raouf, Jezdimir Knezevic, and Daoud Ait-Kadi. Handbook of Maintenance Management and Engineering. London: Springer, 2009.
- Carter, R.A., 2001. Shovel maintenance gains from improved designs. Tools and Techniques 106 (8), S7 (Elsevier Engineering Information).
- Cross, M. (1988), ``Raising the value of maintenance in the corporate environment", Management Research News, Vol. 11 No. 3, pp. 8-11.
- Campbell, John D., and Andrew K.S Jardine. Maintenance Excellence. New York: Marcel Dekker Incorporated, 2001.

- Dekker, R. (1996), ``Applications of maintenance optimization models: a review and analysis", Reliability Engineering & System Safety, Vol. 51, pp. 229-40.
- EEA (European Environment Agency), Environmental indicators: Typology and overview. "Technical Report No 25", 1999, Copenhagen.
- Gallimore, K., Penlesky, R., 1988. A framework for developing maintenance strategies. Production and Inventory Management Journal (First Quarter), 16–22.
- Geraerds, W.M.J. (1985), ``The cost of downtime for maintenance: preliminary considerations", Maintenance Management International, Vol. 5, pp. 13-21.
- International Electrotechnical Commission (2006), "International electrotechnical vocabulary", IEV 191-07-01, available at: http://std.iec.ch/iev/iev.nsf (accessed July 1).
- J.S. Craver, Fisher Books, 1996, P.237
- Kaplan, R. S. and Norton, D. P. (1992). The balanced scorecard – measures that drive performance, Harvard Business Review, Vol. 70, pp. 71-79.
- Kaplan, R. S and Norton, D. P (1996). The Balanced Scorecard: Translating Strategy into Action, Harvard Business School Press
- Kaplan, R. S. (1983). Measuring manufacturing performance: a new challenge for managerial accounting research, Accounting Review, Vol.58. No. 4. pp. 686-703.
- Kumar, U. & Ellingsen, H.P. (2000). Development and implementation of maintenance performance indicators for the Norwegian oil and gas industry. Proceedings of the 14th International Maintenance Congress (Euro maintenance 2000), 7-10 March 2000, Gothenburg, Sweden, pp. 221-228.
- Kutucuoglu, K. Y., Hamali, J., Irani, J. and Sharp, J. M. (2001). A framework for managing maintenance using performance measurement systems, International Journal of Operation and Production Management, Vol. 21, No. ½, pp. 173-194.
- Kelly, A., 1997. Maintenance Strategy. Butterworth Heinemann, UK.
- Liyanage, J. P. and Kumar, U. (2003). Towards a value-based view on operations and maintenance performance management, Journal of Quality in Maintenance Engineering, Vol. 9, pp. 333-350.
- Madu, C., 2000. Competing through maintenance strategies. International Journal of Quality and Reliability Management 17 (9), 937–948.

  Mckone, K., Elliott, W., 1998. TPM: planned and autonomous maintenance: bridging the gap between practice and research. Production and Operations Management 7 (4), 335–351.
- Neely, A., Gregory, M. and Platts, K. (1995), "Performance measurement system design: a literature review and research agenda", International Journal of Operation & Production Management, Vol. 15 No. 4, pp. 80-116.

- Neely, A. D. (1999). The Performance Measurement Revolution: Why Now and What Next? International Journal of Operations and Production Management, 19, 2, pp. 205-228.
- Parida, A. and Kumar, U. (2006), "Maintenance performance measurement (MPM): issues and challenges", Journal of Quality in Maintenance Engineering, Vol. 12 No. 3, pp. 239-51.
- Parida, Aditya. Development of a multi-criteria Hierarchical framework for maintenance performance measurement. Doctoral thesis, Division of operation and maintenance engineering, Luleå: Luleå University, 2006.
- Parida, A. and Chattopadhyay, G. (2007), "Development of a multi-criteria hierarchical framework for maintenance performance measurement (MPM)", Journal of Quality in Maintenance Engineering, Vol. 13 No. 3, pp. 241-58.
- Peter, Liliane, Ludu and Harry (2010). "Development of maintenance function performance measurement framework and indicators", International Journal of Production Economics, Vol.131, pp. 295-302
- Pintelon, L., Gelders, L.F., 1992. Maintenance Management Decision Making. European Journal of Operational Research 58, 301–317.
- Pintelon, L. and Puyvelde, F. V. (1997). Maintenance performance reporting systems: Some experiences, Journal of Quality in Maintenance Engineering, Vol. 3, No. 1, pp. 4-15.
- Pinjala, S.K., Pintelon, L. and Vereecke, A. (2006), "An empirical investigation on the relationship between business and maintenance strategies", International Journal of Production Economics, Vol. 104, pp. 214-29.
- Riis, J. O., Luxhoj, J. T. and Thorsteinsson, U. (1997). A situational maintenance model, International Journal of Quality & Reliability Management, Vol. 14 No. 4, pp. 349-366.
- Reliability Theory with application preventive maintenance, I. Gertsbakh, Berlin: Springer-Verlag 2000, ISBN 3450-67275-3
- Reliability for Technology, Engineering and Management; Paul Kales; Prentice Hall; 1998.
- Salmein, J. (2005). Measuring performance and determining success factor of construction sites, Doctoral dissertation, Helsinki University of Technology, ISBN. 951-22-7493-0.
- Swanson, L., 2001a. Linking maintenance strategies to performance. International Journal of Production Economics 70, 237–244.
- Swanson, L. (1997), "An empirical study of the relationship between production technology and maintenance management", International Journal of Production Economics, Vol. 53, pp. 191-207.
- Strategies", Journal of Quality in Maintenance Engineering, Vol. 12 No. 1, pp. 7-20.
- Tsang, A.H.C. (1998), "A strategic approach to managing maintenance performance", Journal of Quality in Maintenance Engineering, Vol. 4 No. 2, pp. 87-94.

- Tsang, A.H.C., Jardine, A.K.S. and Kolodny, H. (1999), "Measuring maintenance performance: a holistic approach", Journal of Quality in Maintenance Engineering, Vol. 19 No. 7, pp. 691-715.

- Tsang, A.H.C. (2002), "Strategic dimensions of maintenance management", Journal of Quality in Maintenance Engineering, Vol. 8 No. 1, pp. 7-39.

- Underhåll terminologi - Maintenance terminology, Svensk Standard SS-EN 13306, Stockholm: SIS Förlag AB 2001

- Wireman, T, (1998). "Developing Performance Indicators for Managing Maintenance", Industrial Press, Inc, New York.

- Zeng, S.W., 1997. Discussion on maintenance strategy, policy and corresponding maintenance systems in manufacturing. Reliability Engineering and System Safety 55, 151–162.

- Water transmission directorate, (2011). "Statistical Report – 2011), Electricity & Water Authority. Kingdom of Bahrain

- Water Transmission Directorate,(2011). "WTD Policies and Procedure handbook", Electricity & Water Authority. Kingdom of Bahrain

Appendix A

# Details of pumps Considered in the study

Appendix A, Details of Pumps in Each Individual Pumping Station

Table 1A - Llist of pumps for Hamala A2 ground Forwarding Station ( Commissioned in 1970)

| No. | Pump Name | Model | Capacity | | Driver (KW) | RPM | Head (M) | Duty / Standby | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | (L/S) | (MG/D) | | | | | |
| 1 | GW TO WR PUMP 1 | EBARA 350x250xCJNM | 310 | 5.9 | 450 | 1490 | 101 | Two Duty & One Standby | |
| 2 | GW TO WR PUMP 2 | EBARA 350x250xCJNM | 310 | 5.9 | 450 | 1490 | 101 | | |
| 3 | GW TO WR PUMP 3 | EBARA 350x250xCJNM | 310 | 5.9 | 450 | 1490 | 101 | | |
| 4 | GW TO HTB PUMP 1 | EBARA 350x200xCKNM | 210 | 4.0 | 250 | 1490 | 86 | One Duty & One Standby | |
| 5 | GW TO HTB PUMP 2 | EBARA 350x200xCKNM | 210 | 4.0 | 250 | 1490 | 86 | | |

Table 2A -list of pumps for Hamad Town Distribution Station ( Commissioned in 1989)

| No. | Pump Name | Model | Capacity | | Driver (KW) | RPM | Head (M) | Duty / Standby | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | (L/S) | (MG/D) | | | | | |
| 1 | BW TO TOWER PUMP 1 | KUBOTA FIZK300x200 | 150 | 2.85 | 90 | 1450 | 40.67 | One Duty & One Standby | |
| 2 | BW TO TOWER PUMP 2 | KUBOTA FIZK300x200 | 150 | 2.85 | 90 | 1450 | 40.67 | | |

Table 3A - List of pumps for Hamad Town Blending Station ( Commissioned in 1985)

| No. | Pump Name | Model | Capacity | | Driver (KW) | RPM | Head (M) | Duty / Standby | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | (L/S) | (MG/D) | | | | | |
| 1 | TOWER PUMP 1 | EBARA 350x250xCGNM | 260 | 4.94 | 110 | 1490 | 35 | One Duty & One Standby | |
| 2 | TOWER PUMP 2 | EBARA 350x250xCGNM | 260 | 4.94 | 110 | 1490 | 35 | | |
| 3 | GW BLENDING PUMP 1 | EBARA 350x300xCFNM | 210 | 4.0 | 30 | 985 | 9.6 | One Duty & One Standby | |
| 4 | GW BLENDING PUMP 2 | EBARA 350x300xCFNM | 210 | 4.0 | 30 | 985 | 9.6 | | |
| 5 | DW BLENDING PUMP 1 | EBARA 500x450 CEM | 575 | 10.92 | 110 | 990 | 10.2 | One Duty & One Standby | |
| 6 | DW BLENDING PUMP 2 | EBARA 500x450 CEM | 575 | 10.92 | 110 | 990 | 10.2 | | |
| 7 | HTD FORWARD PUMP 1 | KUBOTA DVL36FZZ 350x300 | 420 | 8.0 | 107 | 1450 | 24.27 | One Duty & One Standby | |
| 8 | HTD FORWARD PUMP 2 | KUBOTA DVL36FZZ 350x300 | 420 | 8.0 | 107 | 1450 | 24.27 | | |

Table 4A - List of pumps for West Riff'a #1 Blending Station ( Commissioned in 1970)

| No. | Pump Name | Model | Capacity | | Driver (KW) | RPM | Head (M) | Duty / Standby | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | (L/S) | (MG/D) | | | | | |
| 1 | WEST TOWER PUMP 1 | EBARA 350x250xCGNM | 250 | 4.75 | 150 | 1490 | 45 | One Duty & One Standby | |
| 2 | WEST TOWER PUMP 2 | EBARA 350x250xCGNM | 250 | 4.75 | 150 | 1490 | 45 | | |
| 3 | EAST TOWER PUMP 1 | EBARA 350x250xCGNM | 250 | 4.75 | 150 | 1490 | 45 | One Duty & One Standby | |
| 4 | EAST TOWER PUMP 2 | EBARA 350x250xCGNM | 250 | 4.75 | 150 | 1490 | 45 | | |
| 5 | GW BLENDING PUMP 1 | EBARA 450x400xCFNM | 400 | 7.6 | 75 | 985 | 14 | One Duty & One Standby | |
| 6 | GW BLENDING PUMP 2 | EBARA 450x400xCFNM | 400 | 7.6 | 75 | 985 | 14 | | |
| 7 | DW BLENDING PUMP 1 | WEIR SDA 400/500 B | 470 | 8.93 | 76.5 | 740 | 11 | Two Duty & one standby | |
| 8 | DW BLENDING PUMP 2 | WEIR SDA 400/500 B | 470 | 8.93 | 76.5 | 740 | 11 | | |
| 9 | DW BLENDING PUMP 3 | WEIR SDA 400/500 B | 470 | 8.93 | 76.5 | 740 | 11 | | |
| 10 | HTB FORWARD PUMP 1 | EBARA 350x300xCFNM | 280 | 5.32 | 110 | 1490 | 29 | Two Duty & one standby | |
| 11 | HTB FORWARD PUMP 2 | EBARA 350x300xCFNM | 280 | 5.32 | 110 | 1490 | 29 | | |
| 12 | HTB FORWARD PUMP 3 | EBARA 350x300xCFNM | 280 | 5.32 | 110 | 1490 | 29 | | |

Table 5A - List of Pumps for West Riff'a #2 Blending Station ( Commissioned in 2002)

| No. | Pump Name | Model | Capacity | | Driver (KW) | RPM | Head (M) | Duty / Standby | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | | | (L/S) | (MG/D) | | | | | |
| 1 | DW BLENDING PUMP 1 | WEIR SDAAZ 600/800 C | 880 | 16.7 | 250 | 740 | 15.8 | One Duty & One Standby | |
| 2 | DW BLENDING PUMP 2 | WEIR SDAAZ 600/800 C | 880 | 16.7 | 250 | 740 | 15.8 | | |
| 3 | GW BLENDING PUMP 1 | WEIR SDA 250/250 B | 168 | 3.2 | 45 | 1460 | 18.5 | One Duty & One Standby | |
| 4 | GW BLENDING PUMP 2 | WEIR SDA 250/250 B | 168 | 3.2 | 45 | 1460 | 18.5 | | |
| 5 | BW TO TOWER PUMP 1 | WEIR SDAH 350/450 B | 510 | 9.7 | 405 | 1480 | 47.5 | Two Duty & One Standby | |
| 6 | BW TO TOWER PUMP 2 | WEIR SDAH 350/450 B | 510 | 9.7 | 405 | 1480 | 47.5 | | |
| 7 | BW TO TOWER PUMP 3 | WEIR SDAH 350/450 B | 510 | 9.7 | 405 | 1480 | 47.5 | | |

Appendix B

# Activity description for Mechanical Section

Appendix B , Activity Description for Mechanical Section

1. Activity description of pump major maintenance

| SECTION : MECHANICAL | ACTIVITY CODE | 4401 |
|---|---|---|
| ACTIVITY TITLE : | Pump major maintenance | |
| ACTIVITY DESCRIPTION | Major Maintenance on pump shall include Inspection, dismantling, Checking and Assessment of all parts which are found undergone wear & tear and judged beyond economical repairs or overrun its cost effective life cycle, then they are replaced with similar or equivalent specification. The activity shall include (i) Cleaning (ii) Bearings, sleeves, bushes, packing, mechanical seal & wear rings replacement (iii) Casing, Shaft & impeller replacement if they are beyond economical repair (iv) Dynamic balancing (v) Commissioning and final testing. | |
| SCOPE OF ACTIVITY - | An average of 20 pumps per year of various capacities. | |
| ACTIVITY PROCEDURES - | As per Scope of Work prepared by the Section | |
| RESPONSIBLE PERSONNEL | Mechanical Engineer/Sr. Technician & Technician | |
| FREQUENCY / CRITERIA | 5 years running time / condition monitoring | |
| JOB CATEGORY | Out sourced to WTD Pre-qualified Contractors / A few pumps are overhauled in house. | |

2. Activity description of pump routine PPM

| SECTION : MECHANICAL | ACTIVITY CODE | 4402 |
|---|---|---|
| ACTIVITY TITLE : | Pump routine PPM | |
| ACTIVITY DESCRIPTION | Pump routine PPM shall include inspection, checking and assessment of all parts. The activity shall include (i) Cleaning (ii) Maintain sealing (iii) Lubrication (iv) Vibration | |

| | |
|---|---|
| | measurement (v) Recording Running parameters ie; Flow, Pressure, Temp. etc; |
| SCOPE OF ACTIVITY - | ALL pumps in WTD System. |
| ACTIVITY PROCEDURES - | Task Sheet Attached |
| RESPONSIBLE PERSONNEL | Mechanical Technician/Mechanical Fitter |
| FREQUENCY / CRITERIA | Monthly or Quarterly as per the PPM Schedule |
| JOB CATEGORY | This activity is done in-house by mechanical maintenance section. |

3. Activity description of vibration measurement and analysis

| SECTION : MECHANICAL | ACTIVITY CODE | 4403 |
|---|---|---|

| | |
|---|---|
| ACTIVITY TITLE : | VIBRATION MEASUREMENT AND ANALYSIS |
| ACTIVITY DESCRIPTION | Vibration measurement and analysis includes measurement of vibration level of the rotating equipment at the supporting points –bearing- to assess their health and diagnose any kind of mechanical/electrical problems at an early stage or just after failure initiation. |
| SCOPE OF ACTIVITY | All the rotating equipment –mainly pumps and motors – within WTD network. |
| ACTIVITY PROCEDURES | Vibration measurement is carried out using SKF Microlog MCXA50 with its associated software PRISM4, which has the capability of: data presentation, analysis, reporting, history & record keeping |
| RESPONSIBLE PERSONNEL | Mechanical Engineer/Sr. Technician & Technician |
| FREQUENCY / CRITERIA | Monthly |
| JOB CATEGORY | This activity is done in house by mechanical maintenance section-condition monitoring group. |

Appendix C

# Planned preventive procedure

EWA
هيئة الكهرباء والماء
Electricity & Water Authority
Kingdom of Bahrain

إدارة نقل المياه
WATER TRANSMISSION DIRECTORATE

# WTD - STANDARD PROCEDURES

| TITLE | REF. NO. : WTD-S-06-2012 |
|---|---|
| **PLANNED PREVENTIVE MAINTENANCE (PPM)** | EFFECTIVE DATE : 06 – Aug - 2012 |
| | NO. OF PAGES : 9 |

| REVISION NUMBER | REVIEW FREQUENCY | NEXT REVISION DATE |
|---|---|---|
| 5 | TWO YEARS | AUG 2014 |

| REVIEWED BY STANDARD PROCEDURE COMMITTEE | | SIGNATURE | DATE |
|---|---|---|---|
| A.Rasool Ghuloom | Member | | 6/8/2012 |
| Sunil John | Member | | 6-8-12 |
| Manoj Keswani | Member | | 6-8-12 |
| Jaffer Jawad | Member | | 6/8/12 |
| D.H. Panchal | Member | | 6/8/12 |
| Varughese Idicula | Member | | 6/8/12 |

| CHECKED BY | | SIGNATURE | DATE |
|---|---|---|---|
| A. Hameed Al Shaikh | COMMITTEE CHAIRMAN | | 9/8/2012 |

| APPROVED BY | | SIGNATURE | DATE |
|---|---|---|---|
| Ali Redha Hussain | DIRECTOR | | 12/08/2012 |

**Supportive Documents if any:-** NIL

**This Procedure issued in 1998, Revision – 1 (1998), Revision – 2 (1998), Revision – 3 (2009), Revision – 4 (2011)**

***This version supersedes the Standard Procedure WTD-S-06-2011, issued in 28/ 6/ 2011***

Water Transmission Directorate
Standard Procedures

Standard Procedure No. WTD – S – 06 – 2012

# PLANNED PREVENTIVE MAINTENANCE (PPM)

## 1.0 PURPOSE:-

To implement a Planned Preventive Maintenance procedure that will provide guide lines for timely maintenance of the Water Transmission assets, in order to achieve the pre-determined targets of Equipment Availability and Reliability.

## 2.0 GENERAL GUIDE LINES:-

Initially, the Asset Register (AR) is prepared manually or electronically with all the necessary information such as Manufacturer's Details, Name Plate details, Service, Identification Number etc. This Asset Register is updated as and when equipment is replaced / added or any modification occurs in the system.

Based on the Equipment Asset Register, PPM list is prepared in consultation with concerned Engineer, selecting the equipment to be covered by the PPM, and the sequence prioritized considering (i) Safety & Criticality of the equipment, (ii) Productivity factor (iii) replacement cost (iv) Previous failure history and (v) manufacturer recommendation. The frequency of PPM is decided for each equipment depending on equipment performance ratio or failure history. The whole PPM programme spanning the 52 weeks of the year will be termed as PPM "Master Schedule". Thereafter on monthly basis, separate programme for each Pumping / Blending station will be established listing the selected equipment, completion due dates with special instruction if any, which will be termed as PPM "Monthly Schedule". According to the equipment list, PPM cards are prepared.

## 3.0 PROCEDURE:-

The PPM programme will be prepared, executed and supported through systematic & coordinated activities of Planning Group, Maintenance Section & Operation Group.

### 3.1 Responsibilities of Planning Group: ( See Annexure -I )

Prime responsibilities of Planning Group will be to implement & Monitor the PPM programme, the main task shall include:-

3.1.1 Prepare the "Master Schedule" in co-ordination with all concerned.

3.1.2 Prepare., the "Monthly Schedule" for the specified station with equipment details and due dates for the PPM and forward to concerned engineer along with PPM Card, Task Sheet and Costing Sheet.

3.1.3 Receive from maintenance section the completed PPM cards, costing sheet and record the status and re-schedule for the subsequent PPM.

3.1.4 Prepare monthly "Backlog Report" and attend PPM meeting review and to co-ordinate for re-scheduling the delayed / un-attended PPM job

3.1.5 Prepare "PPM Monthly Performance Statistics" and "Costing Sheet" for evaluation and incorporation in WTD Monthly Report.

3.1.6 Receive, review, discuss and update any alteration in the PPM system on yearly basis prior to preparing the master schedule of the following year.

### 3.2 Responsibilities of Maintenance Sections: ( See Annexure-II)

Prime responsibilities of Maintenance Section will be to execute the PPM programme. The main task shall include:

3.2.1 Co-ordinate with Planning Group in preparing yearly "Master Schedule".

3.2.2 Receive the monthly PPM schedule from Planning, check the availability of materials and resources, arrange necessary "Safety Documents" and undertake the PPM jobs as scheduled.

3.2.3 Return the completed PPM cards to Planning Group along with costing sheet and advise the status of all delayed / un-attended PPM Jobs.

3.2.4 If any abnormalities found during the PPM event (other than PPM task) should be informed immediately to the Sr. Technician / Engineer and remedial action to be taken to complete the job as early as possible.

3.2.5 Attend the PPM meeting for reviewing Backlog Reports, Re-scheduling the delayed / unattended PPM jobs and maintain all the records.

3.2.6 On yearly basis review/study the PPM Master List for any changes needed to improve the system and forward the same to Planning Group.

## 3.3 Responsibilities of Operation Group:

Prime responsibilities of Operation Group shall include:

3.3.1 Co-ordinate with Planning and Maintenance in preparing the Master Schedule.

3.3.2 Issue Safety Documents as per request and requirements.

3.3.3 Attend the PPM meeting for reviewing Backlog Reports, Re-scheduling the delayed / unattended PPM Jobs.

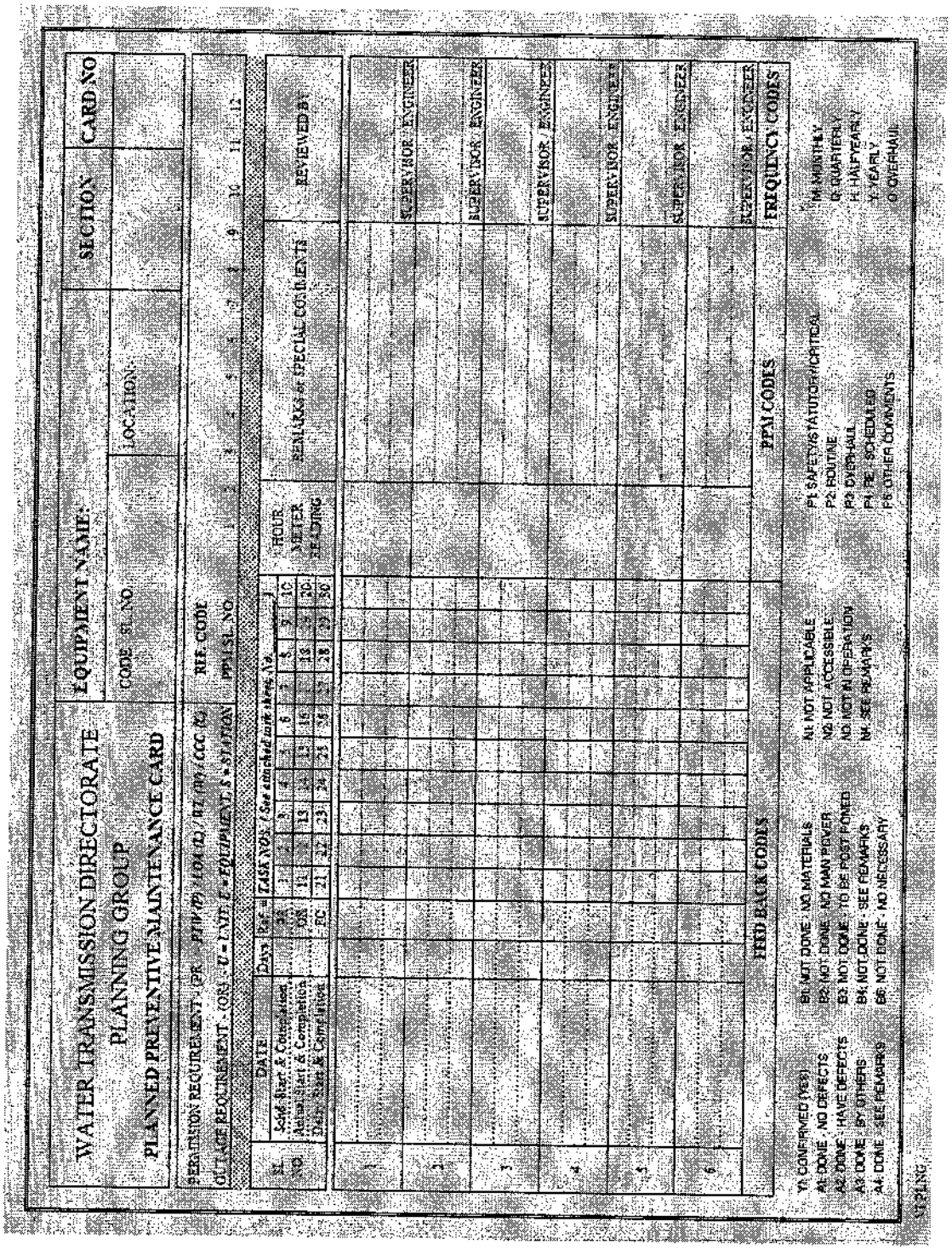
3.3.4 Prepare and submit to all Maintenance Sections equipment changeover schedule.

## 4.0 ENCLOSURE:-

- PPM Card Copy – ( Front & Back Side)
- Flow Chart – Planning & Operation Group Actions ( ANNEXURE – I)
- Flow Chart – Maintenance Section Actions ( ANNEXURE – II)

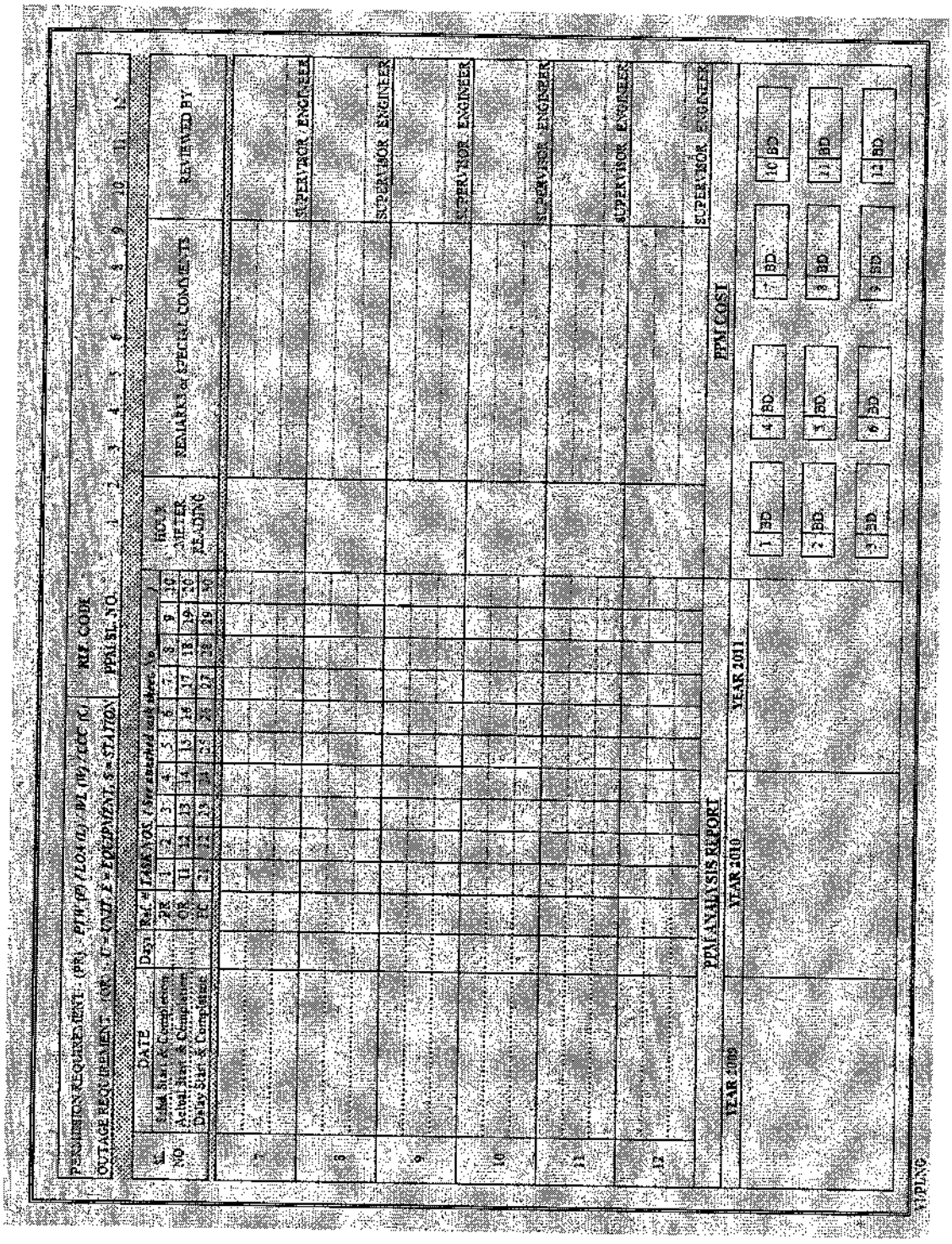
**********

## PPM CARD (FRONT SIDE)



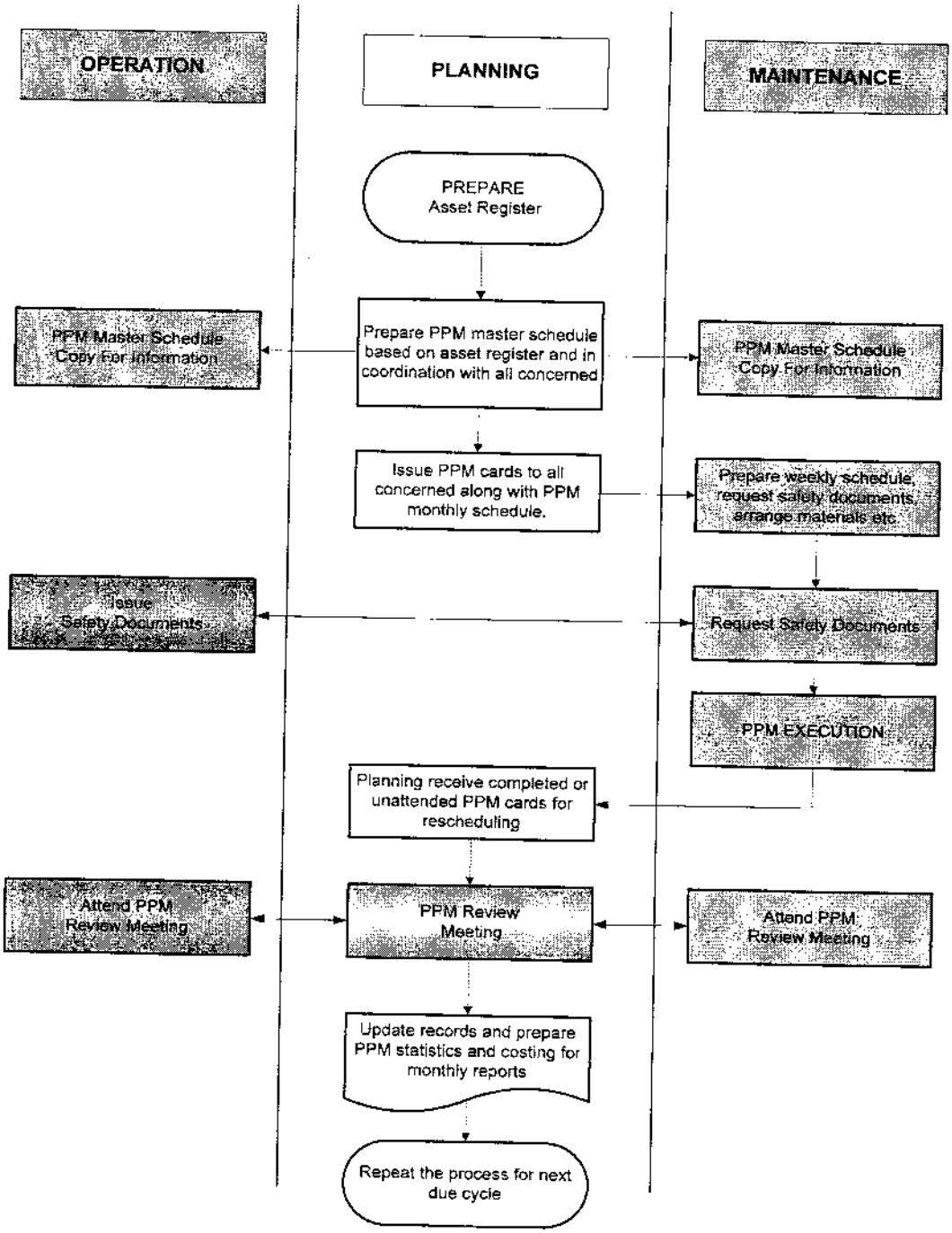

*This version supersedes the Standard Procedure WTD-S-06-2011, issued in 20-11-2011*

## PPM CARD (BACK SIDE)



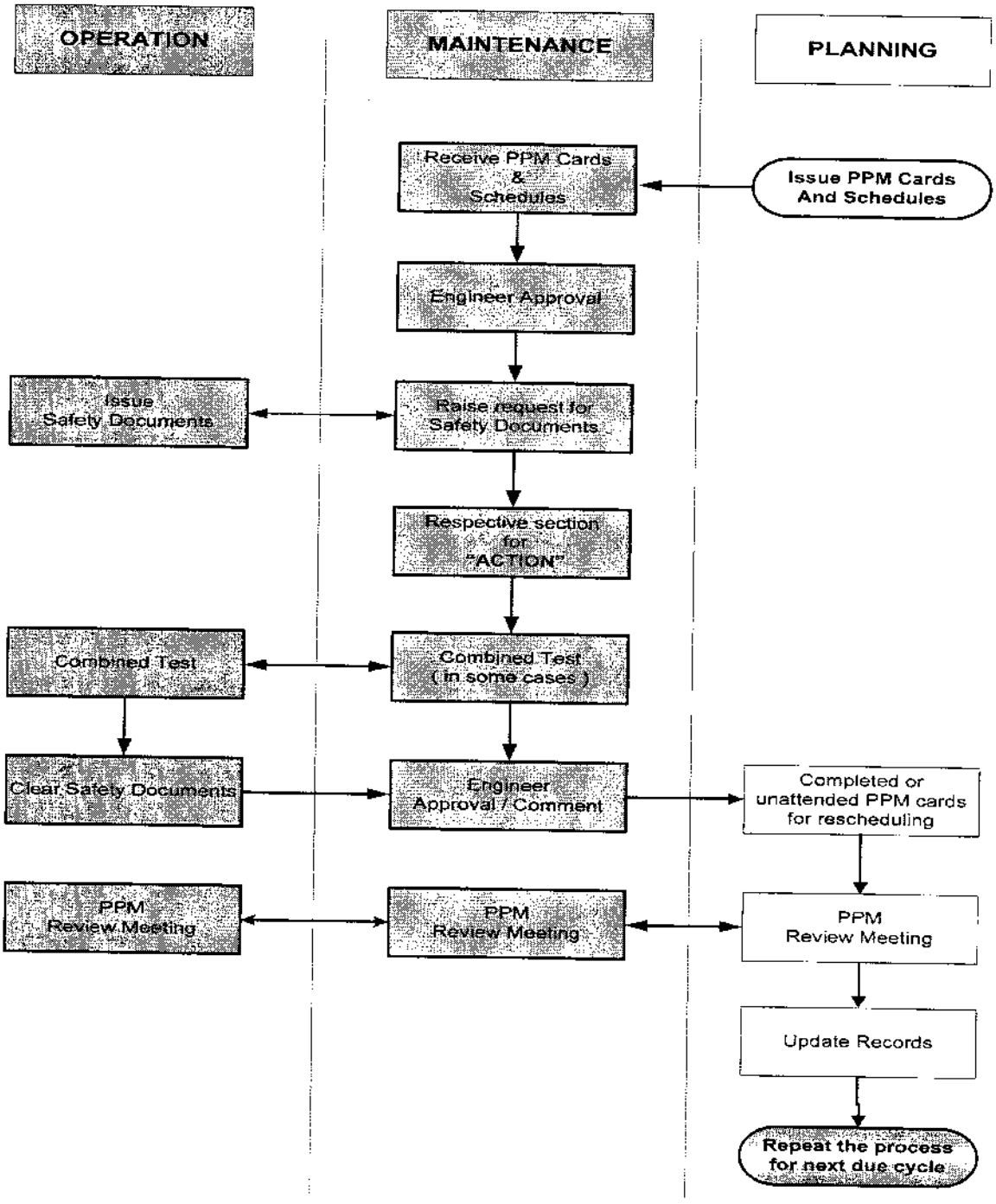

*This version supersedes the Standard Procedure WTD-S-06-2011, issued in 20-11-2011*

# PLANNING & OPERATION GROUP ACTIONS (ANNEXURE – I)




*This version supersedes the Standard Procedure WTD-S-06-2011, issued in 20-11-2011*

# MAINTENANCE ACTIONS (ANNEXURE – II)




*This version supersedes the Standard Procedure WTD-S-06-2011, issued in 20-11-2011*

Appendix D

# Pump task sheet

# WATER TRANSMISSION DEPARTMENT
## MAINTENANCE DIVISION
## PPM TASK FOR PUMP

LOCATION:----------
SERVICE:----------
P.M. DATE:----------
EQUIP. CODE:----------
PPM CARD NO:----------

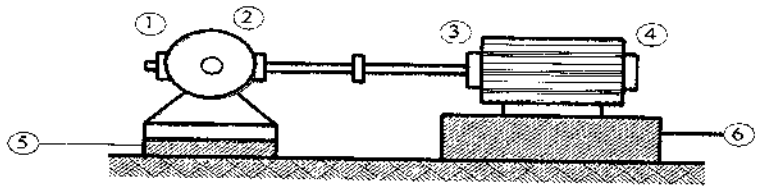
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| A | RUNNING CHECK | | | | | | | |
| 1 | HOUR METER READING | | HRS | 10 | LEAKAGE - FLANGE,JOINT & BODY | YES | NO | |
| 2 | CURRENT ABSORPTION | | AMPS | 11 | AIR VENT / BLEEDING LINE | OK | NO | |
| 3 | SPEED | | RPM | 12 | DRAINING LINE | OK | BLOCKED | |
| 4 | NO. OF PUMPS WORKING | | | 13 | PUMP BODY CONDITION | OK | NO | |
| 5 | FLOW RATE | | L/S | 14 | FOUNDATION BOLTS | OK | NO | |
| 6 | SUCTION PRESSURE | | M | 15 | BASEMENT FRAME &FOUNDATION | OK | NO | |
| 7 | DISCHARGE PRESSURE | | M | 16 | SUCTION VALVE LEAKAGE (GLAND , BODY & JOINT) | OK | NO | |
| 8 | STUFFING BOX LEAKAGE | | | 17 | DISCHARGE VALVE LEAKAGE (GLAND , BODY & JOINT) | OK | NO | |
| 9 | OIL LEVEL | OK | LOW HIGH | 18 | NRV LEAKAGE (GLAND, BODY, JOINTS, SOUND,ARM | OK | NO | |
| B | TURN OFF CHECK | | | | | | | |
| 19 | (INSURE THE PUMP SET IS OFF , EMERGENCY PUSH BOTTOM IS IN OFF POSITION AND "UNDER MAINTENANCE " (NOTICE IS PLACED ON THE UNIT ) (CONFIRM THIS IN RECIEVED SHEET) | | | | | | | |
| 20 | BEARING GREASE /OIL LEVEL ,AND CONDITION | | | | | OK | LOW | HIGH |
| 21 | OIL SEAL AND WATER THROWER | | | | | OK | NO | |
| 22 | RUBBER BUSHES/SPIDER FOR TEAR AND WEAR | | | | | OK | NO | |
| 23 | HOLDING BOLTS AND NUTS | | | | | OK | NO | |
| 24 | CHECH SUCTION, DISCHARGE , NON RETAURN VALVE, ROTATION / LUBRICATION | | | | | OK | NO | |

25 CHECK AND REGISTER ALIGNMENT READING , (EVERY SIX MONTH)

| | ALIGNMENT | COUPLING GAP | REMARKS |
|---|---|---|---|
| TOP | | | |
| 90° | | | |
| 180° | | | |
| 270° | | | |

SPICIAL REMARKS/ INSTRUCTION

| | |
|---|---|
| CARRIED OUT BY: | CHECK BY : |
| NAME: | NAME: |
| SIGN/DATE: | SIGN/DATE: |




VIBRATION READING/ AFTER OVERHAULING / BEFORE OVERHAULING

PPM REF. : ----------
DATE : ----------
TIME :----------

LOCATION :----------
SERVICE:----------
EQUIPMENT NO :----------

| | 1 | | | 2 | | | 3 | | | 4 | | | 5 | | | 6 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | H | V | A | H | V | A | H | V | A | H | V | A | H | V | A | H | V | A |
| DISPLACEMENT (um) | | | | | | | | | | | | | | | | | | |
| VELOCITY (mm/sec) | | | | | | | | | | | | | | | | | | |

| | 1 | | | 2 | | | 3 | | | 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | H | V | A | H | V | A | H | V | A | H | V | A |
| NOISE LEVEL ATM | | | | | | | | | | | | |
| BEARINGS TEMPERATURE($^{O}$C) | | | | | | | | | | | | |

| | VERTICAL | | HORIZANTAL | | REMARKS |
|---|---|---|---|---|---|
| ALIGNMENT | ANGULARITY | OFFEST | ANGULARITY | OFFEST | |
| | | | | | |
| | ANGULARITY | OFFEST | ANGULARITY | OFFEST | |
| | | | | | |

LEGEND H= HORIZONTAL V=VERTICAL A=AXIAL

READING TAKEN BY : ----------

Appendix E

# Pump overhauling plan

# MAINTENANCE DEPARTMENT , MECHANICAL SECTION
## PUMP OVERHAUALING PROGRAM

| NO. | STATION - CODE AND PUMP DETAILS | MODEL/TYPE | SERVICE | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | **HAMALA A2 - GFS** | | | | | | | | | | | |
| 1 | EBARA , 350 x 250 , 450 KW | 350 X 250 CJNM | GW1. WR | | | | OCT | | | | | MARINE |
| 2 | EBARA , 350 x 250 , 450 KW | 350 X 250 CJNM | GW2. WR | | | FEB | | | | SEP | | TEMCO, MARINE |
| 3 | EBARA , 350 x 250 , 450 KW | 350 X 250 CJNM | GW3. WR | | | | | APR | | | | Replaced with new pump. Old one reconditioned and available in the W/S, Marine |
| 4 | EBARA , 300 x 200 , 250 KW | 300 X 200 CKNM | GW1. HTB | | | | NOV | | | | | Replaced with new casing/ Bah W/S / MARINE |
| 5 | EBARA , 300 x 200 , 250 KW | 300 X 200 CKNM | GW2. HTB | | | | | NOV | | | | Reconditioned & replaced casings, Marine |
| II | **HAMAD TOWN BLENDING STATION** | | | | | | | | | | | |
| 1 | EBARA , 350 x 300 , 30 KW | 350 X 300 CFNM | GW1 BL | | | | | | | JULY | | CEO 15612 Habib Awa, MARINE |
| 2 | EBARA , 350 x 300 , 30 KW | 350 X 300 CFNM | GW2 BL | MAY | | | | AUG | | | | TEMCO, TEMCO |
| 3 | EBARA , 500 x 450 , 110 KW | 500 X 450 CEM | DW1 | MAY | | | | | | | | TEMCO |
| 4 | EBARA , 500 x 450 , 110 KW | 500 X 450 CEM | DW2 | | MAY** | | | | | | | *CEO 15634 Temco / ** WTD |
| 5 | EBARA , 350 x 250 , 110 KW | 350 X 250 CGNM | BW1 TWR | | | | OCT | | | | | Bah W/S / MARINE |
| 6 | EBARA , 350 x 250 , 110 KW | 350 X 250 CGNM | BW2 TWR | AUG | | | | NOV | | | | BAHRAIN W/S, TEMCO |
| 7 | KUBOTA , 350 x 300 , 107 KW | DVL 364 FZZ | BW1 HTD | JULY | | | | | | APR | | TEMCO |
| 8 | KUBOTA , 350 x 300 , 107 KW | DVL 364 FZZ | BW2 HTD | SEP | | | | SEP | | | | BAHRAIN W/S, TEMCO |
| III | **HAMAD TOWN DIST. - 15** | | | | | | | | | | | |
| 1 | KUBOTA , 300 x 200 , 90 KW | DVL 308 FIZK | BW1 TWR | | JULY | | | | | JUNE | | MARINE, MARINE |
| 2 | KUBOTA , 300 x 200 , 90 KW | DVL 308 FIZK | BW2 TWR | | SEP | | | | | MAY | | MARINE & INDUSTRIAL |
| IV | **WEST RIFA'A I BLENDING STATION** | | | | | | | | | | | |
| 1 | EBARA , 350 x 300 , 110 KW | 350 X 300 CFNM | HT DW1 | | JULY | | | | | | | MARINE & INDUSTRIAL |
| 2 | EBARA , 350 x 300 , 110 KW | 350 X 300 CFNM | HT DW2 | | DEC | | | | | | | MARINE & INDUSTRIAL |

**MAINTENANCE DEPARTMENT , MECHANICAL SECTION**
**PUMP OVERHAUALING PROGRAM**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | EBARA , 350 x 300 , 110 KW | 350 X 300 CFNM | HT DW3 | | AUG | | | | | | | | MARINE & INDUSTRIAL |
| 4 | WEIR 400 x 400 76.5 Kw | SDA 400/500 B-H1 | DW1,RO-BL | | | | | SEP | | | | | Replaced with new pump, TEMCO |
| 5 | WEIR 400 x 400 76.5 Kw | SDA 400/500 B-H1 | DW2,RO-BL | | | | | | OCT | | | | Replaced with new pump, TEMCO |
| 6 | WEIR 400 x 400 76.5 Kw | SDA 400/500 B-H1 | DW3,RO-BL | | | | | | | JAN | | | Replaced with new pump, TEMCO |
| 7 | EBARA , 450 x 400 , 75 KW | 450 X 400 CFNM | GW1 TO BL | | | MAY | | | | | | | TEMCO |
| 8 | EBARA , 450 x 400 , 75 KW | 450 X 400 CFNM | GW2 TO BL | | | | FEB | | | | | | TEMCO |
| 9 | EBARA , 350 x 250 , 150 KW | 350 X 250 CGNM | ER TWR1 | | | | OCT | | | | | | MARINE |
| 10 | EBARA , 350 x 250 , 150 KW | 350 X 250 CGNM | ER TWR2 | | | | | NOV | | | | | TEMCO |
| 11 | EBARA , 350 x 250 , 150 KW | 350 X 250 CGNM | WR TWR1 | | | | DEC | | | | | | MARINE |
| 12 | EBARA , 350 x 250 , 150 KW | 350 X 250 CGNM | WR TWR2 | | | | | | MAY | | | | TEMCO |
| | **WEST RIFFA'A II BLENDING STATION** | | | | | | | | | | | | |
| 1 | WEIR | SDAAZ 600 / 300C | DW1 TO BT | | | | | | | JUNE | | | |
| 2 | WEIR | SDAAZ 600 / 300C | DW2 TO BT | | | | | | | AUG | | | MARINE |
| 3 | WEIR | SDA250/250 B | GW1 TO BT | | | | NOV | | | | | | MARINE |
| 4 | WEIR | SDA250/250 B | GW2 TO BT | | | | | | | JULY | | | MARINE |
| 5 | WEIR | SDAH350/450 B | BW1 TO TWR | | | | | MAR | | | | | MARINE |
| 6 | WEIR | SDAH350/450 B | BW2 TO TWR | | | | | | AUG | | | | TEMCO |
| 7 | WEIR | SDAH350/450 B | BW3 TO TWR | | | | | | | | | | MARINE |

Appendix F

# Work request card procedure

# WTD - STANDARD PROCEDURES

| TITLE | REF. NO. : WTD-S-12-2013 |
|---|---|
| **WORK REQUEST CARD (WRC) PROCEDURE** | EFFECTIVE DATE : 20 - May - 2013 |
| | NO. OF PAGES : 19 |

| REVISION NUMBER | REVIEW FREQUENCY | NEXT REVISION DATE |
|---|---|---|
| 4 | TWO YEARS | MAY 2015 |

| REVIEWED BY STANDARD PROCEDURE COMMITTEE | | SIGNATURE | DATE |
|---|---|---|---|
| Sunil John | Member | | 20/5/2013 |
| Ali A. Jalil Tarrif | Member | | 20/05/2013 |
| Mohammed Juma | Member | | 20.5.2013 |
| Jaffer Jawad | Member | | 20.5.2013 |
| D.H. Panchal | Member | | 20.05.2013 |
| Varughese Idicula | Member | | 20/5/2013 |

| CHECKED BY | | SIGNATURE | DATE |
|---|---|---|---|
| A.Rasool Ghuloom | COMMITTEE CHAIRMAN | | 20/5/13 |

| APPROVED BY | | SIGNATURE | DATE |
|---|---|---|---|
| Ebrahim Abdulla Al Kaabi | DIRECTOR | | 23-5-2013 |

**Supportive Documents if any:-**

(1) Operation Procedure No. 141 dated 23-11-2012 (Issuing of WRC through MMS for Critical & Non-Critical Delete).
(2) Operation Procedure No. 108 dated 22-05-2005 (Request for Permit). Both are enclosed.

This Procedure issued in 1997, Revision – 1 (1998), Revision – 2 (1998), Revision – 3 (2011)

Water Transmission Directorate Standard Procedure

*This version supersedes the Standard Procedure WTD-S-12-2011, issued in 20-11-2011*

Standard Procedure No. WTD – S – 12 – 2013

# WORK REQUEST CARD (WRC) PROCEDURE

## 1.0 PURPOSE

To implement Work Request Card (WRC) procedure that will provide guide lines for accomplishing various maintenance jobs, in order to keep the Water Transmission Premises and Equipment at its optimized operating condition.

## 2.0 GENERAL GUIDE LINE

2.1 The database (Maintenance Management System - MMS) has been installed earlier & in use for accomplishing various maintenance jobs in order to keep all the records including raising new work request cards, Safety Documents, various types of reports, costing, history and cancellation.

2.2 The WRC's are categorized as (1) for Defect Cards, (2) for Job Cards or (3) Modifications. For this purpose WRC's are to be properly ticked and marked as "**Defect Card**" when the job is to rectify a defect found on the transmission network, "**Job Card**" for all other jobs that does not affect the network operation whereas "**Modification Card**" for those jobs related to improve the existing network. The staff who raises the WRC will be called "REQUESTOR" and has to assign the priority for the job in accordance to Priority List available in the database. All WRCs' to be entered in the MMS by all groups under Operations & System Control Department (the list of Responsibility of Entering WRC's is shown in ANNEXURE – 1A & 1B) shall be accepted by the issuer and Planning Group to print out the summary for distribution in the Planning Co-ordination Meeting held on daily basis to

discuss the progress or action to be taken and work schedule of the WRCs' issued on every working day. Maintenance sections database authorized personnel can print out the WRCs' through their Office PCs' and necessary safety documents can be raised through the system by Field Operation Group. After completion of the job and if satisfied, the issuer to sign the hardcopy of the WRC. Then the concerned maintenance section Engineer / Technician will enter in the system the completion date and comments, details of manpower hours utilized, materials etc. and forward the WRC hardcopy to Planning Group to record/accept the WRC in the system.

## 3.0 MAINTENANCE MANAGEMENT SYSTEM (MMS) FACILITY

The following are the major functions/reports available in the *MMS* system which will help all concerned sections to keep records and carry out maintenance activities within the stipulated time. ( *These functions/reports can be updated according to sections requirements)*

### 3.1 MMS Functions/Reports enabling to:

a) Raise new Work Request Card (WRC)
b) Carry out searching and sorting as per Priority, locations, Dates, Sections.

c) Summarize:

- Total WRC raised by dates or periods.
- Pending WRC by sections.
- Total WRC pending by dates.
- Completed WRC details by section / period.
- Completed accepted WRC details.
- Completed - not accepted WRC details.

d) Provide

- FLAG details.
- WRC Costing details.
- WRC manpower hour details.
- Monthly report.
- Job status report.
- WRC status/costing report.
- WRC received by sections / equipment.
- Completed WRC by sections.
- WRC Planning acceptance reports.
- IDA Report.

## 4.0 ACTION TO BE TAKEN IN CASE OF MMS FAILURE

4.1 Planning Group will co-ordinate with all sections responsible for entering WRC's and issuing them on time or as early as possible every day.

4.2 To raise any safety documents, Operation Procedure No. 108, dated 22/05/2005 has to be followed. (See ANNEXURE – 5)

4.3 To raise internal WRC, the requestor has to raise the WRC manually and inform Planning Group Engineer/Technician to maintain record.

4.4 Planning Group will enter all the WRC transferring details in the system once the system is restored.

4.5 Once the MMS is re-activated, all concerned maintenance sections to enter the completion details and manpower hour details etc .. of all WRCs' raised during system failure period.

## 5.0 RESPONSIBILITIES OF THE REQUESTOR

5.1 The requestor should provide as much necessary details as possible and should verify that the specified defect/job is not already raised by any other staff to avoid duplication of work.

5.2 He should then call either WCC or Filed Operations staff to furnish them with the location, defect/job description, equipment details and reason for the defect (if any) and the priority assigned. The concerned Operation Group will then enter the defect/job details in the system and in-turn will provide the requestor with the WRC number which is generated automatically in the system for registering it in the Station Log Book for future reference on the defect/job.

5.3 To raise any Internal Work Request Card (Section to Section, not through Operations & System Control Department) the Requestor should provide necessary details with contact person Name & Telephone Number. A new WRC Serial Number (starting with alphabetic letter followed by four digits) will be generated automatically in the system, which can be used for future reference/records.

## 6.0 RESPONSIBILITIES OF WATER CONTROL CENTER ENGINEER / TECHNICAN

To follow operation procedure No. 141, dated 23/11/2012, (See ANNEXURE – 4)

6.1 For all Defects of "Priority-1", he will immediately inform the Filed Operation Engineer during working hours and Operation On-Call Engineer outside working hours for concurrence on Priority-1 defect/job and if approved by him, the WCC Engineer/Technician will enter the WRC in MMS system.

The Filed Operation Engineer or Operation On-Call Engineer should inform their Respective Engineer/Technician and should proceed for remedial actions as per instructions.

6.2 For non-miscellaneous nature defects/job under priorities (2) & (3) the WCC Engineer/Technician should enter the defect/job details in the MMS system.

## 7.0 RESPONSIBILITIES OF OPERATION ENGINEER/TECHNICIAN

To follow Operation Procedure No.141, dated 23/11/2012, (See ANNEXURE – 4)

7.1 For all "Non-Priority-1" and miscellaneous defects/jobs, will be entered in the MMS system by the Field Operation Group.

7.2 Filed Operation Group will then initial the WRC's for issuing appropriate Safety Documents through MMS system.

## 8.0 RESPONSIBILITIES OF QUALITY AND CORROSION CONTROL

8.1 Any defect/job on any water quality measurement device or equipment in the stations or in the laboratory will be collected and entered in the MMS system by Chemical Engineer/Chemist.

## 9.0 RESPONSIBILITIES OF RECEIVING SECTION (See ANNEXURE – 2)

9.1 Maintenance Section Engineer will review the WRC described in the system, approve it and plan/approve it with his concerned personnel.

9.2 Section Engineer will discuss the defect/jobs with Sr. Technician/Technician as per the priority assigned, task involved, availability of spare parts and materials, as well as the manpower and time required for completing the jobs.

Accordingly, the work schedule will be prepared and "Planned Begin - Close Time" will be entered on the work card and this will be given to the assigned crew and at the same time raise Request For Permit (RFP) to Field Operation Group for issuing Safety Documents.

9.3 The assigned crew will carry out the work after receiving the safety documents as scheduled, and the work completion dates, work done comments, material details, manpower details etc. will be entered in the MMS system by the concerned maintenance section and hard copy will be returned to Planning Group signed by the Requestor as "Accepted" and "Completed" with required entries for Planning Group acceptance and verification.

## 10.0 RESPONSIBILITIES OF PLANNING GROUP (See ANNEXURE – 3)

10.1 WRC Work Category / Summary List.

Planning Engineer to generate WRC summary list through MMS system to verify the "Work Category" of each WRC whether it is "Defect", "Job" or "Modification" and distribute it to all maintenance sections and Field Operation Group representatives' for daily meeting.

10.2 Planning Co-Ordination Daily Meeting.

This meeting will be held every working day for the purpose of planning and scheduling the WRCs' as per priority and in consultation with Field Operation representative regarding the time and period for issuing safety documents and for the co-ordination required from other sections. Any discrepancies/amendments, WRC transfer details, changing priority etc. will be discussed accordingly, the work card entry for planned time" Begin and Close" will be either confirmed or re-scheduled as per the requirement.

10.3 Pending Jobs Weekly Review Meeting.

This meeting is once a week to review pending jobs with each maintenance section separately. The status will be discussed and updated accordingly.

## 11.0 ENCLOSURES

- List of Responsibility of Entering WRC's, ANNEXURE – 1A & 1B
- WRC Flow Chart, Maintenance Activity, ANNEXURE – 2
- WRC Flow Chart, Planning Activity, ANNEXURE – 3
- Operation Procedure, Issue of WRC through MMS, ANNEXURE – 4
- Operation Procedure, Request for Permit, ANNEXURE – 5

ANNEXURE – 1A

list of Responsibility of Entering WRC's

# Issuing & Entering a WRC on Miscellaneous Devices under Field Operation Responsibility

| Category | Device | Detail |
|---|---|---|
| Civil | Civil Work | All Civil Works in the stations & any kind of paintings (also pump painting). |
| | Premise Maintenance | All Work Request Cards related to:<br>1. Service Water Leak.<br>2. Toilets & Kitchens.<br>3. Service Tanks.<br>4. Car Park.<br>5. Station Drainage. |
| | Sampling Point | All Work Request Cards related to sampling points. |
| | Irrigation | All Work Request Cards related to Irrigation Tap & Hoses. |
| | Cable Sealing | All sealing Work Request Cards. |
| | All Devices | Corrosion works. |
| | All Sign Boards | All Work Request Cards related to:<br>1. Sign Boards.<br>2. Caution Notices.<br>3. Device Numbering.<br>4. Tagging. |
| | Chambers | All Work Request Cards related to Chamber Civil Works & Valve Keys. |

ANNEXURE – 1A (Continue)

| | | |
|---|---|---|
| Electrical | All Lightings | All Work Request Cards related to Floodlights, ESR Lightings, Warning Lights, Premise Fluorescent Lights, Street Lights & Security Room Lightings. |
| | Ventilation Fans | All Work Request Cards related to Ventilation Fans. |
| | Cooling Fans | All Cooling Fans in Control Room Panel & $Cl_2$ PLC System. |
| | Exhaust Fans & Air Fans | All Work Request Cards related to Exhaust Fans & Air Fans. |
| | Mimic Panel | Lighting & Indication Lamps. |
| | S/B Generator | Filling Diesel. |
| | Overhead Crane | All Electrical problems. |
| Mechanical | Sump Pumps | All Work Request Cards related to Sump Pumps. |
| | Storage Tanks (ESR's & GST's) | All Work Request Cards related to Storage Tanks Drain Valves, Cathodic Protection, Transfer of Water from GST to GST. |
| | Hi-Up | All Work Request Cards related to Hi-Up. |
| | Overhead Crane | All Mechanical problems. |
| Instrument | Chlorine System | Chlorine Weighting Scale. |
| Process Control | Control Room Devices | Printers & Telephones. |
| Others | Salmabad Head Quarter or Stations | First Aid Box, Control Room Cupboard, Telephone Bill, Main Gate Intercom, Area Foreman or any Salmabad Offices Miscellaneous Requirements. |

**Note:** Any Work Request Cards on the above devices will be the responsibility of WCC if it becomes Priority (1).

ANNEXURE – 1B

list of Responsibility of Entering WRC's

# WRC's Issuing & Entering under WCC Responsibility

| Category | Device | Detail |
|---|---|---|
| Electrical | Pumps (including duty & standby) | Rotor shaft, coupling & any other electrical problems. |
| | Motor (including duty & standby) | 1. Motor Complete Assembly.<br>2. RTD's up to motor terminal box.<br>3. Space heater.<br>4. Brush gear for slip ring motor.<br>5. Resistance Panel.<br>6. Power cable .<br>7. Switches and Push Button.<br>8. Sacrificing anodes for submersible motors.<br>9. Cable.<br>10. Level electrodes & cables.<br>11. Isolators ( Field )<br>12. Motor starter.<br>13. Protection relay.<br>14. Indication lights. |
| | Main Power | All stations Main Power related problems. |
| | Power Transformers | 1. Transformer Unit.<br>2. Power Cables.<br>3. Control Cables.<br>4. Temp. Indicators.<br>5. Silica Gel. |

ANNEXURE – 1B (Continue)

| | | |
|---|---|---|
| Electrical | Air compressor & Accessories | All Work Request Cards related to Air Compressors (duty & standby). |
| | Panel Board + Switch Gear & Accessories | 1. Bus bar, ACB's & VCB's.<br>2. Switch Gear Protection Relays.<br>3. Power Dist. Board.<br>4. MCCB, Fuses, Isolators.<br>5. Starter & Cables.<br>6. Protection Relay + CT<br>7. Ammeter, Volt meter<br>8. Cubical Panel. |
| | Instrument MIMIC Panel | Supply Cables |
| | Chlorination System & Associated Equipment. | 1. Motor & Starter<br>2. Power Cable.<br>3. Main fuses.<br>4. Motor protection relay. |
| | S/B Generator Set, Generator House, Electrical Fittings. | 1. Lights & Fittings.<br>2. Battery Charger<br>3. Battery Cells<br>4. Gen. Control Panel.<br>5. Starter, Motor and Dynamo Charger.<br>6. Elect. Heater and Fan Motor.<br>7. Alternator Unit and Exciter.<br>8. Voltage Regulator.<br>9. Motorized Louver Actuator.<br>10. Solenoid for the valve.<br>11. Voltmeter - Ammeter.<br>12. Changeover Panel.<br>13. Frequency Meter. |

ANNEXURE – 1B (Continue)

| | | |
|---|---|---|
| **Electrical** | Surge Vessels & System. | 1. Main Power Supply<br>2. Main MCB<br>3. Protection Relay.<br>4. Power Cables. |
| | Ground Storage Tank. | Main Power supply to the CB , Valves , Level Tx |
| | Elevated Tank | 1. MOV Power Supply<br>2. Power dist. Board |
| | Valves | 1. MOV Power Supply<br>2. MOV Main MCB |
| **Mechanical** | Pumps<br>(including main & standby) | 1-Suction & Discharge Valves.<br>2- Inboard & Outboard Bearings.<br>3- Inboard & Outboard Gland Packing.<br>4- Pumps NRV.<br>5. SDFS Cooling System. |
| | Chlorination system & Associated Equipment | 1. Booster Pump Assembly.<br>2. Maintenance of Chlorine Booster Pump. |
| | S/B Generator Set, Generator House, Electrical Fittings. | Diesel Engine Failure. |
| | Surge Vessels | All Work Request Cards related to Surge Vessel. |
| | All Valves including MOV's & Manual Valves | All Work Request Cards related to Valves except Drain Valves. |

ANNEXURE – 1B (Continue)

| | | |
|---|---|---|
| Process Control | Control Room Devices | 1. All DCS Systems in Stations.<br>2. All SCADA Systems & RTU's in Stations. |
| | Motor | 1. Status of SIC terminal.<br>a) Running / Stopped<br>b) Normal / Failed<br>c) Remote / Local<br>Which are connected to SIC cabinet<br>2. VVVF ( VSD ) |
| | Panel Board + Switch Gear & Accessories | 1. Temp. / Vibration Monitoring.<br>2. PLC Control Panel.<br>3. Marshalling Panel.<br>4. SCADA System / Cabinet.<br>5. RTU Cabinets.<br>6. 48 VDC System Cabinets. (UPS System )<br>7. Communication System of those stations with established links.<br>8. VVVF drive unit ( VSD ) |
| | Chlorination System | 1. Chlorination PLC in Seef Blending Station.<br>2. Chlorination PLC in WR-II Stations. |
| | Ground Storage Tank | 1. Level Indication at SCADA & DCS.<br>2. MOV Actuators. |
| | Valves | MOV Actuators of ESR Outlet MOV, GST Inlet /Outlet MOV. |
| | Pumping Mains | Main Valves Actuators. |
| | Surge Vessel / Towers | MOV Actuators. |

ANNEXURE – 1B **(Continue)**

| | | |
|---|---|---|
| **Instrument** | Chlorine System | 1. Chlorination Gas or Water or Chlorinated Water Leak.<br>2. Chlorine Change-Over Valve.<br>3. Chlorination System Failure. |
| | Flow Transmitters | All Flow Transmitters (inside & outside stations). |
| | Distribution PTX | Distribution Pressure Transmitters. |
| | Level Transmitters | All GST's & ESR's Level Transmitters. |
| | Gauges or Meters | 1. Pressure Gauges.<br>2. Pumps Temperature, RPM and Vibration Meters.<br>3. Pumping Mains Pressure Switches. |
| **Tanks & Trunks** | General | 1. Water Leaks.<br>2. Trunks Damages.<br>3. Accidents on Trunks. |

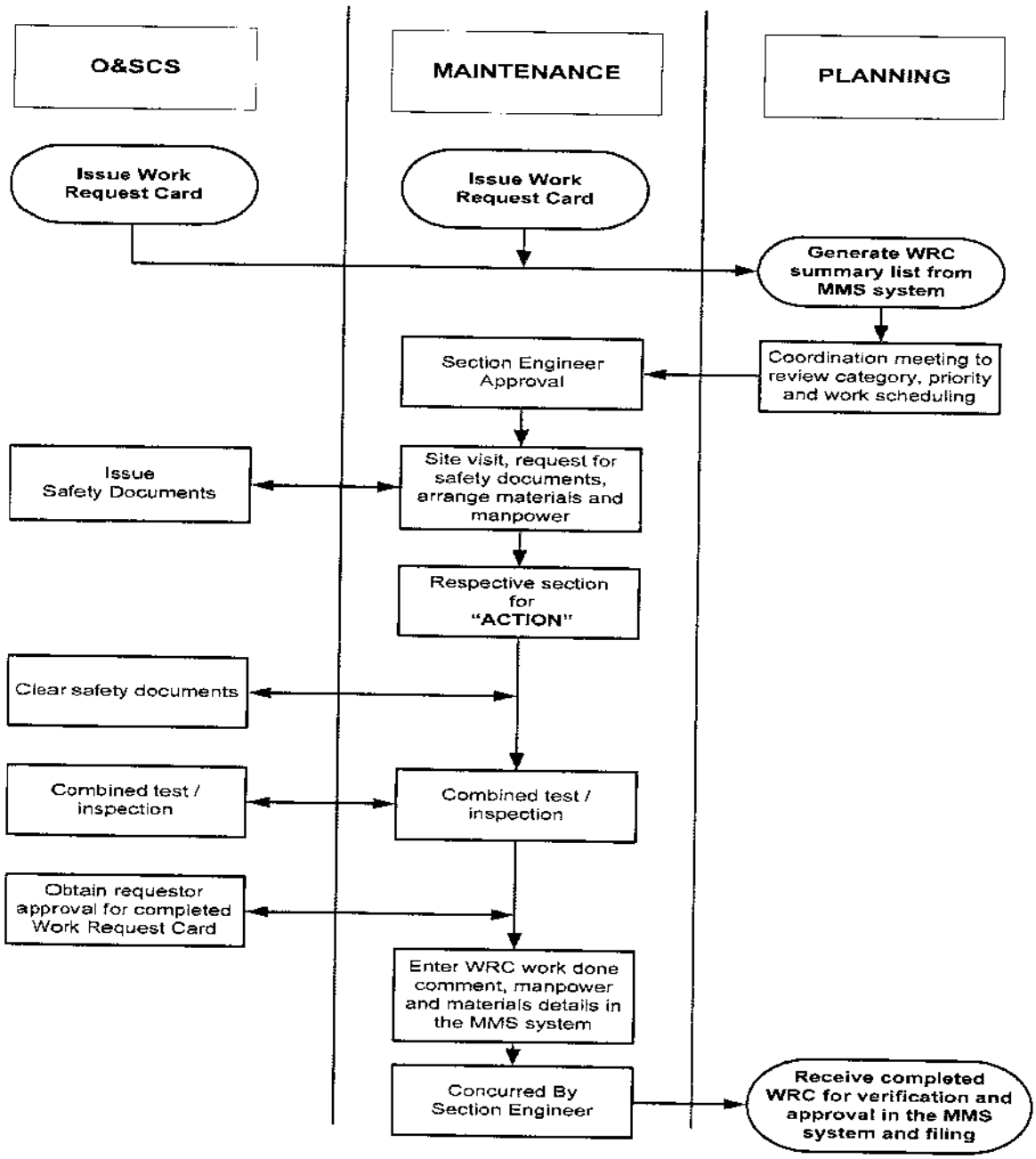
**Note:**

1) Any Work Request Cards on the above devices will be the responsibility of WCC regardless of the priority.

2) Any Work Request Card related to Incident, Damage & Accident Report to be the responsibility of WCC regardless of the priority.

ANNEXURE - 2

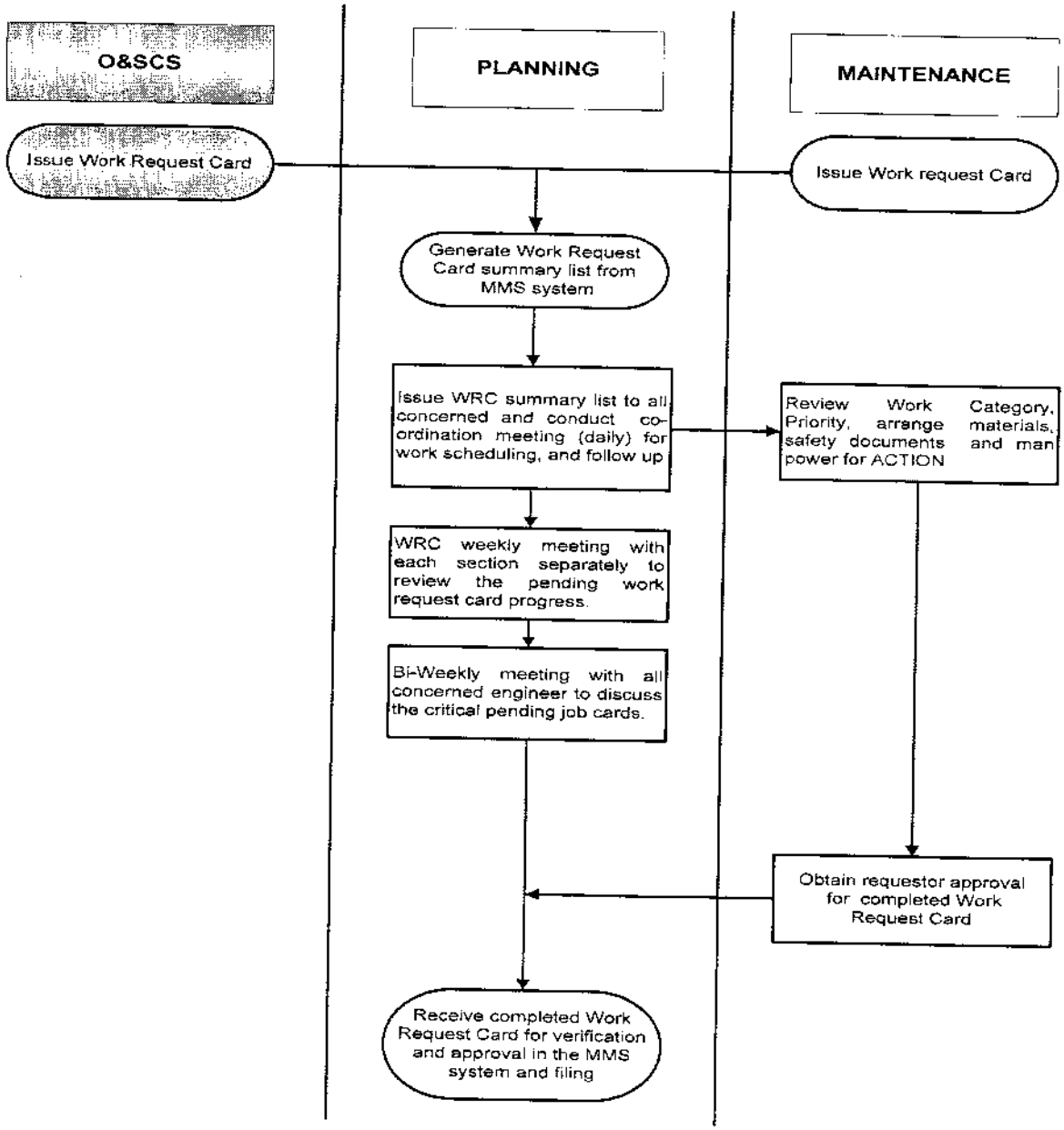
## WRC FLOW CHART – MAINTENANCE ACTIVITY




*This version supersedes the Standard Procedure WTD-S-12-2011, issued in 20-11-2011*

ANNEXURE - 3

# WRC FLOW CHART – PLANNING ACTIVITY



ANNEXURE - 4

| Water Transmission Directorate<br>Field Operation section<br>Operating Procedures / Instructions | |
|---|---|
| Operation Procedure No.: 141 | Date: 23/11/2012 |
| Sub: Issuing of Work Request Card through MMS for Critical & Non-critical Defects | الموضوع: اصدار بطاقات طلب العمل من خلال MMS للأجهزة الحساسة وغير الحساسة |
| With effect from 1/12/2012 all Shift Field Operation Staff must adhere to the following:<br>• All senior and blending plant technicians should report to their supervisors for non-critical defect to issue **Work Request Card** through MMS system as per the attached list.<br>• All WRC for critical equipment such as pumps, motors, UPS, etc., should be reported to **Water Control Center** for issuing WRC.<br>• All priority (1) WRC should be raised by WCC for critical and non-critical equipments.<br><br>All should strictly follow the above instructions. | اعتبارا من تاريخ 1/12/2012 يجب على جميع موظفي وحدة العمليات الميداني الالتزام بالآتي :<br>• على جميع فنيي محطات الخلط اخطار مشرفيهم بشأن بطاقات العمل لجميع الأجهزة الغير الحساسة حسب القائمة المرفقة من أجل ادخالها في برنامج (MMS).<br>• جميع بطاقات العمل للأجهزة الحساسة مثل المضخات والمحركات الكهربائية يجب إخطار مركز التحكم من أجل اصدارها.<br>• جميع بطاقات العمل لجميع الأجهزة الحساسة وغير الحساسة ذات الضرورة الملحة رقم (١) يجب أن تصدر من قبل مركز التحكم.<br><br>الجميع مطالب بالتقيد بما ورد أعلاه من تعليمات. |
| Prep. by : A.Rasool Ghuloom Baba<br>إعداد : عبدالرسول غلوم بابا<br>( رئيس قسم مركز التحكم بالمياه بالإنابة ) | Approved by: Muneer Hajjaj<br>بموافقة : منير حجاج<br>(رئيس قسم التشغيل ومراقبة النظم)<br>24/11/2012 |

*This version supersedes the Standard Procedure WTD-S-12-2011, issued in 20-11-2011*

ANNEXURE - 5

**Water Transmission Directorate**
**Maintenance Section**

**Operating Procedures / Instructions**

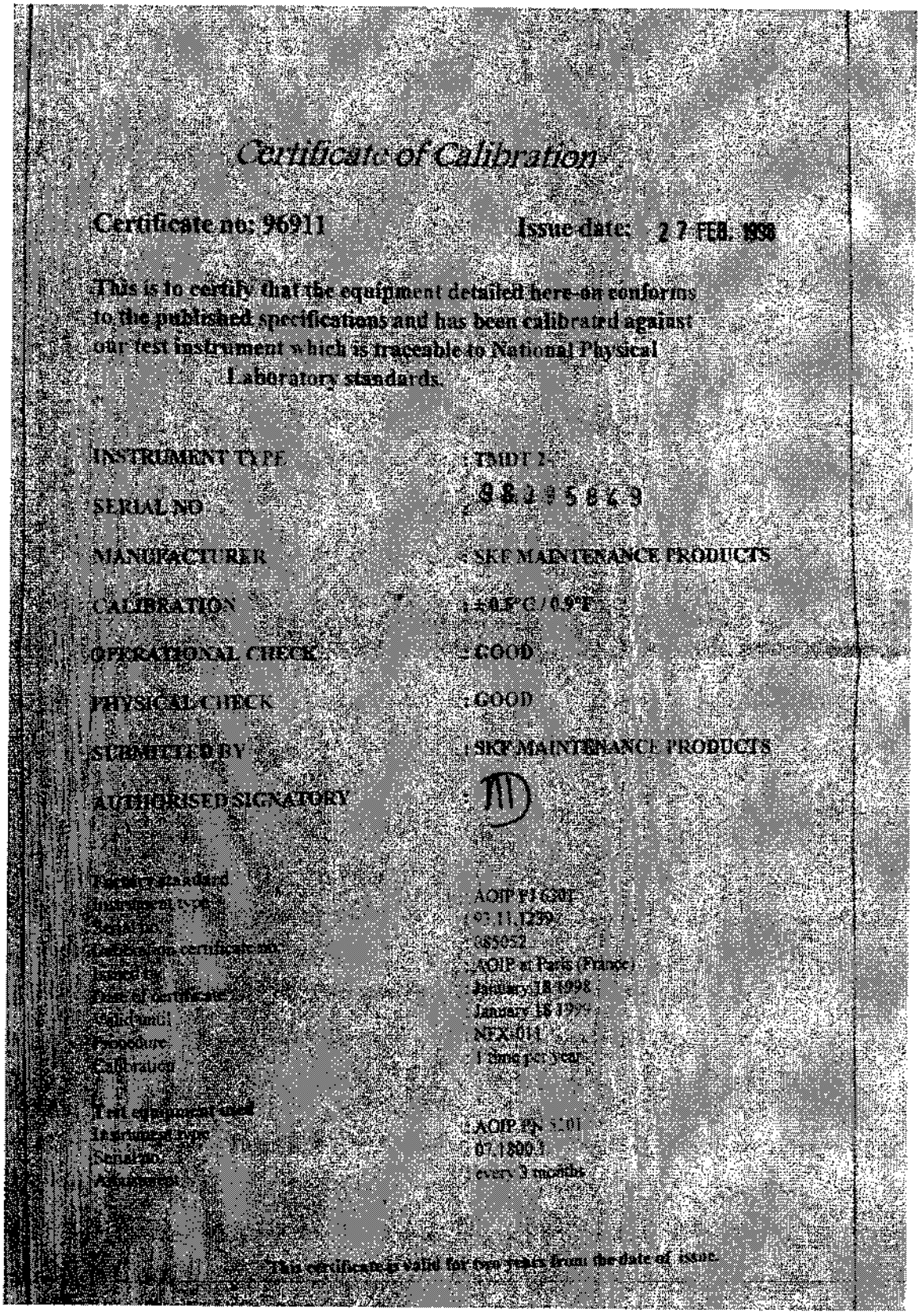
| Operation Procedure No. 108 | Date: 22/5/2005 |
|---|---|
| **Subject: Request for Permit** | **الموضوع : إذن تصاريح العمل** |
| With immediate effect, no permit to work Shall be issued if the permit request was not printed from the computerized maintenance system and clearly the acceptance from the operation department should be marked. In the case of the system is down, the manual permit request to filled and to be passed to the planning section for stamping and approval. Planning section should keep a copy which to be registered later in the system. | ابتداء من تاريخه، فإنه يرجى عدم إصدار تصاريح العمل ما لم تكن طلبات هذه التصاريح صادرة من نظام الحاسب الآلي مبيّنا عليه الموافقة من قسم التشغيل دون الحاجة إلى الختم. وفي حالة وجود أي عطب للنظام فإنه يستبدل بالنظام اليدوي ولكن بشرط أن يمرر على قسم التخطيط لختمه والتوقيع عليه والاحتفاظ بنسخه له للتسجيل لاحقا في النظام |
| Prep. By : Ebrahim Rashid Al Aradi<br>إعداد : إبراهيم راشد العرادي<br>(رئيس قسم الصيانة) | Approved by: Amin Abbas Khamis<br>بموافقة : أمين عباس خميس<br>(رئيس دائرة نقل المياه) |

*This version supersedes the Standard Procedure WTD-S-12-2011, issued in 20-11-2011*

Appendix G

# Calibration certificate of thermometer

Appendix G : Copy of Calibration Certificate for TMD T2 Device



# Certificate of Calibration

**Certificate no: 96911** **Issue date: 27 FEB. 1998**

**This is to certify that the equipment detailed here-on conforms to the published specifications and has been calibrated against our test instrument which is traceable to National Physical Laboratory standards.**

| | |
|---|---|
| **INSTRUMENT TYPE** | : TMDT 2 |
| **SERIAL NO** | : 9821586 3 |
| **MANUFACTURER** | : SKF MAINTENANCE PRODUCTS |
| **CALIBRATION** | : ± 0.5°C / 0.9°F |
| **OPERATIONAL CHECK** | : GOOD |
| **PHYSICAL CHECK** | : GOOD |
| **SUBMITTED BY** | : SKF MAINTENANCE PRODUCTS |
| **AUTHORISED SIGNATORY** | : |

| | |
|---|---|
| Test standard | : AOIP FI 630E |
| Instrument type | : 97.11.1239 |
| Serial no. | : 685052 |
| Calibration certificate no. | : AOIP at Paris (France) |
| Issued by | : January 18 1998 |
| Date of certificate | : January 18 1999 |
| Calibration | : NEX-011 |
| Procedure | : 1 time per 1 year |
| Calibration | |
| Test equipment used | : AOIP PN 5.01 |
| Instrument type | : 07.1800.3 |
| Serial no. | : every 3 months |
| Adjustment | |

**This certificate is valid for two years from the date of issue.**

Appendix H

# Summary of defects, frequency, time and cost for all Hamala A2 GFS pumps

Appindix H

Summary of defects, frequency, time and cost for all Hamala A2 GFS pumps

| No. | Types of defects | West Riff'a #1 Pump | | | West Riff'a #2 Pump | | | West Riff'a #3 Pump | | | Hamad Town #1 I | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time |
| 1 | leakage from discharge line /valve | 3 | 49.37 | 224.65 | 2 | 8.83 | 22.40 | 4 | 75.00 | 235.30 | 2 | 27.00 |
| 2 | Gland packing of the pump is leaking | 18 | 321.49 | 1,021.12 | 22 | 232.00 | 628.19 | 18 | 276.00 | 1,124.77 | 10 | 496.02 |
| 3 | Gland packing of the pump is smoking | 2 | 7.50 | 13.88 | 2 | 37.00 | 107.51 | 0 | 0.00 | 0.00 | 0 | 0.00 |
| 4 | Gland packing of the suction valve is leaking | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 |
| 5 | Gland packing of the discharge valve is leaking | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 |
| 6 | Check valve is passing | 4 | 122.00 | 377.10 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 1 | 5.50 |
| 7 | Check valve is hammering / not working properly | 1 | 150.00 | 433.20 | 0 | 0.00 | 0.00 | 3 | 24.00 | 67.10 | 0 | 0.00 |
| 8 | Drain valve is blocked /leaking/broken | 1 | 1.00 | 3.00 | 2 | 18.66 | 60.14 | 0 | 0.00 | 0.00 | 2 | 19.00 |
| 9 | Suction pressure gauge is not working | 2 | 4.00 | 50.20 | 2 | 3.50 | 49.00 | 3 | 9.00 | 25.00 | 2 | 4.50 |
| 10 | Disharge pressure gauge is not working | 1 | 2.75 | 56.60 | 0 | 0.00 | 0.00 | 4 | 14.00 | 160.20 | 0 | 0.00 |
| 11 | Casing is leaking from pin hole | 1 | 112.00 | 323.80 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 |
| 12 | Inboard bearing is noisy | 3 | 26.00 | 40.70 | 2 | 106.00 | 1,569.90 | 0 | 0.00 | 0.00 | 3 | 70.75 |
| 13 | Outboard bearing is noisy | 0 | 0.00 | 0.00 | 1 | 2.00 | 4.80 | 0 | 0.00 | 0.00 | 2 | 92.50 |
| 14 | Inboard bearing temperature is high | 0 | 0.00 | 0.00 | 1 | 5.00 | 15.00 | 0 | 0.00 | 0.00 | 0 | 0.00 |
| 15 | Outboard bearing temperature is high | 2 | 40.25 | 115.58 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 1 | 13.00 |
| 16 | Inboard bearing grease is coming out | 0 | 0.00 | 0.00 | 2 | 31.50 | 85.06 | 1 | 3.50 | 8.40 | 0 | 0.00 |
| 17 | Outboard bearing grease is coming out | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 |
| 18 | Problem in load breaker switch | 6 | 215.00 | 542.80 | 3 | 173.00 | 553.93 | 1 | 21.00 | 52.00 | 0 | 0.00 |
| 19 | Problem in power supply | 1 | 25.00 | 84.98 | 0 | 0.00 | 0.00 | 1 | 18.00 | 49.93 | 0 | 0.00 |
| 20 | Tripping due to under current | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 |
| 21 | Tripping due to over current | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 |
| 22 | Tripping due to over load | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 |
| 23 | Pump not working on remote | 2 | 14.00 | 40.20 | 1 | 24.00 | 80.30 | 0 | 0.00 | 0.00 | 0 | 0.00 |
| 24 | Motor inboard bearing is noisy | 1 | 2.00 | 4.80 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 1 | 9.00 |
| 25 | Motor outboard bearing is noisy | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 |
| 26 | Pressure switch is not functioning / tripping pum | 1 | 8.00 | 40.70 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 |
| | **total** | **49** | **1,100.36** | **3,373.30** | **40** | **641.49** | **3,176.22** | **35** | **440.50** | **1,722.69** | **24** | **737.27** |

| Pump | Hamad Town #2 Pump | | | WR 1&2&3 Pumps | | | WR & HTB Pumps | | | HTB Pumps | | | Total Summary | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost |
| 63.50 | 0 | 0.00 | 0.00 | 1 | 17.50 | 129.25 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 12 | 177.70 | 675.10 |
| 1,854.61 | 13 | 252.02 | 3,725.70 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 81 | 1,577.53 | 8,354.39 |
| 0.00 | 2 | 13.00 | 34.26 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 6 | 57.50 | 155.65 |
| 0.00 | 1 | 20.49 | 38.27 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 1 | 20.49 | 38.27 |
| 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 |
| 5.83 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 5 | 127.50 | 382.93 |
| 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 4 | 174.00 | 500.30 |
| 51.90 | 4 | 83.50 | 172.79 | 0 | 0.00 | 0.00 | 2 | 16.50 | 42.98 | 0 | 0.00 | 0.00 | 11 | 138.66 | 330.81 |
| 10.00 | 2 | 3.00 | 7.00 | 1 | 4.00 | 10.80 | 0 | 0.00 | 0.00 | 2 | 16.00 | 42.55 | 14 | 44.00 | 194.55 |
| 0.00 | 2 | 8.00 | 51.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 1 | 4.00 | 10.80 | 8 | 28.75 | 278.60 |
| 0.00 | 1 | 96.00 | 1,767.70 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 2 | 208.00 | 2,091.50 |
| 214.99 | 5 | 144.50 | 1,876.47 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 13 | 347.25 | 3,702.06 |
| 390.11 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 3 | 94.50 | 394.91 |
| 0.00 | 1 | 6.00 | 20.20 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 2 | 11.00 | 35.20 |
| 21.40 | 1 | 52.25 | 155.33 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 4 | 105.50 | 292.30 |
| 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 3 | 35.00 | 93.46 |
| 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 |
| 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 10 | 409.00 | 1,148.73 |
| 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 2 | 43.00 | 134.90 |
| 0.00 | 4 | 11.00 | 29.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 4 | 11.00 | 29.00 |
| 0.00 | 1 | 4.00 | 11.20 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 1 | 4.00 | 11.20 |
| 0.00 | 1 | 8.00 | 22.80 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 1 | 8.00 | 22.80 |
| 0.00 | 0 | 0.00 | 0.00 | 4 | 47.00 | 220.45 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 7 | 85.00 | 340.95 |
| 45.50 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 2 | 11.00 | 50.30 |
| 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 |
| 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 0 | 0.00 | 0.00 | 1 | 5.00 | 15.00 | 2 | 13.00 | 55.70 |
| **2,657.84** | **38** | **701.76** | **7,911.71** | **6** | **68.50** | **360.50** | **2** | **16.50** | **42.98** | **4** | **25.00** | **68.35** | **198** | **3,731.38** | **19,313.59** |

Appendix I

# Summary of defects, frequency, time and cost for all HTBS pumps

Appindix I

Summary of defects, frequency, time and cost for all HTBS pumps

| No. | Types of defects | DW Pump #1 | | | DW Pump #2 | | | GW Pump #1 | | | GW Pump #2 | | | Tower Pump #1 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost |
| 1 | leakage from discharge line /valve | 4 | 125.75 | 299 | 3 | 75 | 217.7688 | 1 | 2 | 3.7 | 0 | 0 | 0 | 2 | 9.5 | 22.8 |
| 2 | Gland packing of the pump is leaking | 12 | 254 | 785.8238 | 6 | 42.5 | 129.3 | 6 | 31 | 60.65 | 8 | 80 | 604.28 | 5 | 78 | 184.8937 |
| 3 | Gland packing of the pump is smoking | 1 | 4.5 | 14.1 | 1 | 1 | 4.5 | 1 | 12 | 19.2 | 1 | 6 | 15.3 | 2 | 53 | 181.65 |
| 4 | Gland packing of the suction valve is leaking | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | Gland packing of the discharge valve is leaking | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | Shaft is jammed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 10.5 | 25.2 | 1 | 46 | 128.3438 |
| 7 | Coupling is damaged | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 67 | 903.61 | 1 | 14 | 28 |
| 8 | Pump is not sucking water | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 13 | 46 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | Relieve valve is blocked | 3 | 32 | 71.3 | 4 | 27 | 67.3 | 1 | 2 | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | Check valve is passing | 1 | 7 | 14 | 3 | 39 | 77.8 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 15 | 36.5 |
| 11 | Check valve is hammering / not working properl | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 15 | 38.7 | 0 | 0 | 0 |
| 12 | Drain valve is blocked /leaking/broken | 2 | 26 | 73.8 | 1 | 12.666667 | 40.15 | 3 | 8.5 | 16.45 | 2 | 12.5 | 30 | 1 | 20 | 451.8 |
| 13 | Suction pressure gauge is not working | 0 | 0 | 0 | 8 | 34.5 | 85.65 | 0 | 0 | 0 | 1 | 4 | 10.8 | 1 | 8 | 11.4 |
| 14 | Disharge pressure gauge is not working | 0 | 0 | 0 | 5 | 23 | 76.3 | 1 | 5 | 10 | 1 | 15 | 55 | 3 | 14 | 31.65 |
| 15 | Casing is leaking from pin hole | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | Inboard bearing is noisy | 2 | 55.16 | 150.32 | 0 | 0 | 0 | 1 | 2 | 8 | 2 | 10 | 34 | 0 | 0 | 0 |
| 17 | Outboard bearing is noisy | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 9.2 | 0 | 0 | 0 |
| 18 | Inboard bearing temperature is high | 1 | 5 | 26.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | Outboard bearing temperature is high | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | Inboard bearing grease is coming out | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | Outboard bearing grease is coming out | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | Problem in load breaker switch | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | Problem in power supply | 0 | 0 | 0 | 1 | 14 | 36.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | Tripping due to under current | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | Tripping due to over current | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 | Tripping due to over load | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | Pump not working on remote | 2 | 14 | 32.2 | 1 | 12 | 38.3 | 2 | 20 | 74 | 1 | 12 | 44.4 | 0 | 0 | 0 |
| 28 | Motor inboard bearing is noisy | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 29 | Motor outboard bearing is noisy | 2 | 17 | 59.95 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 6 | 19.2 | 0 | 0 | 0 |
| 30 | Pressure switch is not functioning / tripping pum | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31 | Ampere meter is hunting/not giving correct reading/not working | 2 | 20 | 120.5 | 2 | 20 | 163.88 | 0 | 0 | 0 | 1 | 9 | 33.3 | 2 | 14 | 132 |
| 32 | Capacitor is burnt out | 0 | 0 | 0 | 2 | 17 | 129.2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 8 |
| 33 | Display screen is not working/no reading | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 50 | 150.0875 | 1 | 15 | 56.4 | 0 | 0 | 0 |
| 34 | Speed controler is not working | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 21 | 68.6 | 4 | 29 | 104.8375 | 0 | 0 | 0 |
| 35 | RPM is not working | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 25 | 83.7 | 1 | 3 | 9 | 0 | 0 | 0 |
| 36 | Cooling fan is not working | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 8 | 24.2 | 1 | 3 | 12.25 | 0 | 0 | 0 |
| 37 | failed without alarm | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 7 | 19.6 | 4 | 49 | 3150.5 | 0 | 0 | 0 |
| | **Total** | **32** | **560.41** | **1647.2** | **37** | **317.67** | **1066.5** | **29** | **206.5** | **590.19** | **36** | **350** | **5156** | **20** | **275.5** | **1217** |

| Tower Pump #2 | | | HTD Pump #1 | | | HTD Pump #2 | | | DW1&2 / HTD 1&2 / PSR1 &2 | | | Total no. of Defects | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost |
| 3 | 22.5 | 68.675 | 4 | 59.25 | 145.09 | 5 | 52.5 | 146.0125 | 3 | 53 | 200.85 | 25 | 399.5 | 1103.8913 |
| 4 | 41.5 | 154.6937 | 0 | 0 | 0.00 | 6 | 77.583334 | 175.7583 | 2 | 4 | 4 | 49 | 608.58333 | 2099.3995 |
| 2 | 46 | 142.1 | 0 | 0 | 0.00 | 3 | 26 | 120.75 | 0 | 0 | 0 | 11 | 148.5 | 497.6 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 14 | 92 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 56.5 | 153.5438 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 95 | 1023.61 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 13 | 46 |
| 2 | 58 | 152.2 | 2 | 46 | 106.80 | 1 | 7.6599998 | 13.8 | 0 | 0 | 0 | 8 | 61 | 144.6 |
| 1 | 20 | 59.5 | 0 | 0 | 0.00 | 1 | 7 | 14 | 0 | 0 | 0 | 10 | 172.66 | 401.1 |
| 1 | 5.5 | 17.75 | 0 | 0 | 0.00 | 2 | 18.5 | 43 | 0 | 0 | 0 | 3 | 42 | 112.2 |
| 1 | 4 | 10.8 | 2 | 8 | 20.20 | 1 | 2.6666667 | 6.4 | 0 | 0 | 0 | 12 | 103.66667 | 672.95 |
| 4 | 17 | 67.0813 | 1 | 8 | 18.00 | 1 | 3.4166667 | 8.2 | 0 | 0 | 0 | 14 | 61.166667 | 145.25 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 2 | 18 | 27.3 | 0 | 0 | 0 | 16 | 85.416667 | 266.2313 |
| 3 | 130 | 471.58 | 1 | 6 | 5.10 | 4 | 179.66667 | 546.6933 | 0 | 0 | 0 | 2 | 18 | 27.3 |
| 0 | 0 | 0 | 1 | 12 | 40.20 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 382.82667 | 1215.6933 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 16 | 49.4 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0 | 1 | 10 | 33.1 | 1 | 5 | 26.25 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 10 | 33.1 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 7 | 56.35 | 4 | 20 | 56.00 | 0 | 0 | 0 | 1 | 3 | 10.4125 | 7 | 44 | 159.1625 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 14 | 41.5 | 0 | 0 | 0.00 | 6 | 49 | 129.4 | 1 | 8 | 29.6 | 15 | 129 | 389 |
| 1 | 161 | 609.42 | 2 | 10 | 23.00 | 5 | 78.5 | 206.9 | 0 | 0 | 0 | 9 | 249.5 | 839.32 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 2 | 142 | 471.3625 | 0 | 0 | 0 | 5 | 165 | 550.5125 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 28 | 65.8 | 15 | 175 | 7,099.90 | 9 | 116 | 443.625 | 0 | 0 | 0 | 33 | 382 | 8059.005 |
| 1 | 15.5 | 44.65 | 3 | 52.5 | 184.25 | 1 | 7 | 19.95 | 0 | 0 | 0 | 8 | 96 | 386.05 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 1 | 4 | 13.6 | 0 | 0 | 0 | 6 | 69 | 220.0875 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 2 | 61 | 701.54 | 0 | 0 | 0 | 8 | 111 | 874.9775 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 28 | 92.7 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 11 | 36.45 |
| 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 56 | 3170.1 |
| **29** | **584** | **2053.7** | **35** | **396.75** | **######** | **52** | **850.49** | **3088.3** | **8** | **78** | **277.96** | **278** | **3619.3** | **22795** |

Appendix J

# Summary of defects, frequency, time and cost for all HTDS pumps

Appindix J

Summary of defects, frequency, time and cost for all HTDS pumps

| No. | Types of defects | Tower Pump # 1 | | | Tower Pump # 2 | | | Other Comibnations | | | Total no. of Defects | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost |
| 1 | leakage from discharge line (Header) from Pin hole | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 1 | 16 | 50.60 | 1 | 16 | 50.6 |
| 2 | Gland packing of the pump is leaking | 2 | 17 | 52.00 | 0 | 0 | 20.00 | 0 | 0 | 0.00 | 2 | 17 | 72 |
| 3 | Gland packing of the pump is smoking | 1 | 13 | 52.70 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 1 | 13 | 52.7 |
| 4 | Gland packing of the suction valve is leaking | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 5 | Gland packing of the discharge valve is leaking | 1 | 13 | 33.15 | 2 | 23 | 56.50 | 0 | 0 | 0.00 | 3 | 36 | 89.65 |
| 6 | Suction / discharge valve is jammed | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 7 | Coupling cove to be refixed | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 8 | Problem in discharge MOV /Actuator/stuck in position | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 9 | Problem in suction MOV /Actuator/stuck in position | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 10 | Check valve is leaking | 1 | 8 | 13.60 | 2 | 15 | 41.60 | 0 | 0 | 0.00 | 3 | 23 | 55.2 |
| 11 | Check valve is hammering / not working properly / Passing | 3 | 56 | 124.90 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 3 | 56 | 124.9 |
| 12 | Drain valve is blocked /leaking/broken | 0 | 0 | 0.00 | 7 | 53 | 101.60 | 0 | 0 | 0.00 | 7 | 53 | 101.6 |
| 13 | Suction pressure gauge is not working | 1 | 3 | 7.20 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 1 | 3 | 7.2 |
| 14 | Disharge pressure gauge is not working | 2 | 10 | 27.20 | 1 | 2 | 4.80 | 0 | 0 | 0.00 | 3 | 12 | 32 |
| 15 | Actuator is leaking water from gear box | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 16 | Inboard bearing is noisy | 1 | 15 | 30.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 1 | 15 | 30 |
| 17 | Outboard bearing is noisy | 1 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 1 | 0 | 0 |
| 18 | Inboard bearing temperature is high | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 19 | Outboard bearing temperature is high | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 20 | Inboard bearing grease is coming out | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 21 | Outboard bearing grease is coming out | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 22 | Vibration sensor is not reading / Tripping on high vibratio | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 23 | Problem in power supply | 3 | 25 | 79.50 | 1 | 5 | 23.00 | 0 | 0 | 0.00 | 4 | 30 | 102.5 |
| 24 | Tripping on LCP | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 25 | Trippingon phase unbalance | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 26 | Problem in DCS / data is stuck in display screen | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 27 | Pump not working on sequence | 1 | 6 | 20.10 | 1 | 6 | 20.10 | 1 | 4 | 12.20 | 3 | 16 | 52.4 |
| 28 | Motor inboard bearing is noisy | 2 | 10.5 | 21.00 | 3 | 10.0333 | 21.68 | 0 | 0 | 0.00 | 5 | 20.5333 | 42.68 |
| 29 | Motor outboard bearing is noisy | 1 | 13 | 2,025.20 | 1 | 5 | 11.00 | 0 | 0 | 0.00 | 2 | 18 | 2036.2 |
| 30 | Level switch is not functioning / alarm standing | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 31 | Motor current reading is low | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 32 | Capacitor is is giving low readings | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 33 | Smell is coming from Resistance box | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 34 | Motor is tripping frequently | 2 | 13.5 | 80.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 2 | 13.5 | 80 |
| 35 | Motor is heating / high winding temperature | 1 | 5 | 12.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 1 | 5 | 12 |
| 36 | Speed cannot be controlled | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0.00 | 0 | 0 | 0 |
| 37 | Filed to start | 0 | 0 | 0.00 | 1 | 10.5 | 30.80 | 0 | 0 | 0.00 | 1 | 10.5 | 30.8 |
| | Total | 23 | 208 | 2578.55 | 19 | 129.533 | 331.08 | 2 | 20 | 62.8 | 44 | 357.533 | 2972.43 |

Appendix K

# Summary of defects, frequency, time and cost for all WR#1 pumps

Appindix K

Summary of defects, frequency, time and cost for all WR#1 pumps

| No. | Types of defects | DW Pump #1 | | | DW Pump #2 | | | DW Pump # 3 | | | GW Pump #1 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency |
| 1 | leakage from discharge line (Header) from Pin hole | 4 | 60.5 | 223.7 | 1 | 14 | 538.7 | 1 | 12 | 33.6 | 0 | 0 | 0 | 0 |
| 2 | Gland packing of the pump is leaking | 4 | 34 | 70.3 | 2 | 111.5 | 657.825 | 2 | 22 | 54 | 0 | 0 | 0 | 1 |
| 3 | Gland packing of the pump is smoking | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 12 | 30 | 0 | 0 | 0 | 0 |
| 4 | Gland packing of the suction valve is leaking | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 14 | 37.8 | 0 | 0 | 0 | 0 |
| 5 | Gland packing of the discharge valve is leaking | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | 18 | 0 | 0 | 0 | 1 |
| 6 | Shaft is jammed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | Coupling is damaged | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | Pump is not sucking water | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | Relieve valve is blocked | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | Check valve is leaking | 6 | 73.5 | 156.35 | 4 | 14 | 44.35 | 3 | 29.5 | 75.05 | 0 | 0 | 0 | 0 |
| 11 | Check valve is hammering / not working properly / Passing | 3 | 76 | 187.5 | 2 | 62 | 1136.65 | 1 | 34.5 | 89.7 | 2 | 61 | 160 | 1 |
| 12 | Drain valve is blocked /leaking/broken | 2 | 19 | 37.9 | 2 | 8 | 7.5 | 2 | 9 | 22.7 | 0 | 0 | 0 | 1 |
| 13 | Suction pressure gauge is not working | 1 | 14 | 32.6 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 10.8 | 1 |
| 14 | Disharge pressure gauge is not working | 1 | 1 | 2 | 0 | 0 | 0 | 2 | 4 | 13.1 | 3 | 7.25 | 14.625 | 1 |
| 15 | Casing is leaking from pin hole | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | Inboard bearing is noisy | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 9 | 37.875 | 0 |
| 17 | Outboard bearing is noisy | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | Inboard bearing temperature is high | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | Outboard bearing temperature is high | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | Inboard bearing grease is coming out | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | Outboard bearing grease is coming out | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | Problem in load breaker switch | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23 | Problem in power supply | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 24 | Tripping due to under current | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 25 | Tripping due to over current | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 | Tripping due to over load | 0 | 0 | 0 | 1 | 20 | 118.95 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 27 | Pump not working on Auto mode / Remote | 3 | 23 | 68 | 1 | 3 | 12 | 1 | 14.45 | 14.45 | 4 | 31.8 | 70.1 | 4 |
| 28 | Motor inboard bearing is noisy | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 31 | 115.5188 | 2 | 15 | 54.2 | 0 |
| 29 | Motor outboard bearing is noisy | 1 | 4 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 26 | 74.01 | 0 |
| 30 | Pressure switch is not functioning / tripping pump | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31 | Ampere meter is flunting/not giving correct reading/not working | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 32 | Capacitor is is giving low readings | 1 | 51 | 366.59 | 1 | 26 | 116.8 | 1 | 21 | 68.2 | 0 | 0 | 0 | 0 |
| 33 | Smell is coming from Resistance box | 2 | 32 | 100.4 | 7 | 198 | 646.2 | 3 | 45.5 | 133.85 | 0 | 0 | 0 | 0 |
| 34 | Motor is tripping frequently | 2 | 51.5 | 160.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35 | Motor is heating | 1 | 0 | 0 | 1 | 1.5 | 6 | 1 | 8 | 24.4 | 0 | 0 | 0 | 0 |
| 36 | Cooling fan is not working | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| 37 | failed without alarm | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 24 | 92.1 | 0 | 0 | 0 | 1 |
| | **Total** | **31** | **439.5** | **1422.4** | **22** | **458** | **3285** | **22** | **285.95** | **822.47** | **16** | **154.05** | **421.61** | **16** |

| GW Pump #2 | | HTB Pump #1 | | | HTB Pump #2 | | | HTB Pump #3 | | | EAST Tower Pump #1 | | | EAST Tower Pump #2 | | | WEST Tower Pun | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time |
| 0 | 0 | 2 | 30 | 59.4 | 0 | 0 | 0 | 1 | 32 | 109.25 | 2 | 43 | 116.9 | 4 | 66 | 181.10 | 1 | 4 |
| 17 | 32.425 | 1 | 6.75 | 16.2 | 2 | 23.25 | 40.275 | 4 | 41 | 154.9 | 10 | 138.5 | 5290.206 | 19 | 146.5 | 521.83 | 1 | 5 |
| 0 | 0 | 1 | 6.99 | 371.434 | 0 | 0 | 0 | 1 | 7 | 16.8 | 3 | 15.25 | 63.3313 | 5 | 32.5 | 115.10 | 0 | 0 |
| 0 | 0 | 1 | 10.5 | 24.15 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 29 | 78.8625 | 1 | 3 | 8.00 | 1 | 18 |
| 14 | 33.6 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 4.9 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 0 | 0 | 1 | 10.5 | 25.15 | 1 | 13 | 22.3 | 1 | 27 | 81.9 | 2 | 11 | 27.3 | 0 | 0 | 0.00 | 1 | 7 |
| 3 | 9 | 0 | 0 | 0 | 2 | 60 | 178.6125 | 0 | 0 | 0 | 2 | 29.66667 | 79.6 | 3 | 89.25 | 2,752.18 | 4 | 125 |
| 26 | 40.9 | 1 | 7 | 25.6 | 1 | 7 | 15.6 | 1 | 5 | 17.6 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 9 | 31.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 6.333333 | 35.20 | 0 | 0 |
| 4 | 12.2 | 1 | 18 | 46.8 | 1 | 1 | 1.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 1 | 8 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 0 | 0 | 2 | 60 | 179.18 | 0 | 0 | 0 | 1 | 2 | 4.8 | 0 | 0 | 0 | 1 | 10 | 33.50 | 0 | 0 |
| 0 | 0 | 1 | 1.5 | 5.1 | 0 | 0 | 0 | 1 | 48 | 90.788 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 4 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 126.3 | 266.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 0 | 0 | 1 | 8 | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 1 | 48 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 6.5 | 22.10 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 16 | 64.9062 | 0 | 0 | 0.00 | 0 | 0 |
| 4 | 13.6 | 3 | 32 | 165.4375 | 2 | 22 | 98.4 | 5 | 83 | 4555.9 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 2 | 16 | 37.4 | 0 | 0 | 0 | 1 | 24 | 110 | 2 | 19 | 145.85 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 12 | 64.4 | 0 | 0 | 0.00 | 1 | 6 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 30 | 104.65 | 1 | 11 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 17 | 57.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 |
| 0.733333 | 2.97 | 1 | 9 | 22.5 | 1 | 6 | 18 | 0 | 0 | 0 | 2 | 8 | 21.7 | 0 | 0 | 0.00 | 0 | 0 |
| **225.03** | **515.3** | **16** | **200.24** | **956.95** | **12** | **148.25** | **412.29** | **16** | **248** | **5036.8** | **26** | **326.42** | **5917.2** | **38** | **409.08** | **3919.5** | **12** | **232** |

| ıp #2 | WEST Tower Pump #2 | | | Other Combinations | | | Total no. of Defects | | |
|---|---|---|---|---|---|---|---|---|---|
| Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost |
| 12 | 6 | 142 | 411.2313 | 16 | 464.24 | 1,298.44 | 38 | 867.74 | 2,984.32 |
| 8 | 3 | 23.5 | 89.475 | 0 | 0 | 0.00 | 49 | 569 | 6,935.43 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 11 | 73.74 | 596.67 |
| 46.8 | 1 | 0 | 0 | 0 | 0 | 0.00 | 7 | 74.5 | 195.61 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 3 | 22 | 56.50 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 16.8 | 2 | 22 | 52.8 | 1 | 19.5 | 82.50 | 22 | 227 | 584.50 |
| 330 | 0 | 0 | 0 | 0 | 0 | 0.00 | 20 | 540.4167 | 4,923.24 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 10 | 81 | 167.80 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 4 | 33.33333 | 110.40 |
| 13.6 | 0 | 0 | 0 | 0 | 0 | 0.00 | 10 | 43.25 | 104.03 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 0 | 2 | 23 | 263.55 | 0 | 0 | 0.00 | 7 | 104 | 518.91 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 2 | 49.5 | 95.89 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 0 | 0 | 0 | 0 | 1 | 4.5 | 11.70 | 2 | 8.5 | 26.70 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 1 | 20 | 118.95 |
| 48 | 0 | 0 | 0 | 2 | 5 | 14.80 | 16 | 251.55 | 493.95 |
| 0 | 1 | 10 | 32 | 0 | 0 | 0.00 | 6 | 70.5 | 239.82 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 5 | 46 | 155.92 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 0 | 1 | 11 | 126.15 | 0 | 0 | 0.00 | 14 | 171 | 5,105.34 |
| 66.7 | 0 | 0 | 0 | 0 | 0 | 0.00 | 7 | 144 | 765.69 |
| 61.7 | 0 | 0 | 0 | 0 | 0 | 0.00 | 15 | 328.5 | 1,111.20 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 2 | 51.5 | 160.10 |
| 0 | 1 | 2 | 12 | 0 | 0 | 0.00 | 4 | 11.5 | 42.40 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 3 | 17 | 57.20 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0.00 | 6 | 47.73333 | 157.27 |
| **603.6** | **17** | **233.5** | **987.21** | **20** | **493.24** | **1407.4** | **264** | **3853.3** | **25708** |

Appendix L

# Summary of defects, frequency, time and cost for all WR#2 pumps

Appindix L

Summary of defects, frequency, time and cost for all WR#2 pumps

| No. | Types of defects | DW Pump #1 | | | DW Pump #2 | | | GW Pump #1 | | | GW Pump #2 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time |
| 1 | leakage from discharge line (Header) from Pin hole | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | Gland packing of the pump is leaking | 11 | 72.33 | 169.30 | 9 | 79.5 | 272.5 | 5 | 53 | 153.55 | 5 | 114.76 |
| 3 | Gland packing of the pump is smoking | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | Gland packing of the suction valve is leaking | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | Gland packing of the discharge valve is leaking | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | Suction / discharge valve is jammed | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | Coupling cove to be refixed | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | Problem in discharge MOV /Actuator/stuck in position | 4 | 19 | 71.60 | 6 | 167 | 305.3 | 2 | 28 | 88.5 | 1 | 10 |
| 9 | Problem in suction MOV /Actuator/stuck in position | 1 | 6.25 | 21.15 | 2 | 15.5 | 54.75 | 2 | 14 | 49.2 | 1 | 7.5 |
| 10 | Check valve is leaking | 11 | 180.917 | 394.85 | 9 | 179.5 | 519 | 0 | 0 | 0 | 0 | 0 |
| 11 | Check valve is hammering / not working properly / Passin | 1 | 6 | 16.20 | 7 | 108.5 | 259.5 | 2 | 48 | 134.45 | 1 | 30 |
| 12 | Drain valve is blocked /leaking/broken | 2 | 8 | 20.00 | 3 | 33 | 51.85 | 2 | 8 | 19.1 | 5 | 36.5 |
| 13 | Suction pressure gauge is not working | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 14 | Disharge pressure gauge is not working | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | Actuator is leaking water from gear box | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | Inboard bearing is noisy | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | Outboard bearing is noisy | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | Inboard bearing temperature is high | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 16 |
| 19 | Outboard bearing temperature is high | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | Inboard bearing grease is coming out | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21 | Outboard bearing grease is coming out | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 22 | Vibration sensor is not reading / Tripping on high vibratio | 19 | 118 | 639.20 | 1 | 12 | 30.6 | 8 | 85 | 446.15 | 0 | 0 |
| 23 | Problem in power supply | 0 | 0 | 0.00 | 2 | 34 | 104.8 | 2 | 19 | 62.55 | 1 | 3 |
| 24 | Tripping on LCP | 5 | 18 | 63.00 | 3 | 17 | 41.9 | 3 | 43 | 669.64 | 0 | 0 |
| 25 | Trippingon phase unbalance | 0 | 0 | 0.00 | 0 | 0 | 0 | 2 | 38 | 98.8 | 3 | 26 |
| 26 | Problem in DCS / data is stuck in display screen | 4 | 33 | 112.60 | 4 | 36 | 121.6 | 2 | 19.5 | 66.85 | 1 | 7 |
| 27 | Pump not working on Auto mode / Remote | 1 | 6 | 20.40 | 5 | 47.5 | 146.8 | 1 | 6 | 9.6 | 5 | 33 |
| 28 | Motor inboard bearing is noisy | 0 | 0 | 0.00 | 2 | 50 | 132.6 | 2 | 6 | 20.2 | 0 | 0 |
| 29 | Motor outboard bearing is noisy | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30 | Level switch is not functioning / alarm standing | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31 | Motor current reading is low | 0 | 0 | 0.00 | 1 | 7.8 | 19.11 | 0 | 0 | 0 | 0 | 0 |
| 32 | Capacitor is is giving low readings | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33 | Smell is coming from Resistance box | 1 | 6 | 14.40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34 | Motor is tripping frequently | 0 | 0 | 0.00 | 0 | 0 | 0 | 1 | 17 | 44.7 | 0 | 0 |
| 35 | Motor is heating / high winding temperature | 2 | 35 | 93.80 | 1 | 8 | 24.4 | 1 | 4 | 8 | 5 | 36 |
| 36 | Speed cannot be controlled | 0 | 0 | 0.00 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 8 |
| 37 | Filed to start | 3 | 42.5 | 139.45 | 3 | 12 | 31.4 | 1 | 10 | 31 | 10 | 51.75 |
| | **Total** | 65 | 550.997 | 1775.95 | 58 | 807.3 | 2116.11 | 36 | 398.5 | 1902.29 | 41 | 379.51 |

| ? | Tower Pump # 1 | | | Tower Pump # 2 | | | Tower Pump # 3 | | | Other Comibnations | | | Total Summary | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost | Frequency | Time | Cost |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| 342.852 | 8 | 62.5 | 190.05 | 11 | 187.08 | 1008.88 | 8 | 80 | 219.675 | 0 | 0 | 0 | 57 | 649.17 | 2,356.81 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| 0 | 1 | 4 | 9.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 9.60 |
| 0 | 1 | 120 | 359.119 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 120 | 359.12 |
| 0 | 0 | 0 | 0 | 1 | 35 | 101.725 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 35 | 101.73 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 14 | 29 | 0 | 0 | 0 | 1 | 14 | 29.00 |
| 33.7 | 9 | 54 | 181.402 | 10 | 123.5 | 460.379 | 3 | 19 | 68 | 0 | 0 | 0 | 35 | 420.5 | 1,208.88 |
| 22.75 | 4 | 56 | 158.346 | 1 | 12 | 30 | 1 | 3 | 28.55 | 0 | 0 | 0 | 12 | 114.25 | 364.75 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 360.417 | 913.85 |
| 77.4 | 1 | 2.5 | 6 | 1 | 28 | 79.8 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 223 | 573.35 |
| 73.05 | 4 | 16.5 | 28.9 | 5 | 28.5 | 50.2 | 1 | 2 | 2.9 | 1 | 4 | 11.4 | 23 | 136.5 | 257.40 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 10.8 | 0 | 0 | 0 | 1 | 4 | 10.80 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| 0 | 5 | 214 | 740.619 | 3 | 269 | 1518.95 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 483 | 2,259.57 |
| 0 | 4 | 85.5 | 334.456 | 1 | 14 | 39.8 | 6 | 187.81 | 889.456 | 0 | 0 | 0 | 11 | 287.31 | 1,263.71 |
| 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0.00 |
| 54.4 | 1 | 9 | 30.3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 25 | 84.70 |
| 0 | 0 | 0 | 0 | 1 | 75.5 | 272.906 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 75.5 | 272.91 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| 0 | 4 | 63 | 197.1 | 0 | 0 | 0 | 5 | 11 | 40.4 | 0 | 0 | 0 | 37 | 289 | 1,353.45 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 6.5 | 22.1 | 0 | 0 | 0 | 6 | 62.5 | 201.45 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 96 | 316.659 | 0 | 0 | 0 | 20 | 174 | 1,091.20 |
| 68.8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 64 | 167.60 |
| 25.9 | 7 | 26.75 | 94.7875 | 4 | 22 | 65.7 | 6 | 20.5 | 56.9 | 2 | 15 | 47.4 | 30 | 179.75 | 591.74 |
| 103.4 | 3 | 40 | 121.467 | 1 | 6.5 | 22.1 | 0 | 0 | 0 | 3 | 26 | 219.1 | 19 | 165 | 642.87 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 109.5 | 265.175 | 0 | 0 | 0 | 7 | 165.5 | 417.98 |
| 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 64 | 132.8 | 0 | 0 | 0 | 2 | 64 | 132.80 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 14 | 49.7 | 2 | 14 | 49.70 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 7.8 | 19.11 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.00 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 6 | 14.40 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 5.6 | 0 | 0 | 0 | 2 | 19 | 50.30 |
| 116.8 | 1 | 27 | 76.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 110 | 319.40 |
| 23.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 18.5 | 2 | 12 | 41.70 |
| 162.513 | 4 | 106 | 1000.51 | 1 | 27 | 76.4 | 0 | 0 | 0 | 0 | 0 | 0 | 22 | 249.25 | 1,441.28 |
| **1116.76** | **57** | **886.75** | **3529.06** | **42** | **828.08** | **3726.84** | **47** | **619.31** | **2088.01** | **9** | **63** | **346.1** | **355** | **4533.45** | **16,601.13** |

Appendix M

# Mean time between failure for leakage of gland packing defect

## Appendix M

## Mean time between failure for leakage of gland packing defect

**Assumption : Failure rate is constant for all pumps**

**Station: Hamala A2 GFS**

Type of defect: Gland Packing leakage

Equipment Name: West Riffa Pump #1

Frequency: 18

Table 1M – MTBF table for WR pump #1 at Hamala A2 GFS

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs | TTF (Hrs) in Ascending order | % Cumulative Percentage of failure (failure no. / Sample size) |
|---|---|---|---|---|---|
| 0 | 1-1-2005 | 0 | 0 | 0 | 0 |
| 1 | 26-1-2005 | 600 | 20 | 144 | 5.56 |
| 2 | 2-11-2005 | 6720 | 6 | 192 | 11.11 |
| 3 | 28-12-2005 | 1344 | 9.66 | 360 | 16.67 |
| 4 | 14-1-2006 | 408 | 6 | 408 | 22.22 |
| 5 | 8-4-2006 | 2016 | 24.5 | 408 | 27.78 |
| 6 | 14-11-2006 | 5280 | 95 | 576 | 33.33 |
| 7 | 26-12-2006 | 1008 | 1.5 | 576 | 38.89 |
| 8 | 12-3-2007 | 1824 | 6.34 | 600 | 44.44 |
| 9 | 29-3-2007 | 408 | 18 | 1008 | 50.00 |
| 10 | 4-9-2007 | 3816 | 33 | 1344 | 55.56 |
| 11 | 19-9-2007 | 360 | 6 | 1824 | 61.11 |
| 12 | 11-8-2008 | 7848 | 22 | 2016 | 66.67 |
| 13 | 4-9-2008 | 576 | 5.5 | 3816 | 72.22 |
| 14 | 28-9-2008 | 576 | 2.5 | 4464 | 77.78 |
| 15 | 6-10-2008 | 192 | 21 | 5280 | 83.33 |
| 16 | 12-10-2008 | 144 | 10 | 6720 | 88.89 |
| 17 | 16-4-2009 | 4464 | 12 | 7848 | 94.44 |
| 18 | 7-9-2011 | 20976 | 10 | 20976 | 100.00 |
| **Total** | | **58560** | **309** | | |

MTBF calculated = 58560 / 18 = 3253.33 Hrs

**MTBF from Weibull probability chart = 3400 Hrs**

MTTR = 309 / 18 = 17.16 Hrs

$\lambda$ = 1/ MTBF = 1/ 3253.33 = 0.0003 failure / hour

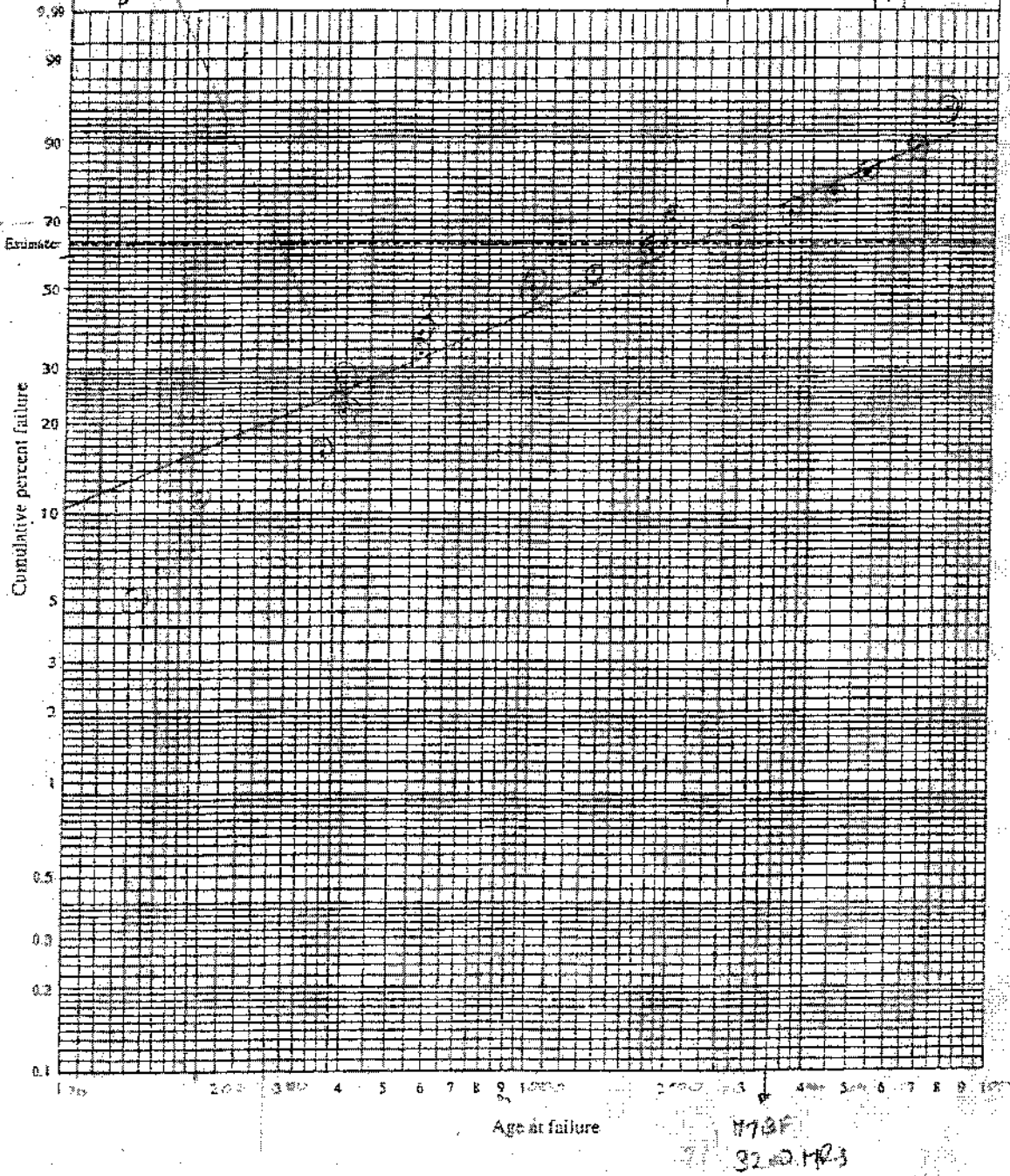
A = MTBF / MTBF÷MTTR = 3253.33 / 3253.33+17.16 = 0.995

Defect. Gland Packing Leakage.

Hamaker 42 GPS
VVR #1

Weibull probability by 3-cycle log

| Test Number | Article and source | Sample Size | N | 18 |
|---|---|---|---|---|
| Date | Type of test | Shape | β | 0.8 |
| $P_\mu$ 74 66 62 60 58 56 54 52 51 50 49 48 | Mean μ | Characteristic Life | η | 2100 |
| β 0.5 1 2 3 4 5 | | Minimum Life | γ | |




H78F
32.0 MR-3

**Station: Hamala A2 GFS**

Type of defects: Gland Packing leakage

Equipment Name: West Riff'a Pump #2

Frequency: 22

Table 2M – MTBF table for WR pump #2 at Hamala A2 GFS

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs | TTF (Hrs) in Ascending order | % Cumulative Percentage of failure (failure no. / Sample size) |
|---|---|---|---|---|---|
| 0 | 1-1-2005 | 0 | 0 | 0 | 0 |
| 1 | 3-11-2005 | 7344 | 2 | 24 | 4.55 |
| 2 | 20-1-2006 | 1872 | 6 | 72 | 9.09 |
| 3 | 2-6-2006 | 3648 | 5 | 96 | 13.64 |
| 4 | 3-9-2007 | 10536 | 10 | 96 | 18.18 |
| 5 | 25-11-2007 | 1992 | 10 | 120 | 22.73 |
| 6 | 25-12-2007 | 720 | 6 | 168 | 27.27 |
| 7 | 27-2-2008 | 1536 | 2 | 240 | 31.82 |
| 8 | 1-3-2008 | 72 | 54 | 312 | 36.36 |
| 9 | 1-5-2008 | 1464 | 6 | 408 | 40.91 |
| 10 | 29-5-2008 | 672 | 10 | 672 | 45.45 |
| 11 | 8-6-2008 | 240 | 4 | 720 | 50.00 |
| 12 | 9-6-2008 | 24 | 4 | 1464 | 54.55 |
| 13 | 13-6-2008 | 96 | 3 | 1536 | 59.09 |
| 14 | 17-6-2008 | 96 | 34 | 1584 | 63.64 |
| 15 | 24-3-2009 | 6720 | 10.5 | 1872 | 68.18 |
| 16 | 6-4-2009 | 312 | 9 | 1992 | 72.73 |
| 17 | 11-4-2009 | 120 | 7 | 3648 | 77.27 |
| 18 | 28-4-2009 | 408 | 0 | 6696 | 81.82 |
| 19 | 5-5-2009 | 168 | 0 | 6720 | 86.36 |
| 20 | 10-7-2009 | 1584 | 14 | 7344 | 90.91 |
| 21 | 15-4-2010 | 6696 | 6 | 10536 | 95.45 |
| 22 | 17-7-2011 | 10992 | 13.5 | 10992 | 100.00 |
| **Total** | | **57312** | **216** | | |

MTBF calculated = 47312 / 22 = 2605.09 Hrs

**MTBF from Weibull probability chart = 2600 Hrs**

MTTR = 216 / 22 = 9.82 Hrs

$\lambda$ = 1/ MTBF = 1/ 2605.09 = 0.00038 failure / hour

A = MTBF / MTBF+MTTR = 2605.09 / 2605.09÷9.82 = 0.996

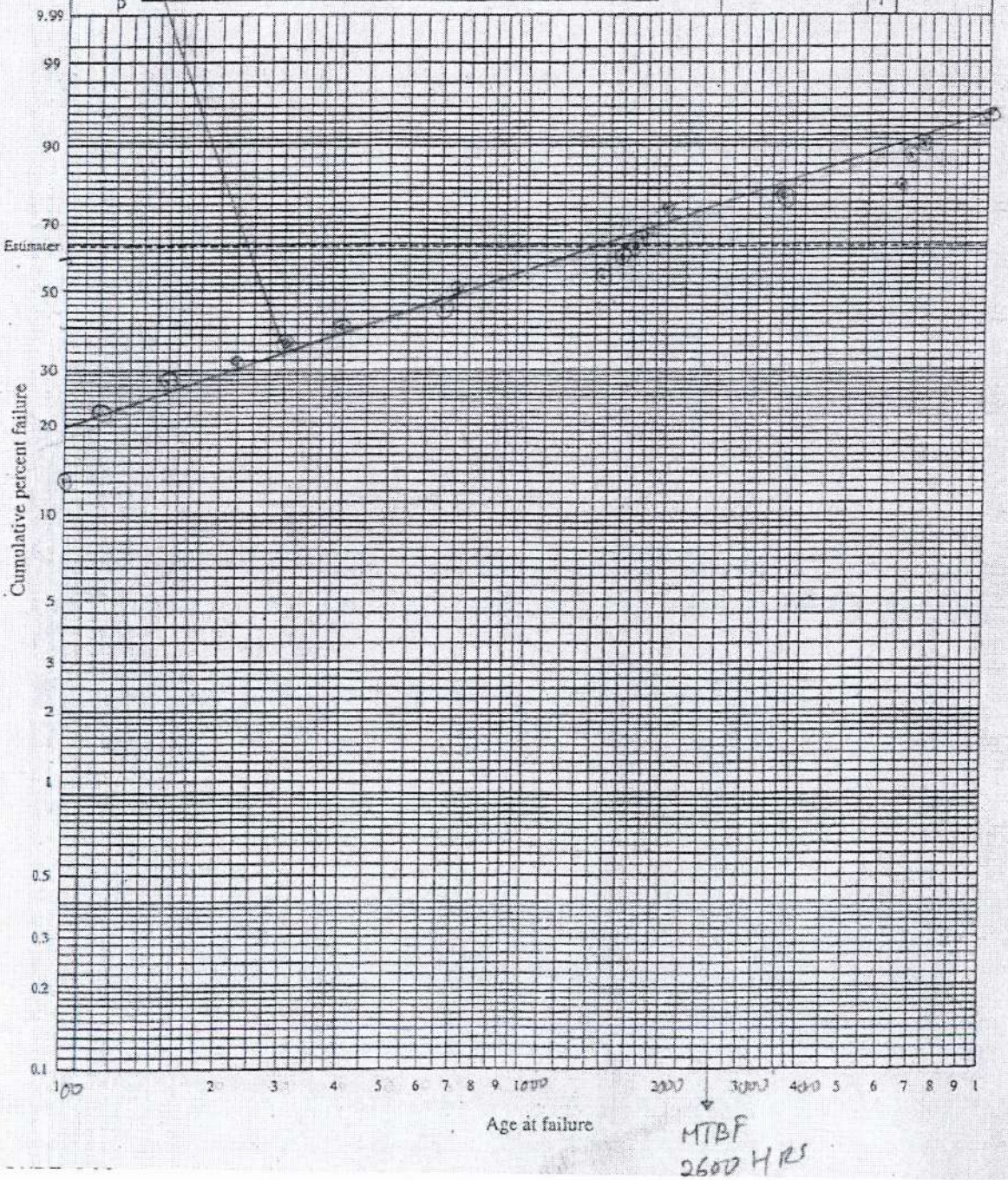
Defect: Gland Packing Leakage.

Hamala A2 GFS

WR #2

Weibull probability by 2-cycle log

| Test Number | Article and source | Sample Size | N | 22 |
|---|---|---|---|---|
| Date | Type of test | Shape | $\hat{\beta}$ | 0.7 |
| $P_\mu$ 74 66 62 60 58 56 54 52 51 50 49 48 | Mean $\hat{\mu}$ | Characteristic Life | $\hat{\eta}$ | 1200 |
| $\hat{\beta}$ 0.5 1 2 3 4 5 | | Minimum Life | $\hat{\gamma}$ | |



**Station: Hamala A2 GFS**

Type of defects: Gland Packing leakage

Equipment Name: West Riff'a Pump #3

Frequency: 19

Table 3M – MTBF table for WR pump #3 at Hamala A2 GFS

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs | TTF (Hrs) in Ascending order | % Cumulative Percentage of failure (failure no. / Sample size) |
|---|---|---|---|---|---|
| 0 | 1-1-2005 | 0 | 0 | 0 | 0 |
| 1 | 15-1-2005 | 336 | 28 | 216 | 5.26 |
| 2 | 15-2-2005 | 744 | 0 | 312 | 10.53 |
| 3 | 2-11-2005 | 6240 | 2 | 336 | 15.79 |
| 4 | 21-6-2006 | 5544 | 58.5 | 360 | 21.05 |
| 5 | 3-10-2006 | 2496 | 5 | 360 | 26.32 |
| 6 | 18-10-2006 | 360 | 5 | 408 | 31.58 |
| 7 | 7-3-2007 | 3360 | 19.5 | 744 | 36.84 |
| 8 | 25-11-2007 | 6312 | 14 | 744 | 42.11 |
| 9 | 8-12-2007 | 312 | 38.5 | 816 | 47.37 |
| 10 | 17-6-2008 | 4608 | 34 | 912 | 52.63 |
| 11 | 21-7-2008 | 816 | 12 | 1776 | 57.89 |
| 12 | 28-8-2008 | 912 | 3.5 | 2040 | 63.16 |
| 13 | 14-9-2008 | 408 | 1.5 | 2496 | 68.42 |
| 14 | 29-9-2008 | 360 | 7 | 3360 | 73.68 |
| 15 | 30-10-2008 | 744 | 8 | 4608 | 78.95 |
| 16 | 23-1-2009 | 2040 | 6 | 5544 | 84.21 |
| 17 | 7-4-2009 | 1776 | 12 | 6240 | 89.47 |
| 18 | 6-2-2010 | 7320 | 1 | 6312 | 94.74 |
| 19 | 15-2-2010 | 216 | 24 | 7320 | 100.00 |
| **Total** | | **44904** | **279.5** | | |

MTBF calculated = 44904 / 19 = 2363.38 Hrs

**MTBF from Weibull probability chart = 2200 Hrs**

MTTR = 279.5 / 19 = 14.7 Hrs

$\lambda$ = 1/ MTBF = 1/ 2363.38 = 0.00043 failure / hour

A = MTBF / MTBF+MTTR = 2363.38 /2363.8+14.7 = 0.994

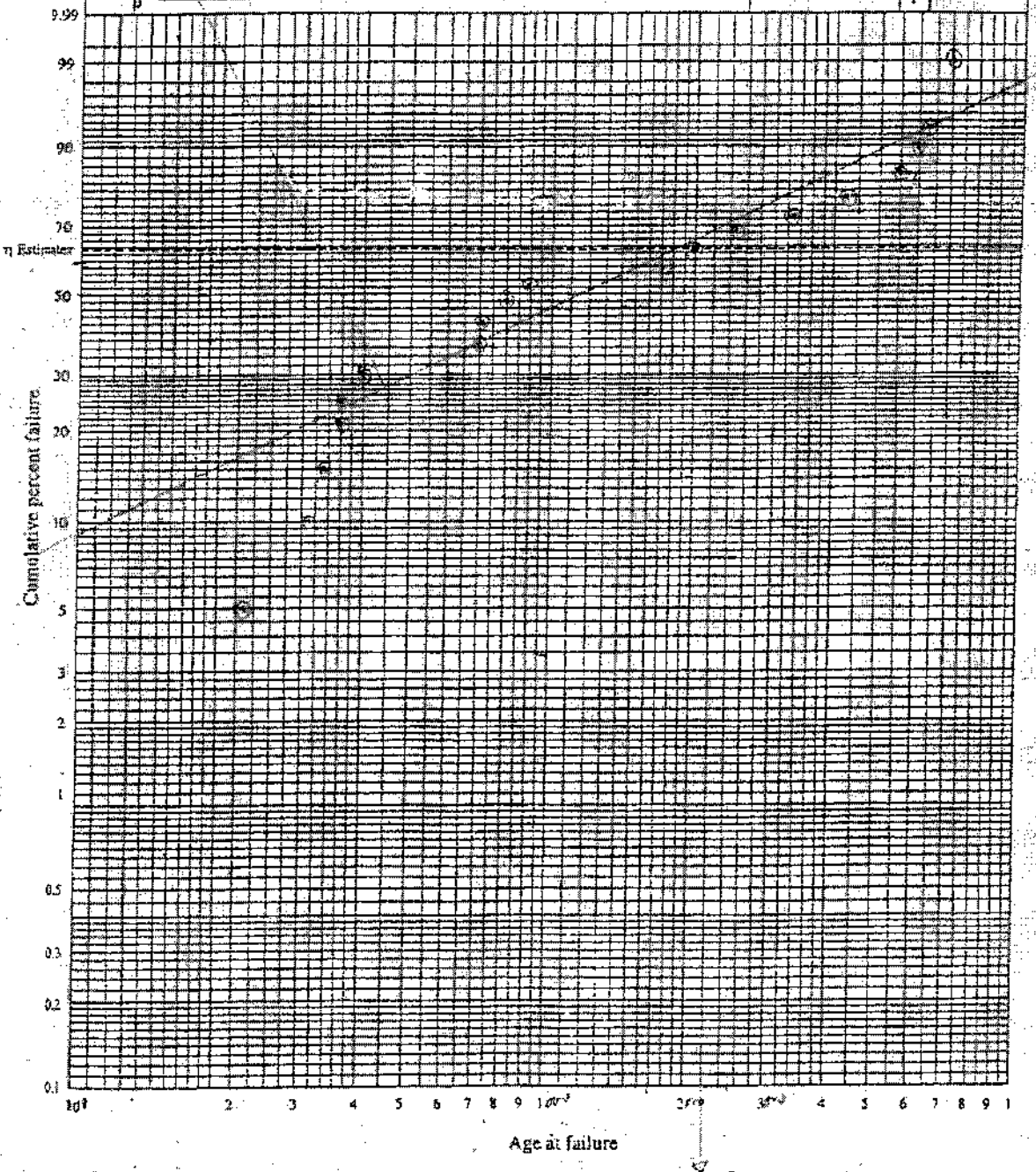
Defect: Gland Packing Leakage

Hamaka A2 GDS

WO #3

Weibull probability by 2-cycle log

| Test Number | Article and source | Sample Size | N | 20 |
|---|---|---|---|---|
| Date | Type of test | Shape | $\hat{\beta}$ | 0.85 |
| $\Gamma_{\hat{\mu}}$ 70 66 62 60 58 56 54 52 51 50 47 46 | Mean $\hat{\mu}$ | Characteristic Life | $\hat{\eta}$ | 310 |
| $\hat{\beta}$ 0.5 1 2 3 4 5 | | Minimum Life | $\hat{\gamma}$ | |




H 19E 2200 HRS

**Station: Hamad Town blending station**

Type of defects: Gland Packing leakage

Equipment Name: Distillate water pump #1

Frequency: 12

Table 4M – MTBF table for DW pump #1 at HTBS

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs | TTF (Hrs) in Ascending order | % Cumulative Percentage of failure (failure no. / Sample size) |
|---|---|---|---|---|---|
| 0 | 1-1-2005 | 0 | 0 | 0 | 0 |
| 1 | 14-1-2005 | 312 | 92.5 | 0 | 8.33 |
| 2 | 6-2-2005 | 552 | 12 | 96 | 16.67 |
| 3 | 1-10-2005 | 5688 | 3 | 312 | 25.00 |
| 4 | 26-10-2005 | 600 | 5.25 | 552 | 33.33 |
| 5 | 30-10-2005 | 96 | 32 | 600 | 41.67 |
| 6 | 7-5-2006 | 4536 | 13 | 888 | 50.00 |
| 7 | 7-7-2006 | 1464 | 11.25 | 1464 | 58.33 |
| 8 | 28-10-2006 | 2712 | 8 | 2712 | 66.67 |
| 9 | 28-10-2006 | 0 | 5 | 4152 | 75.00 |
| 10 | 19-4-2007 | 4152 | 14 | 4536 | 83.33 |
| 11 | 17-5-2007 | 888 | 29 | 5688 | 91.67 |
| 12 | 25-3-2010 | 25032 | 4.5 | 25032 | 100.00 |
| **Total** | | **46032** | **229.5** | | |

MTBF calculated = 46032 / 12 = 3836 Hrs

**MTBF from Weibull probability chart = 3800 Hrs**

MTTR = 229.5 / 12 = 19.125 Hrs

$\lambda$ = 1/ MTBF = 1/ 3836 = 0.00026 failure / hour

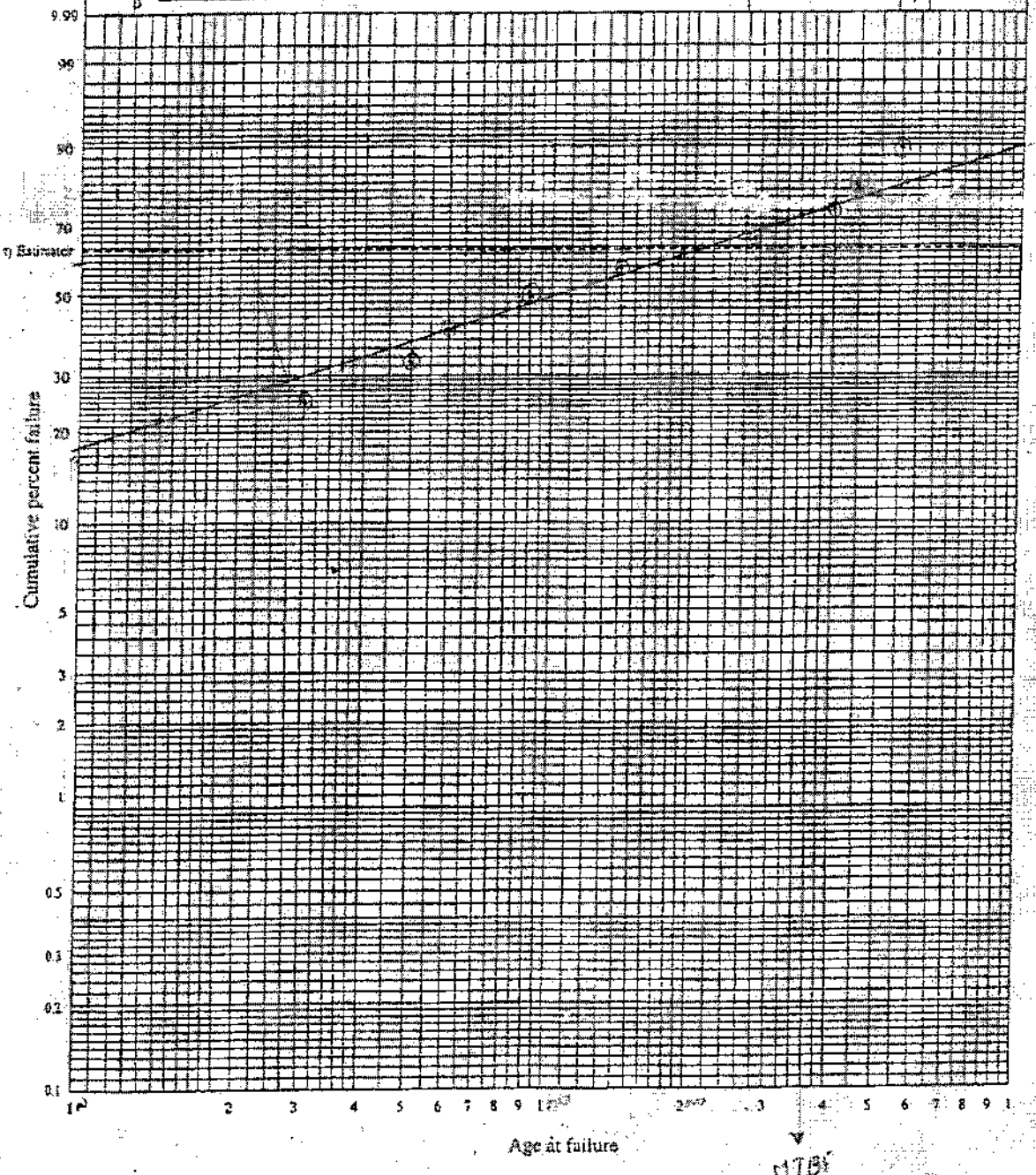
A = MTBF / MTBF+MTTR = 3836 /3836+19.125 = 0.995

Detail: Gland Sealing Package

1-1TBS
DW pump #1

Weibull probability by 2-cycle log

| | | | |
|---|---|---|---|
| Test Number | Article and source | Sample Size N | 13 |
| Date | Type of test | Shape β | 0.6 |
| $P_{\hat{\mu}}$ 74 66 62 60 58 56 54 52 51 50 49 48 | Mean $\hat{\mu}$ | Characteristic Life $\hat{\eta}$ | |
| $\hat{\beta}$ 0.5 1 2 3 4 5 | | Minimum Life $\hat{\gamma}$ | |



**Station: Hamad Town blending station**

Type of defects: Gland Packing leakage

Equipment Name: Hamad Town Distribution pump #2

Frequency: 6

Table 5M – MTBF table for HTD pump # 2 at HTBS

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs | TTF (Hrs) in Ascending order | % Cumulative Percentage of failure (failure no. / Sample size) |
|---|---|---|---|---|---|
| 0 | 1-1-2005 | 0 | 0 | 0 | 0 |
| 1 | 30-11-2006 | 16752 | 9 | 480 | 20.00 |
| 2 | 17-5-2007 | 4032 | 29 | 1680 | 40.00 |
| 3 | 17-1-2008 | 5880 | 4 | 4032 | 60.00 |
| 4 | 27-3-2008 | 1680 | 4.5 | 5880 | 80.00 |
| 5 | 16-4-2008 | 480 | 10 | 16752 | 100.00 |
| **Total** | | **28824** | **56.5** | | |

MTBF calculated = 28824 / 5= 5764.8 Hrs

**MTBF from Weibull probability chart = 4000 Hrs**

MTTR = 56.5 / 5 = 11.3 Hrs

$\lambda$ = 1/ MTBF = 1/ 5764.8 = 0.00017 failure / hour

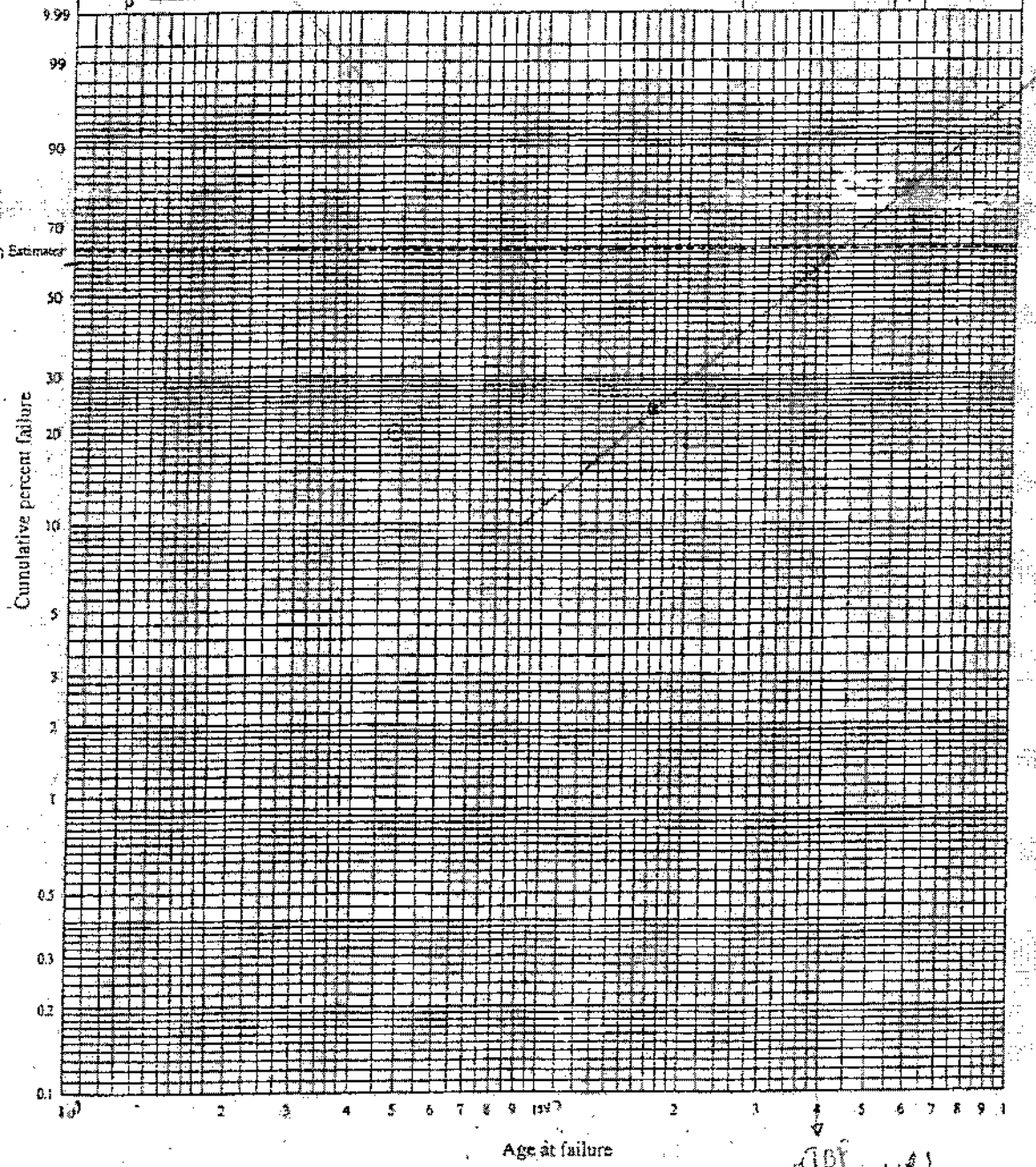
A = MTBF / MTBF+MTTR = 5764.8 /5764.8+9.3 = 0.998

H7BS

H70 pump #2

Weibull probability by 2-cycle log

| Test Number | Article and source | Sample Size | N | 5 |
|---|---|---|---|---|
| Date | Type of test | Shape | $\hat{\beta}$ | 1.7 |
| $P_\mu$ 74 66 62 60 58 56 54 52 51 50 49 48 | Mean | $\hat{\mu}$ | Characteristic Life | $\hat{\eta}$ | 860 |
| $\hat{\beta}$ 0.5 1 2 3 4 5 | Minimum Life | $\hat{\gamma}$ | |




H7BS
H70 H#2

**Station: Hamad Town blending station**

Type of defects: Gland Packing leakage

Equipment Name: Ground water pump #2

Frequency: 8

Table 6M – MTBF table for GW pump #2 at HTBS

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs | TTF (Hrs) in Ascending order | % Cumulative Percentage of failure (failure no. / Sample size) |
|---|---|---|---|---|---|
| 0 | 1-1-2005 | 0 | 0 | 0 | 0 |
| 1 | 1-10-2005 | 6552 | 2 | 2712 | 12.50 |
| 2 | 17-4-2006 | 4752 | 14 | 4368 | 25.00 |
| 3 | 8-8-2006 | 2712 | 13 | 4752 | 37.50 |
| 4 | 17-5-2007 | 6768 | 29 | 4872 | 50.00 |
| 5 | 22-3-2008 | 7440 | 3 | 6552 | 62.50 |
| 6 | 1-7-2010 | 19944 | 9 | 6768 | 75.00 |
| 7 | 30-12-2010 | 4368 | 6 | 7440 | 87.50 |
| 8 | 21-7-2011 | 4872 | 3 | 19944 | 100.00 |
| **Total** | | **57408** | **79** | | |

MTBF calculated = 57408 / 8 = 7176 Hrs

**MTBF from Weibull probability chart = 6400 Hrs**

MTTR = 79 / 8 = 9.875 Hrs

$\lambda$ = 1/ MTBF = 1/ 7176 = 0.00014 failure / hour

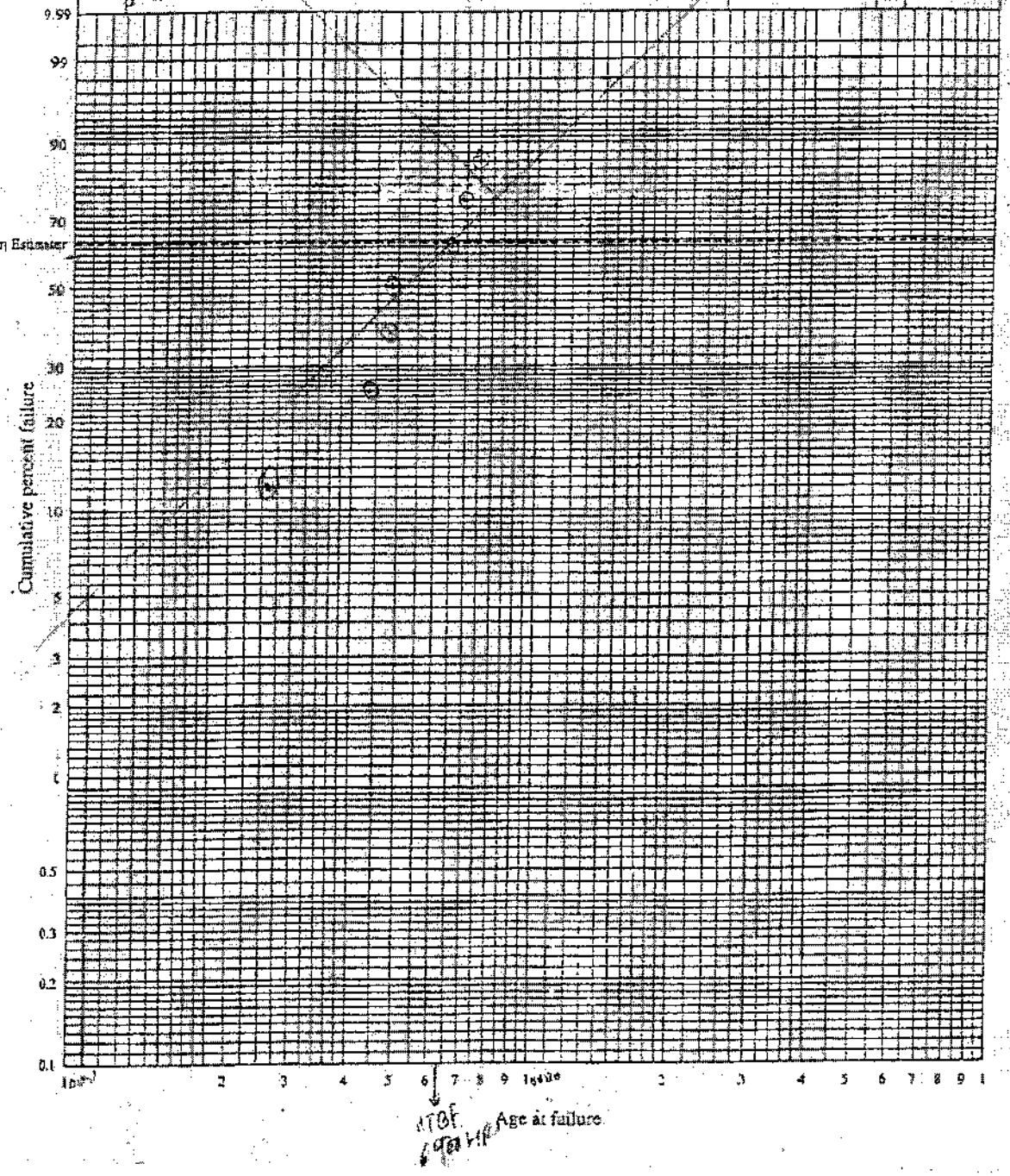
A = MTBF / MTBF+MTTR = 7176 /7176+9.875 = 0.998

Detail : Ground parking leaking.

HTB
GW pump #2

Weibull probability by 2-cycle log

| Test Number | Article and source | Sample Size | N | 9 |
|---|---|---|---|---|
| Date | Type of test | Shape | β | 1.8 |
| $P_y$ 70 66 62 60 58 56 54 52 51 50 49 48 Mean | | Characteristic Life | η | 6500 |
| β 0.5 1 2 3 4 5 | | Minimum Life | γ | |



**Station: West Riff'a # 1 BS**

Type of defects: Gland Packing leakage

Equipment Name: Distillate water pump #1

Frequency: 4

Table 7M – MTBF table for DW pump #1 at WR #1 BS

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs | TTF (Hrs) in Ascending order | % Cumulative Percentage of failure (failure no. / Sample size) |
|---|---|---|---|---|---|
| 0 | 1-1-2005 | 0 | 0 | 0 | 0 |
| 1 | 9-10-2005 | 6744 | 6 | 2928 | 25.00 |
| 2 | 24-9-2006 | 8400 | 12 | 6744 | 50.00 |
| 3 | 24-1-2007 | 2928 | 16 | 8400 | 75.00 |
| 4 | 10-4-2011 | 36888 | 0 | 36888 | 100.00 |
| **Total** | | **54960** | **34** | | |

MTBF calculated = 54960 / 4 = 13740 Hrs

**MTBF from Weibull probability chart = 7400 Hrs**

MTTR = 34 / 4 = 8.5 Hrs

$\lambda$ = 1/ MTBF = 1/ 13740 = 0.000072 failure / hour

A = MTBF / MTBF+MTTR = 13740 / 13740+8.5 = 0.999

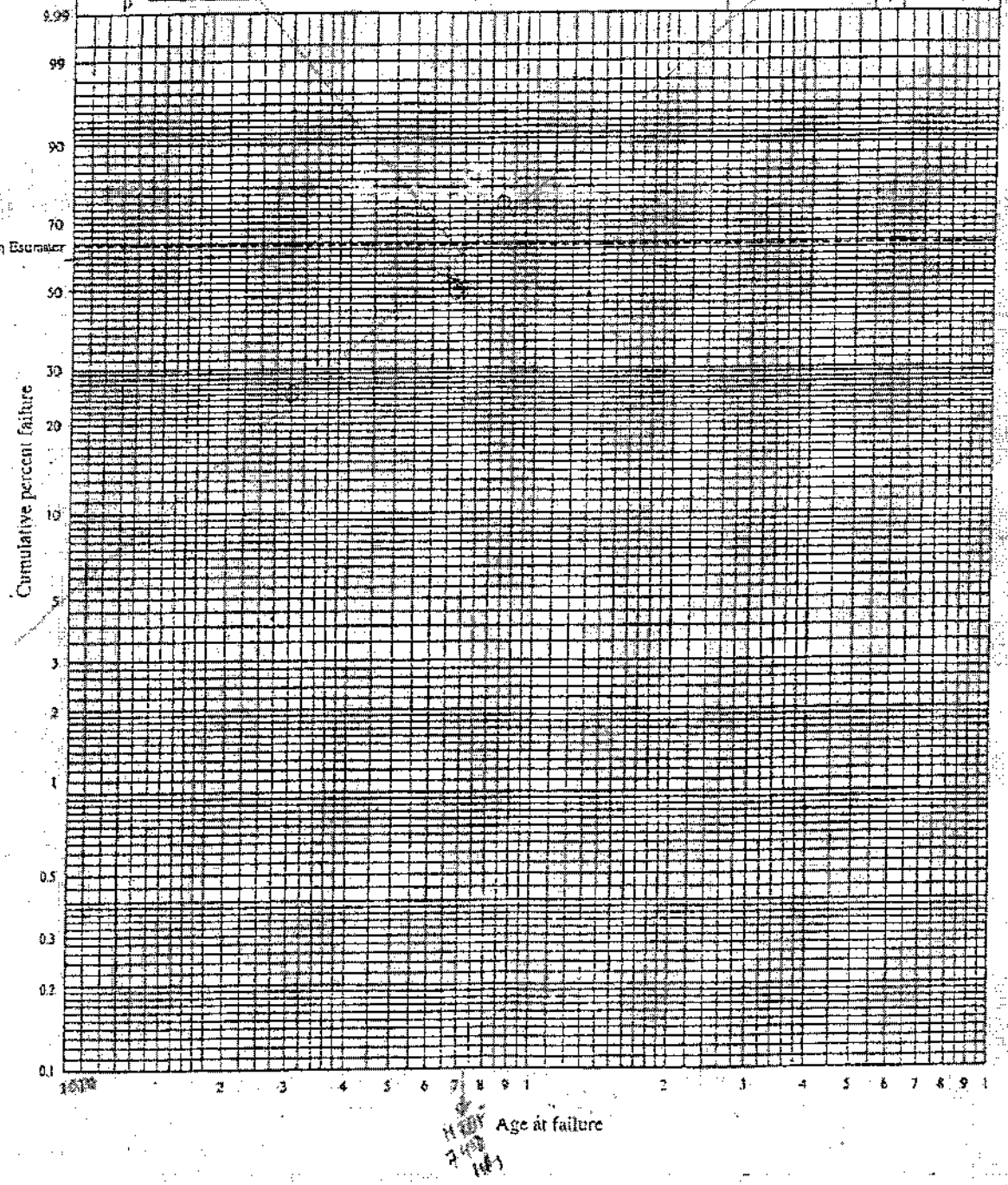
Reject: Gland Packing Leaking

MR #165

DW pump #1

Weibull probability by 2-cycle log

| Test Number | Article and source | Sample Size | N | 41 |
|---|---|---|---|---|
| Date | Type of test | Shape | β | 1.5 |
| $P_\mu$ 74 66 62 60 58 56 54 52 51 50 49 48 | Median | Characteristic Life | η | 7500 |
| β 0.5 1 2 3 4 5 | Minimum Life | | γ | |



**Station: West Riff'a # 1 BS**

Type of defects: Gland Packing leakage

Equipment Name: East tower pump #2

Frequency: 19

Table 8M – MTBF table for East tower pump #2 at WR #1 BS

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs | TTF (Hrs) in Ascending order | % Cumulative Percentage of failure (failure no. / Sample size) |
|---|---|---|---|---|---|
| 0 | 1-1-2005 | 0 | 0 | 0 | 0 |
| 1 | 29-4-2006 | 11592 | 13 | 0 | 5.56 |
| 2 | 22-5-2006 | 552 | 2 | 24 | 11.11 |
| 3 | 17-11-2008 | 21840 | 6.33 | 264 | 16.67 |
| 4 | 4-12-2008 | 408 | 6 | 264 | 22.22 |
| 5 | 14-1-2009 | 984 | 14 | 312 | 27.78 |
| 6 | 14-1-2009 | 0 | 14 | 408 | 33.33 |
| 7 | 27-1-2009 | 312 | 5 | 552 | 38.89 |
| 8 | 28-2-2009 | 768 | 12 | 672 | 44.44 |
| 9 | 21-4-2009 | 1248 | 13 | 768 | 50.00 |
| 10 | 18-6-2009 | 1392 | 1 | 912 | 55.56 |
| 11 | 24-9-2010 | 11112 | 4 | 984 | 61.11 |
| 12 | 5-10-2010 | 264 | 10 | 1248 | 66.67 |
| 13 | 28-11-2010 | 1296 | 6 | 1296 | 72.22 |
| 14 | 5-1-2011 | 912 | 6 | 1392 | 77.78 |
| 15 | 16-1-2011 | 264 | 10 | 2592 | 83.33 |
| 16 | 4-5-2011 | 2592 | 12 | 11112 | 88.89 |
| 17 | 1-6-2011 | 672 | 5 | 11592 | 94.44 |
| 18 | 2-6-2011 | 24 | 0 | 21840 | 100.00 |
| **Total** | | **56232** | **139.33** | | |

MTBF calculated = 56232 / 18 = 3124 Hrs

**MTBF from Weibull probability chart = 2400 Hrs**

MTTR = 139.33 / 18 = 7.74 Hrs

$\lambda$ = 1/ MTBF = 1/ 3124 = 0.00032 failure / hour

A = MTBF / MTBF+MTTR = 3124 / 3124+7.74 = 0.997

Weibull probability by 2-cycle log

| Test Number | Article and source | Sample Size | N | 18 |
|---|---|---|---|---|
| Date | Type of test | Shape | β | 0.65 |
| | | Characteristic Life | η | 1250 |
| | | Minimum Life | γ | |

Cumulative percent failure

99.9
99
90
70
50
30
20
10
5
3
2
1
0.5
0.3
0.2

**Station: West Riff'a # 1 BS**

Type of defects: Gland Packing leakage

Equipment Name: East tower pump #1

Frequency: 10

Table 9M – MTBF table for East tower pump #1 at WR #1 BS

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs | TTF (Hrs) in Ascending order | % Cumulative Percentage of failure (failure no. / Sample size) |
|---|---|---|---|---|---|
| 0 | 1-1-2005 | 0 | 0 | 0 | 0 |
| 1 | 21-3-2006 | 10656 | 3.5 | 264 | 10.00 |
| 2 | 1-4-2006 | 264 | 15 | 456 | 20.00 |
| 3 | 24-4-2006 | 552 | 4.5 | 552 | 30.00 |
| 4 | 22-5-2006 | 672 | 5 | 672 | 40.00 |
| 5 | 23-4-2008 | 16848 | 1.25 | 1536 | 50.00 |
| 6 | 26-8-2008 | 3000 | 12 | 2472 | 60.00 |
| 7 | 29-10-2008 | 1536 | 7 | 3000 | 70.00 |
| 8 | 17-11-2008 | 456 | 11 | 10656 | 80.00 |
| 9 | 28-2-2009 | 2472 | 12 | 15456 | 90.00 |
| 10 | 4-12-2010 | 15456 | 4 | 16848 | 100.00 |
| **Total** | | **51912** | **75.25** | | |

MTBF calculated = 51912 / 10 = 5191.2 Hrs

**MTBF from Weibull probability chart = 5000 Hrs**

MTTR = 75.25 / 10 = 7.025 Hrs

$\lambda$ = 1/ MTBF = 1/ 5191.2 = 0.00019 failure / hour

A = MTBF / MTBF+MTTR = 5191.2 / 5191.2+75.25 = 0.998

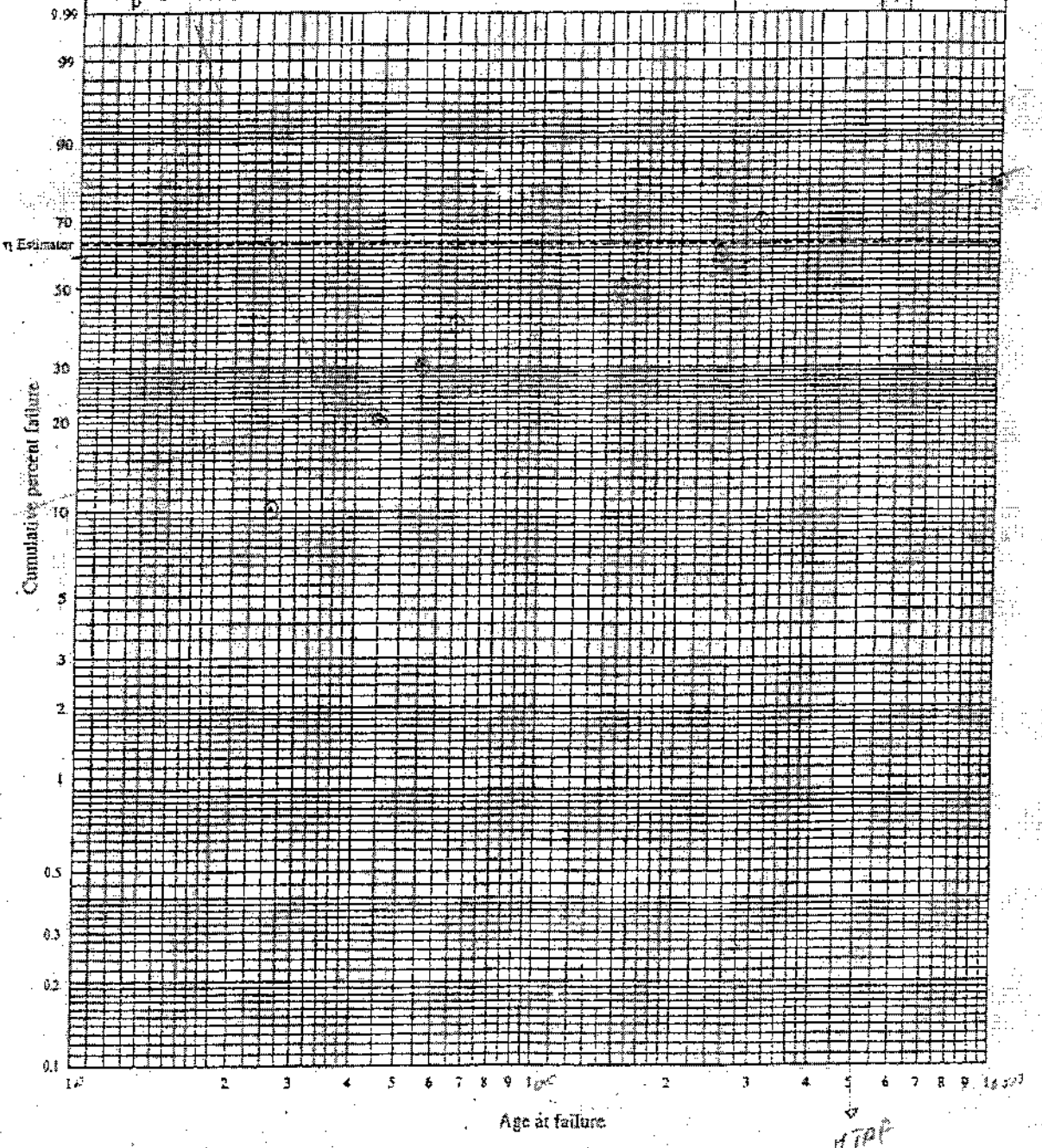
Defect Gland Packing Leaking

West Refit #1

Cast Tower #1

Weibull probability by 2-cycle log

| | | | |
|---|---|---|---|
| Test Number | Article and source | Sample Size N | 10 |
| Date | Type of test | Shape β | 0.25 |
| $P_\mu$ 74 69 63 60 58 56 54 52 51 50 49 48 Mean μ | | Characteristic Life η | 4000 |
| β 0.5 1 2 3 4 5 | | Minimum Life γ | |



**Station: West Riff'a # 2 BS**

Type of defects: Gland Packing leakage

Equipment Name: Distillate water pump #1

Frequency: 11

Table 10M – MTBF table for DW pump #1 at WR #2 BS

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs | TTF (Hrs) in Ascending order | % Cumulative Percentage of failure (failure no. / Sample size) |
|---|---|---|---|---|---|
| 0 | 1-1-2005 | 0 | 0 | 0 | 0 |
| 1 | 10-7-2005 | 4560 | 4.5 | 24 | 9.09 |
| 2 | 23-10-2005 | 2520 | 8 | 192 | 18.18 |
| 3 | 23-11-2005 | 744 | 10.33 | 744 | 27.27 |
| 4 | 13-6-2008 | 22392 | 4 | 840 | 36.36 |
| 5 | 23-12-2008 | 4632 | 4 | 2520 | 45.45 |
| 6 | 27-1-2009 | 840 | 8 | 4368 | 54.55 |
| 7 | 6-8-2009 | 4584 | 4 | 4560 | 63.64 |
| 8 | 4-2-2010 | 4368 | 5 | 4584 | 72.73 |
| 9 | 15-2-2011 | 9024 | 7 | 4632 | 81.82 |
| 10 | 16-2-2011 | 24 | 7.5 | 9024 | 90.91 |
| 11 | 24-2-2011 | 192 | 4 | 22392 | 100.00 |
| **Total** | | **53880** | **66.33** | | |

MTBF = 53880 / 11 = 4898.2 Hrs

**MTBF from Weibull probability chart = 5000 Hrs**

MTTR = 66.33 / 11 = 6.03 Hrs

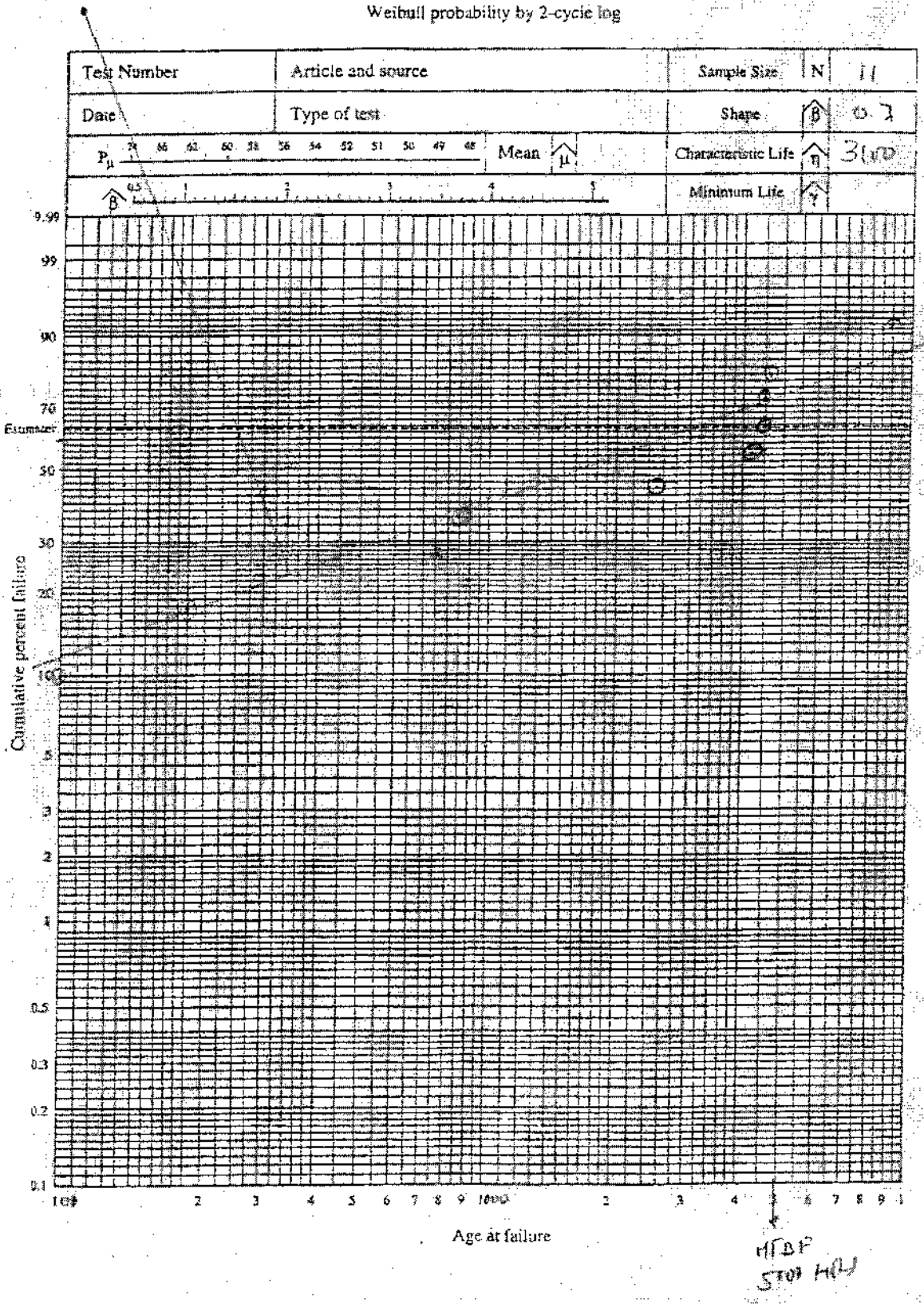
$\lambda$ = 1/ MTBF = 1/ 4898.2 = 0.0002 failure / hour

A = MTBF / MTBF+MTTR = 4898.2 / 4898.2+6.03 = 0.998

Default: Gland Packing Leakage.

West Bank #2 BS

DW pump #1



**Station: West Riff'a # 2 BS**

Type of defects: Gland Packing leakage

Equipment Name: Tower pump #2

Frequency: 11

Table 11M – MTBF table for tower pump #2 at WR #2 BS

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs | TTF (Hrs) in Ascending order | % Cumulative Percentage of failure (failure no. / Sample size) |
|---|---|---|---|---|---|
| 0 | 1-1-2005 | 0 | 0 | 0 | 0 |
| 1 | 5-10-2005 | 6648 | 6.83 | 1416 | 9.09 |
| 2 | 17-6-2006 | 6120 | 7 | 1800 | 18.18 |
| 3 | 16-11-2006 | 3648 | 6 | 2616 | 27.27 |
| 4 | 30-8-2007 | 6888 | 9.75 | 3192 | 36.36 |
| 5 | 17-12-2007 | 2616 | 5.5 | 3648 | 45.45 |
| 6 | 9-8-2008 | 5664 | 10 | 5664 | 54.55 |
| 7 | 23-10-2008 | 1800 | 8 | 6120 | 63.64 |
| 8 | 5-3-2009 | 3192 | 7 | 6288 | 72.73 |
| 9 | 3-5-2009 | 1416 | 0 | 6648 | 81.82 |
| 10 | 1-9-2010 | 11664 | 7 | 6888 | 90.91 |
| 11 | 21-5-2011 | 6288 | 126 | 11664 | 100.00 |
| **Total** | | **55944** | **193.08** | | |

MTBF = 55944 / 11 = 5085.8 Hrs

**MTBF from Weibull probability chart = 5100 Hrs**

MTTR = 193.08 / 11 = 17.55 Hrs

$\lambda$ = 1/ MTBF = 1/ 5085.8 = 0.00019 failure / hour

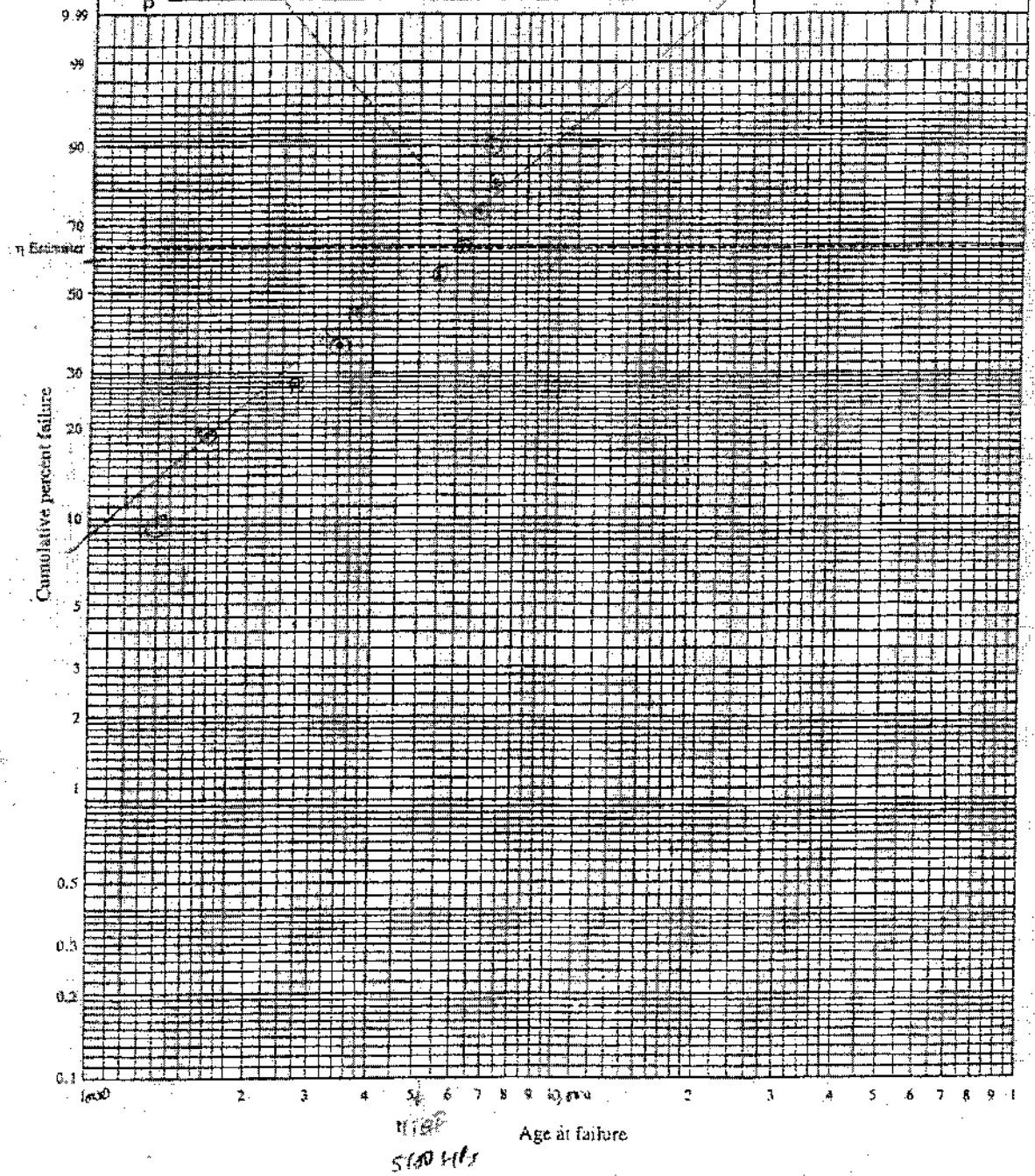
A = MTBF / MTBF+MTTR = 5080.8 / 5085.8+17.55 = 0.996

Default: Gland packing leaking

West RHR #2 BS
Tower pump #2

Weibull probability by 2-cycle log

| Test Number | Article and source | Sample Size N | 11 |
|---|---|---|---|
| Date | Type of test | Shape β | 1.5 |
| $P_{\hat{\mu}}$ .74 .66 .62 .60 .58 .56 .54 .52 .51 .50 .49 .48 | Mean $\hat{\mu}$ | Characteristic Life $\hat{\eta}$ | 5230 |
| $\hat{\beta}$ 0.5 1 2 3 4 5 | | Minimum Life $\hat{\gamma}$ | |




11 @ 5230 HRS

**Station: West Riff'a # 2 BS**

Type of defects: Gland Packing leakage

Equipment Name: Tower pump #3

Frequency: 8

Table 12M – MTBF table for tower pump #3 at WR #2 BS

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs | TTF (Hrs) in Ascending order | % Cumulative Percentage of failure (failure no. / Sample size) |
|---|---|---|---|---|---|
| 0 | 1-1-2005 | 0 | 0 | 0 | 0 |
| 1 | 23-9-2005 | 6360 | 13.5 | 0 | 12.50 |
| 2 | 22-10-2005 | 696 | 10 | 696 | 25.00 |
| 3 | 29-1-2006 | 2376 | 13 | 1200 | 37.50 |
| 4 | 29-1-2006 | 0 | 13 | 2376 | 50.00 |
| 5 | 20-3-2006 | 1200 | 6 | 6360 | 62.50 |
| 6 | 8-1-2007 | 7056 | 7 | 7056 | 75.00 |
| 7 | 22-4-2009 | 20040 | 13.5 | 7848 | 87.50 |
| 8 | 15-3-2010 | 7848 | 4 | 20040 | 100.00 |
| **Total** | | **45576** | **80** | | |

MTBF calculated = 45576 / 8 = 5697 Hrs

**MTBF from Weibull probability chart = 5500 Hrs**

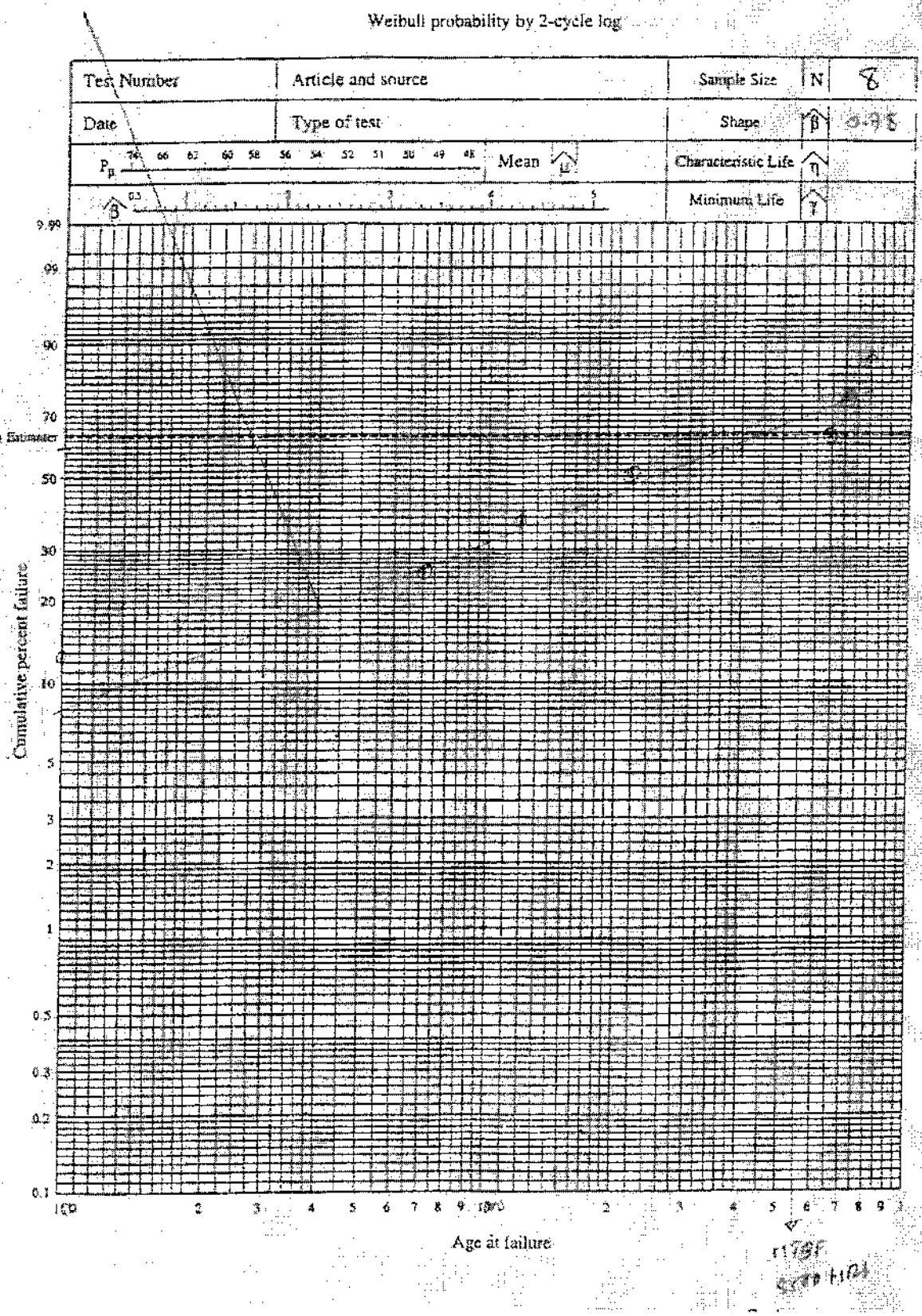
MTTR = 80 / 8 = 10 Hrs

$\lambda$ = 1/ MTBF = 1/ 5697 = 0.00017 failures / hour

A = MTBF / MTBF+MTTR = 5697 / 5697+10 = 0.998

Deck: Gland packing leakage

West Rifle #2 &
Tower pump #3



**Station: Hamad Town Distribution Station**

Type of defects: Gland Packing leakage

Equipment Name: Tower pump #1

Frequency: 2

Table 13M – MTBF table for tower pump #1 at HTDS

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs | TTF (Hrs) in Ascending order | % Cumulative Percentage of failure (failure no. / Sample size) |
|---|---|---|---|---|---|
| 0 | 1-1-2005 | 0 | 0 | 0 | 0 |
| 1 | 14-6-2006 | 12696 | 7 | 4992 | 50 |
| 2 | 8-1-2007 | 4992 | 10 | 12696 | 100 |
| **Total** | | **17688** | 17 | | |

MTBF calculated = 17688 / 2 = 8844 Hrs

**MTBF from Weibull probability chart = 5700 Hrs**

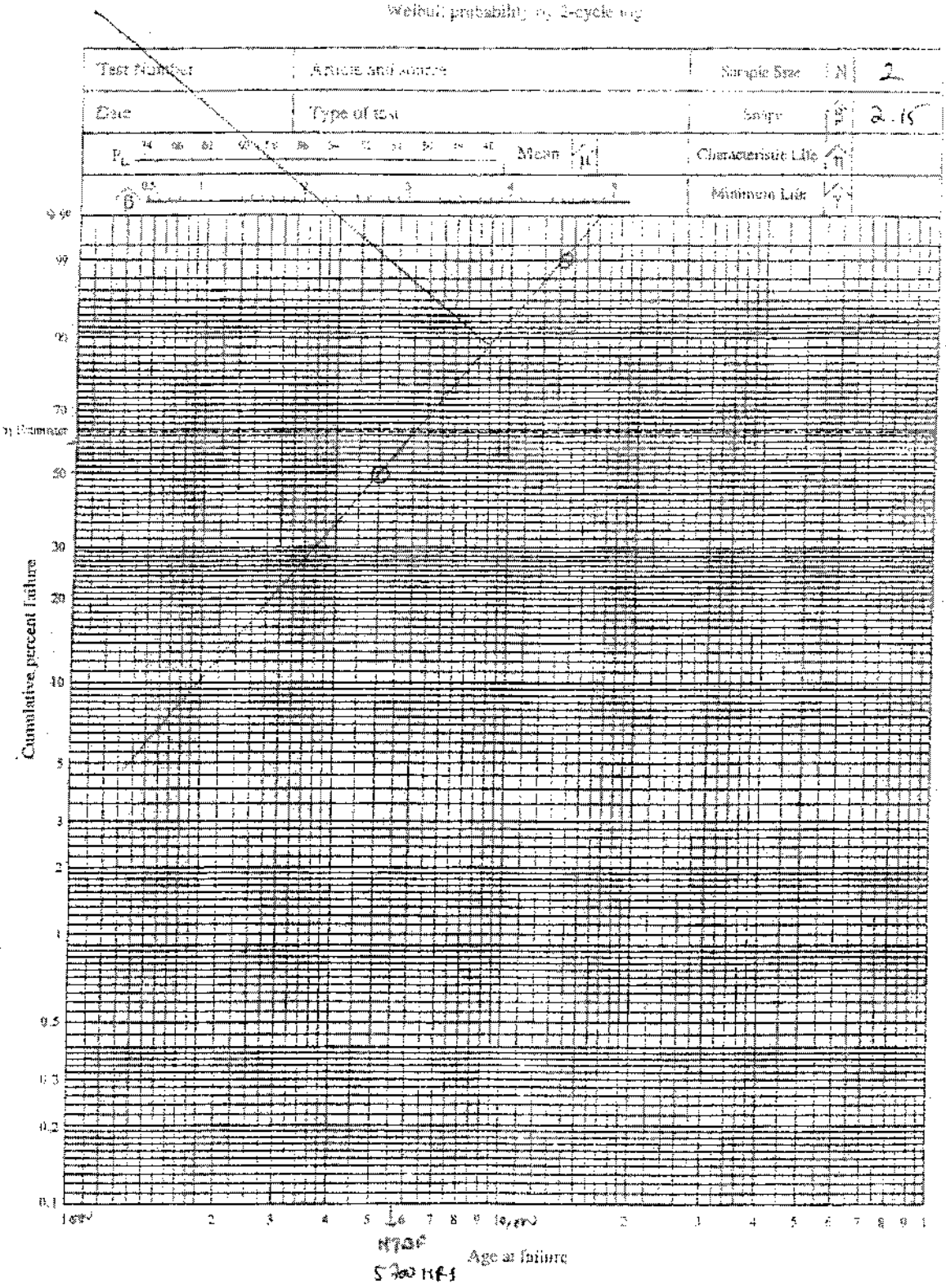
MTTR = 17 / 2 = 8.5 Hrs

$\lambda$ = 1/ MTBF = 1/ 8844 = 0.00011 failure / hour

A = MTBF / MTBF+MTTR = 8844 / 8844+8.5 = 0.999

Hamad Town Distribution

Towers pump #1



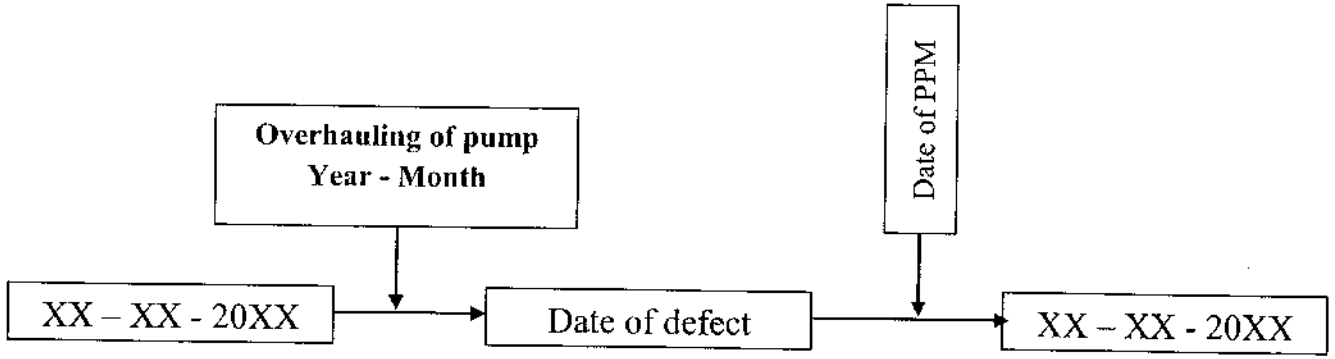
Appendix N

# Relationship between Preventive and corrective maintenance

**Appendix N**

**Relationship Between Planned Preventive maintenance of Pumps and Corrective Maintenance of Gland Packing Defects**

Legend:

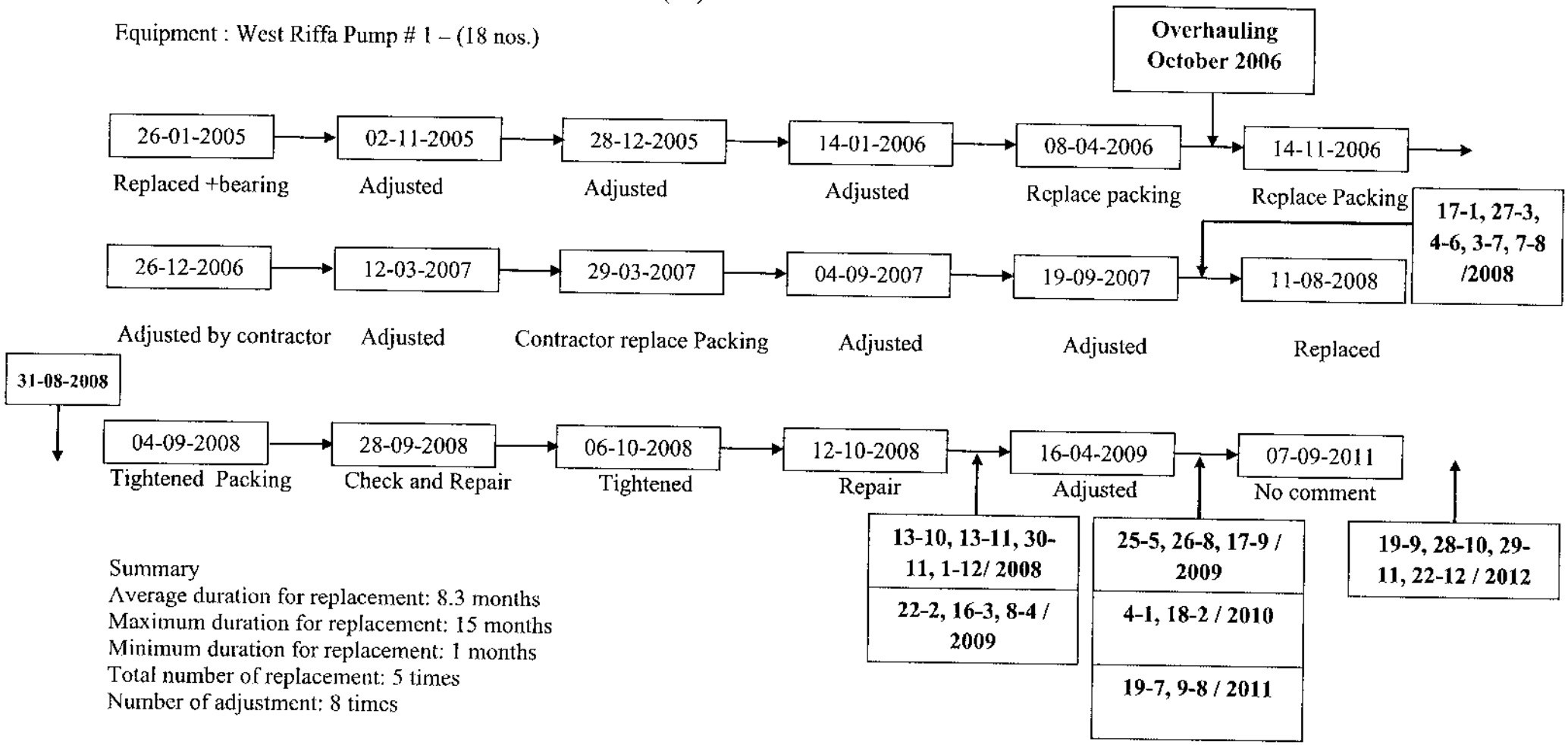



(Type of repair for defect) (Type of repair for defect)

Type of Defect: (Gland Packing of the pump is leaking),

Station :Hamala A2 GFS, total number of defects (81)

Equipment : West Riffa Pump # 1 – (18 nos.)




Summary
Average duration for replacement: 8.3 months
Maximum duration for replacement: 15 months
Minimum duration for replacement: 1 months
Total number of replacement: 5 times
Number of adjustment: 8 times

Table 1 N– Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for West Riff'a pump #1 at Hamala A2 GFS

| PPM task number | Duration between planned preventive maintenance | No of corrective actions for gland packing defect between PPM tasks |
|---|---|---|
| 1 | 17-1-2008 to 27-3-2008 | 0 |
| 2 | 27-3-2008 to 4-6-2008 | 0 |
| 3 | 4-6-2008 to 3-7-2008 | 0 |
| 4 | 3-7-2008 to 7-8-2008 | 0 |
| 5 | 7-8-2008 to 31-8-2008 | 1 |
| 6 | 31-8-2008 to 13-10-2008 | 4 |
| 7 | 13-10-2008 to 13-11-2008 | 0 |
| 8 | 13-11-2008 to 1-12-2008 | 0 |
| 9 | 1-12-2008 to 22-2-2009 | 0 |
| 10 | 22-2-2009 to 16-3-2009 | 0 |
| 11 | 16-3-2009 to 8-4-2009 | 0 |
| 12 | 8-4-2009 to 25-5-2009 | 1 |
| 13 | 25-5-2009 to 26-8-2009 | 0 |
| 14 | 26-8-2009 to 17-9-2009 | 0 |
| 15 | 17-9-2009 to 4-1-2010 | 0 |
| 16 | 4-1-2010 to 18-2-2010 | 0 |
| 17 | 18-2-2010 to 19-7-2011 | 0 |
| 18 | 19-7-2011 to 9-8-2011 | 0 |
| 19 | 9-8-2011 to 19-9-2011 | 1 |
| 20 | 19-9-2011 to 28-10-2011 | 0 |
| 21 | 28-10-2011 to 29-11-2011 | 0 |
| **Total** | **21** | **7** |

Explanation for Table 1N:

The first task for planned preventive maintenance for ground water pump #1 at Hamala A2 GFS implemented on 17 of January 2008 and on 27 March 2008 as per the planned schedule for mechanical maintenance section, there is no corrective action for gland packing between these two days, but for PPM task 6, there were four times of corrective action took place to repair the gland packing from leaking.

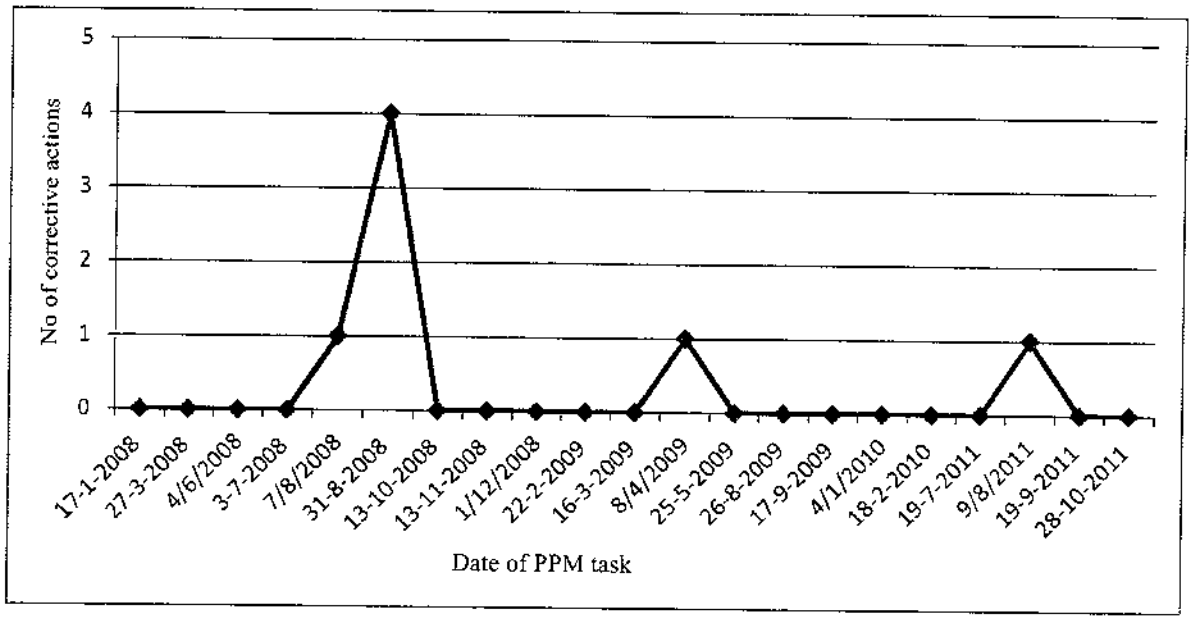


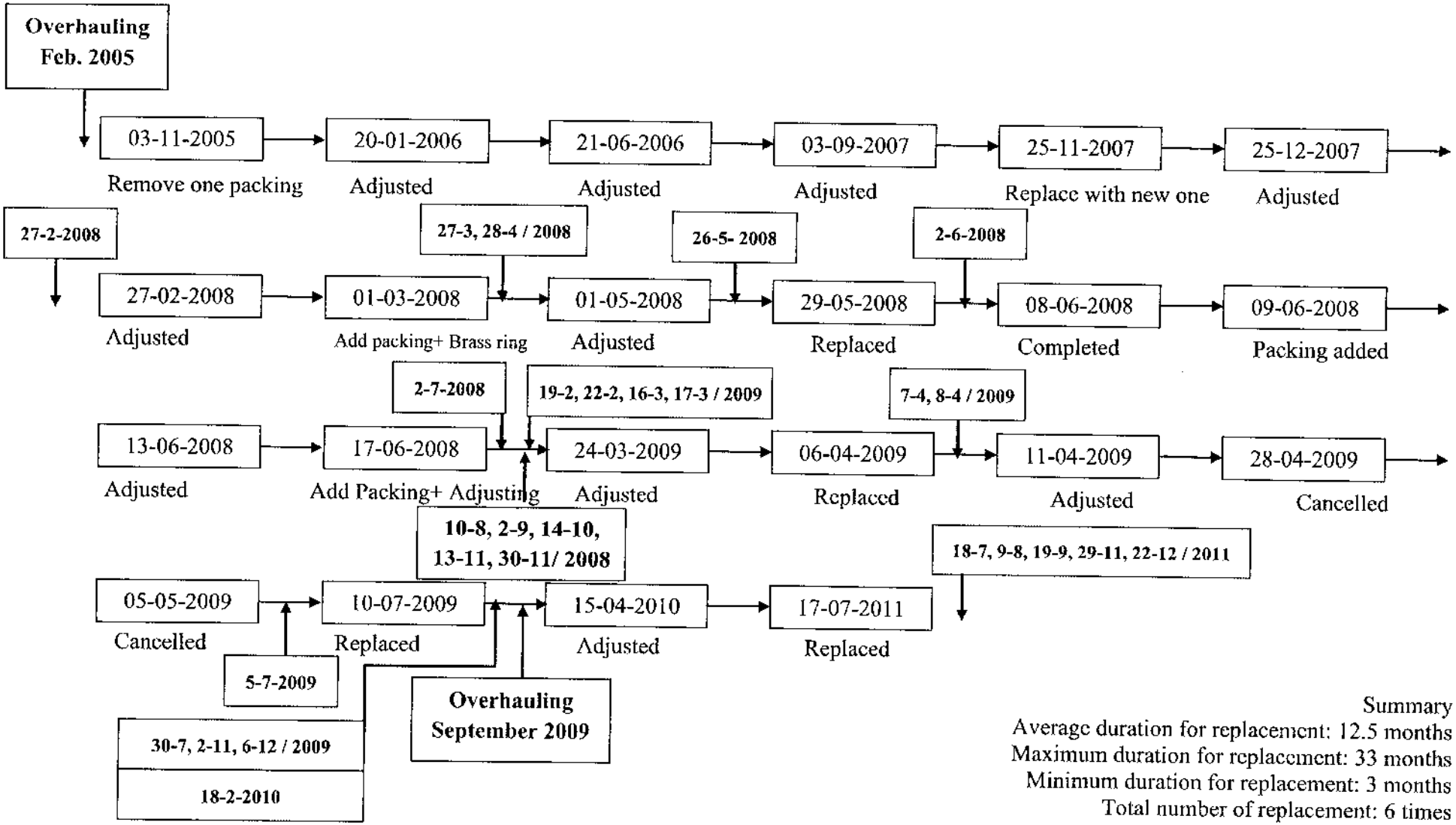

Chart 1 N - Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for West Riff'a pump #1 at Hamala A2 GFS

Explanation for Chart 1N:

The above chart is representation of Table 1 N, no corrective maintenace done from PPM task 1 which conducted on 17-01-2008 up to PPM task 4 which conducted on 3-7-2008, but from PPM task 6 to PPM task 7 (31-08-2008 to 13-10-2008), four corrective maintenance action carried out to repair gland packing.

Station :Hamala A2 GFS, total number of gland packing defects (81 )

Equipment : West Riffa Pump # 2 – (22 nos.)




Summary
Average duration for replacement: 12.5 months
Maximum duration for replacement: 33 months
Minimum duration for replacement: 3 months
Total number of replacement: 6 times
Number of adjustment: 11 times

Table 2 N– Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for West Riff'a pump #2 at Hamala A2 GFS

| PPM task number | Duration between planned preventive maintenance | No of corrective actions for gland packing defect between PPM tasks |
|---|---|---|
| 1 | 27-2-2008 to 27-3-2008 | 2 |
| 2 | 27-3-2008 to 28-4-2008 | 0 |
| 3 | 28-4-2008 to 26-5-2008 | 1 |
| 4 | 26-5-2008 to 2-6-2008 | 1 |
| 5 | 2-6-2008 to 2-7-2008 | 4 |
| 6 | 2-7-2008 to 10-8-2008 | 0 |
| 7 | 10-8-2008 to 2-9-2008 | 0 |
| 8 | 2-9-2008 to 14-10-2008 | 0 |
| 9 | 14-10-2008 to 13-11-2008 | 0 |
| 10 | 13-11-2008 to 30-11-2008 | 0 |
| 11 | 30-11-2008 to 19-2-2009 | 0 |
| 12 | 19-2-2009 to 22-2-2009 | 0 |
| 13 | 22-2-2009 to 16-3-2009 | 0 |
| 14 | 16-3-2009 to7-4-2009 | 2 |
| 15 | 7-4-2009 to 5-7-2009 | 3 |
| 16 | 5-7-2009 to 30-7-2009 | 1 |
| 17 | 30-7-2009 to 2-11-2009 | 0 |
| 18 | 2-11-2009 to 6-12-2009 | 0 |
| 19 | 6-12-2009 to 18-2-2010 | 0 |
| 20 | 18-2-2010 to 18-7-2011 | 2 |
| 21 | 18-7-2011 to 9-8-2011 | 0 |
| 22 | 9-8-2011 to 19-9-2011 | 0 |
| 23 | 19-9-2011 to 29-11-2011 | 0 |
| **Total** | **23** | **16** |

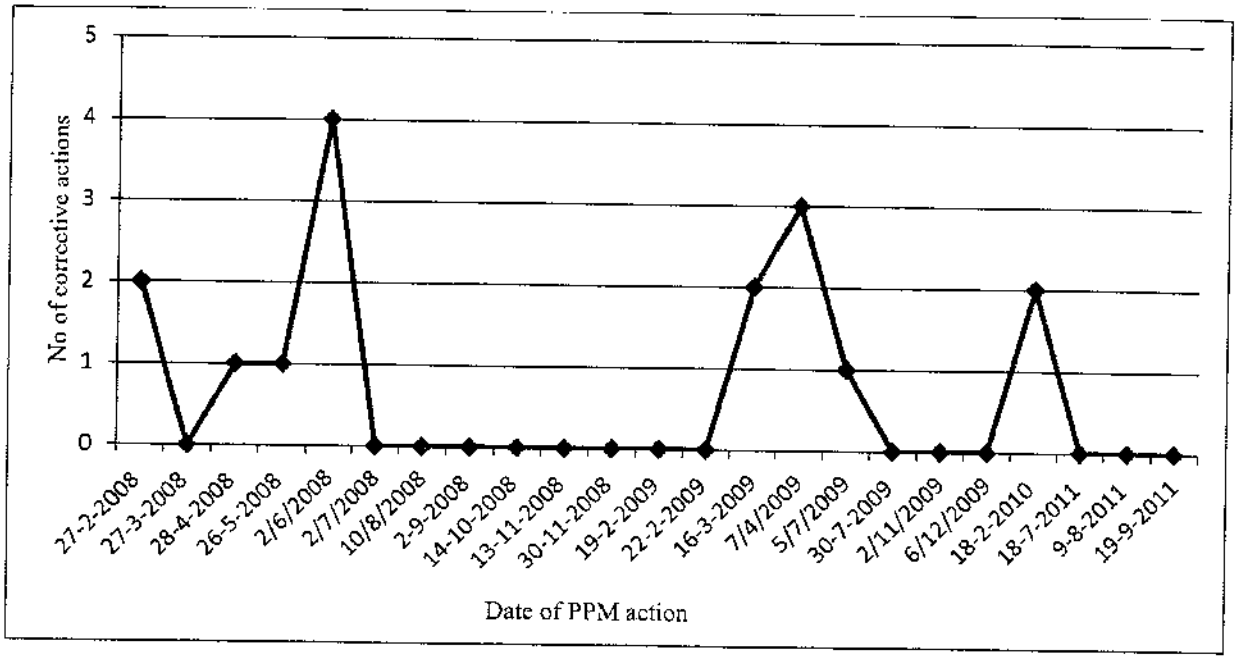
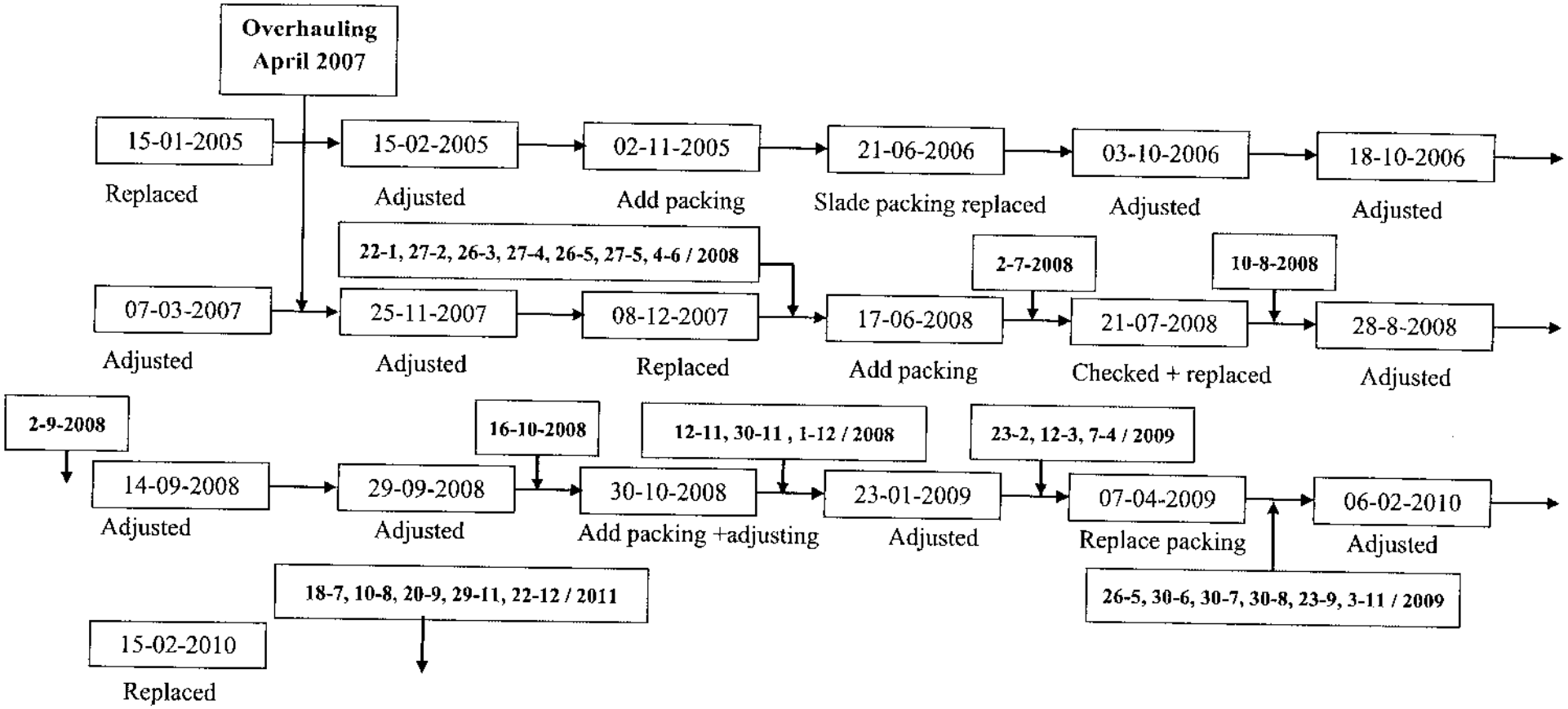



Chart 2 N - Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for West Riff'a pump #2 at Hamala A2 GFS

Station :Hamala A2 GFS, total number of gland packing defects (81 )

Equipment : West Riffa Pump # 3 – (19 nos.)




Summary
Average duration for replacement: 10.3 months
Maximum duration for replacement: 17 months
Minimum duration for replacement: 8 months
Total number of replacement: 6 times
Number of adjustment: 11 times

Table 3 N– Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for West Riffa pump #3 at Hamala A2 GFS

| PPM task number | Duration between planned preventive maintenance | No of corrective actions for gland packing defect between PPM tasks |
|---|---|---|
| 1 | 22-1-2008 to 27-2-2008 | 0 |
| 2 | 27-2-2008 to 26-3-2008 | 0 |
| 3 | 26-3-2008 to 27-4-2008 | 0 |
| 4 | 27-4-2008 to 26-5-2008 | 0 |
| 5 | 26-5-2008 to 4-6-2008 | 0 |
| 6 | 4-6-2008 to 2-7-2008 | 1 |
| 7 | 2-7-2008 to 10-8-2008 | 1 |
| 8 | 10-8-2008 to 2-9-2008 | 1 |
| 9 | 2-9-2008 to 16-10-2008 | 2 |
| 10 | 16-10-2008 to 12-11-2008 | 1 |
| 11 | 12-11-2008 to 30-11-2008 | 0 |
| 12 | 30-11-2008 to 1-12-2008 | 0 |
| 13 | 1-12-2008 to 23-2-2009 | 1 |
| 14 | 23-2-2009 to 12-3-2009 | 0 |
| 15 | 12-3-2009 to 7-4-2009 | 1 |
| 16 | 7-4-2009 to 26-5-2009 | 0 |
| 17 | 26-5-2009 to 30-6-2009 | 0 |
| 18 | 30-6-2009 to 30-7-2009 | 0 |
| 19 | 30-7-2009 to 30-8-2009 | 0 |
| 20 | 30-8-2009 to 23-9-2009 | 0 |
| 21 | 23-9-2009 to 3-11-2009 | 0 |
| 22 | 3-11-2009 to 18-7-2011 | 2 |
| 23 | 18-7-2011 to 10-8-2011 | 0 |
| **Total** | **23** | **10** |

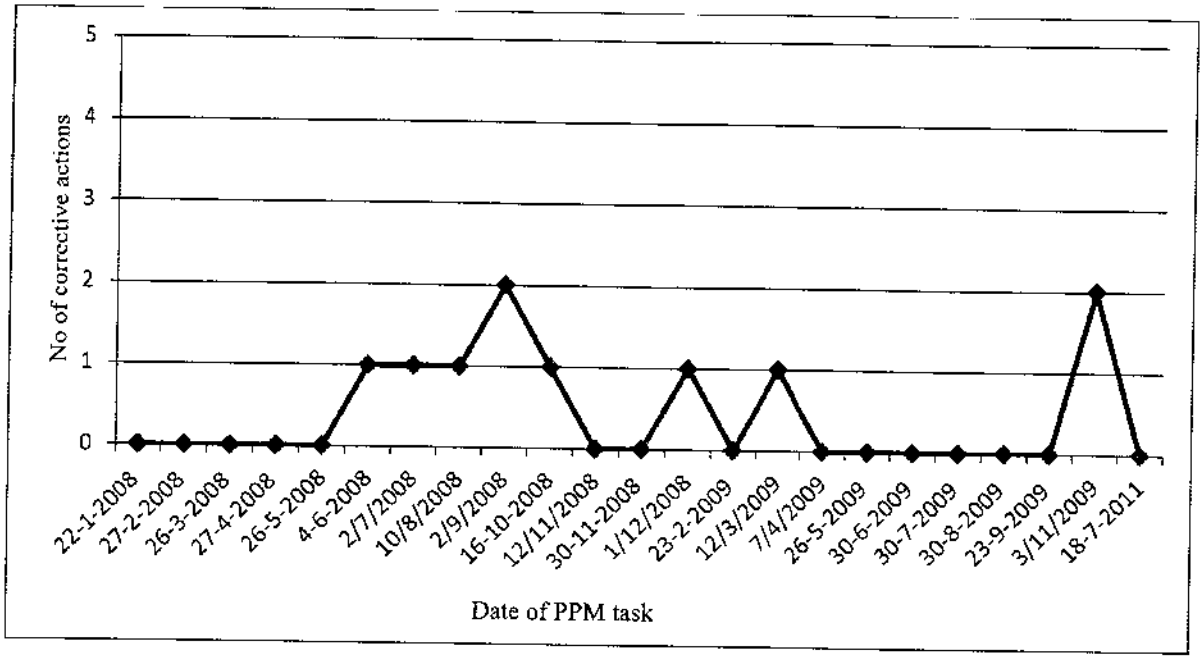
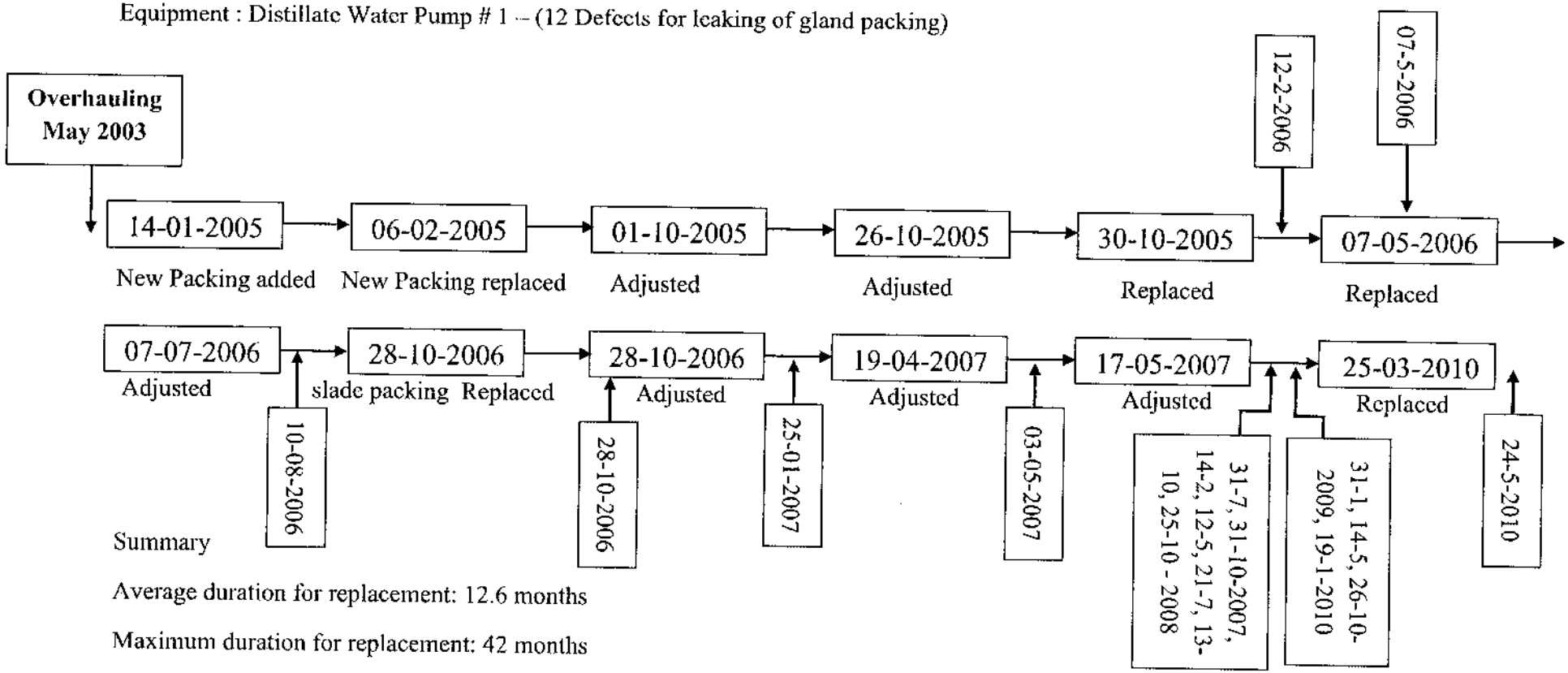



Chart 3 N - Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for West Riffa pump #3 at Hamala A2 GFS

Type of Defect: (Gland Packing of the pump is leaking)

Station : HTBS, total numbers of gland packing defects (49)

Equipment : Distillate Water Pump # 1 – (12 Defects for leaking of gland packing)




Summary

Average duration for replacement: 12.6 months

Maximum duration for replacement: 42 months

Minimum duration for replacement: 6 months

Total number of replacement: 5 times

Number of adjustment: 6 times

Table 4 N– Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for DW pump #1 at HTB

| PPM task number | Duration between planned preventive maintenance | No of corrective actions for gland packing defect between PPM tasks |
|---|---|---|
| 1 | 12-2-2006 to 7-5-2006 | 1 |
| 2 | 7-5-2006 to 10-8-2006 | 1 |
| 3 | 10-8-2006 to 28-10-2006 | 1 |
| 4 | 28-10-2006 to 25-1-2007 | 1 |
| 5 | 25-1-2007 to 3-7-2007 | 1 |
| 6 | 3-5-2007 to 31-7-2007 | 1 |
| 7 | 31-7-2007 to 31-10-2007 | 0 |
| 8 | 31-10-2007 to 14-2-2008 | 0 |
| 9 | 14-2-2008 to 12-5-2008 | 0 |
| 10 | 12-5-2008 to 21-7-2008 | 0 |
| 11 | 21-7-2008 to 13-10-2008 | 0 |
| 12 | 13-10-2008 to 31-1-2009 | 0 |
| 13 | 31-1-2009 to 14-5-2009 | 0 |
| 14 | 14-5-2009 to 26-10-2009 | 0 |
| 15 | 26-10-2009 to 19-1-2009 | 0 |
| 16 | 19-1-2009 to 24-5-2010 | 1 |
| **Total** | **16** | **7** |

Explanation for Table 4 N:

Planned preventive maintenance for distillate water pump at HTBS implemented on 12 of February 2006 and on 7 May 2006 as per the planned schedule for mechanical maintenance section. Between these two days only one problem of gland packing came out and maintenance staff do the neccesary corrective action to rectify the leak.

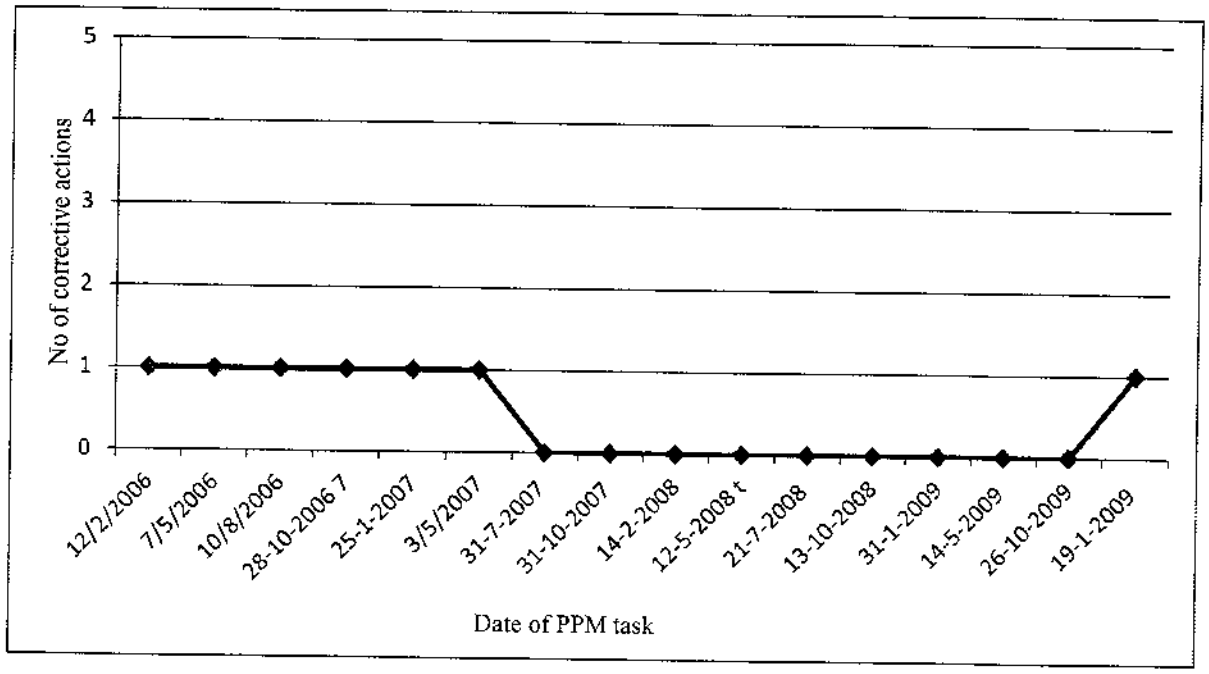
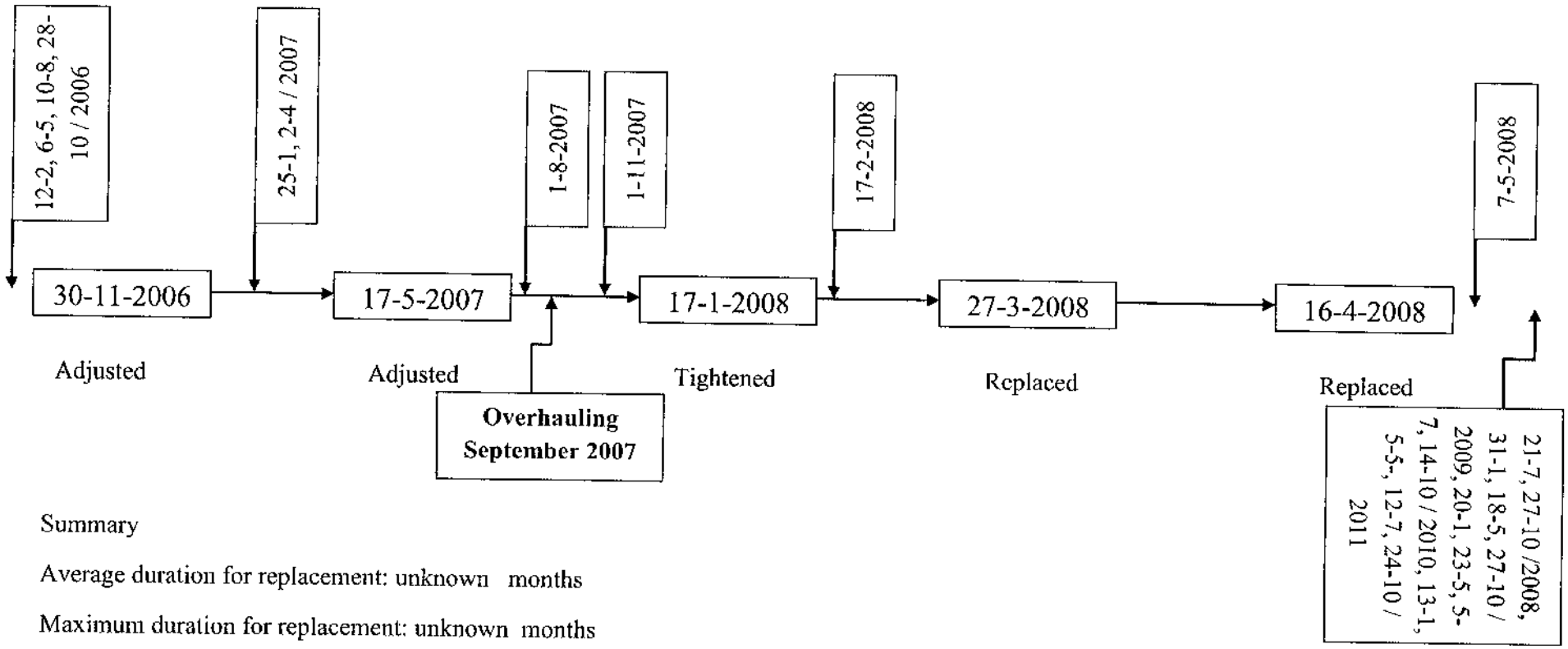



Chart 4 N– Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for DW pump #1 at HTB

Type of Defect: (Gland Packing of the pump is leaking),

Station : HTBS, total numbers of gland packing defects (49)

Equipment : Hamad Town Distribution Pump # 2 – (5 defects for leaking of gland packing)




Summary

Average duration for replacement: unknown months

Maximum duration for replacement: unknown months

Minimum duration for replacement: 3 weeks

Total number of replacement: 2 times

Number of adjustment: 2 times

Table 5N – Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for HTD pump #2 at HTB

| PPM task number | Duration between planned preventive maintenance | No of corrective actions for gland packing defect between PPM tasks |
|---|---|---|
| 1 | 12-2-2006 to 6-5-2006 | 0 |
| 2 | 6-5-2006 to 10-8-2006 | 0 |
| 3 | 10-8-2006 to 28-10-2006 | 1 |
| 4 | 28-10-2006 to 25-1-2007 | 0 |
| 5 | 25-1-2007 to 2-4-2007 | 0 |
| 6 | 2-4-2007 to 1-8-2007 | 1 |
| 7 | 1-8-2007 to 1-9-2007 (overhauling) | 0 |
| 8 | 1-9-2007 to 1-11-2007 | 0 |
| 9 | 1-11-2007 to 17-2-2008 | 1 |
| 10 | 17-2-2008 to 7-5-2008 | 2 |
| 11 | 7-5-2008 to 21-7-2008 | 0 |
| 12 | 21-7-2008 to 27-10-2008 | 0 |
| 13 | 27-10-2008 to 31-1-2009 | 0 |
| 14 | 31-1-2009 to 18-5-2009 | 0 |
| 15 | 18-5-2009 to 27-10-2009 | 0 |
| 16 | 27-10-2009 to 20-1-2010 | 0 |
| 17 | 20-1-2010 to 23-5-2010 | 0 |
| 18 | 23-5-2010 to 5-7-2010 | 0 |
| 19 | 5-7-2010 to 14-10-2010 | 0 |
| 20 | 14-10-2010 to 13-1-2011 | 0 |
| 21 | 13-1-2011 to 5-5-2011 | 0 |
| 22 | 5-5-2011 to 12-7-2011 | 0 |
| 23 | 12-7-2011 to 24-10-2011 | 0 |
| **Total** | **22** | **5** |

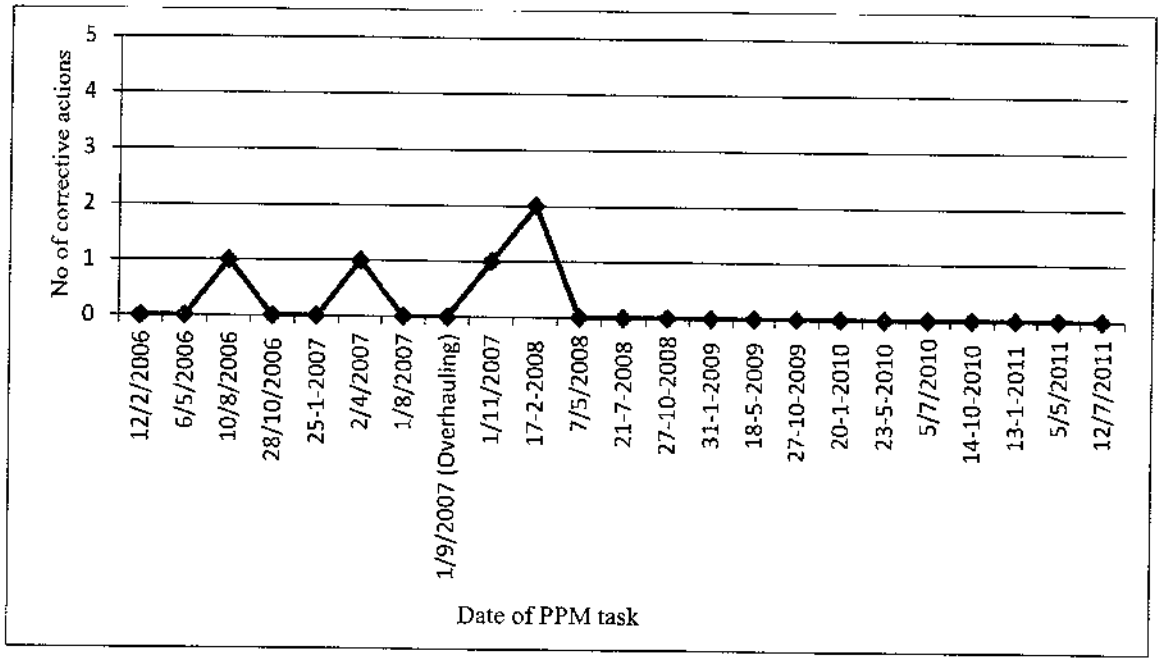
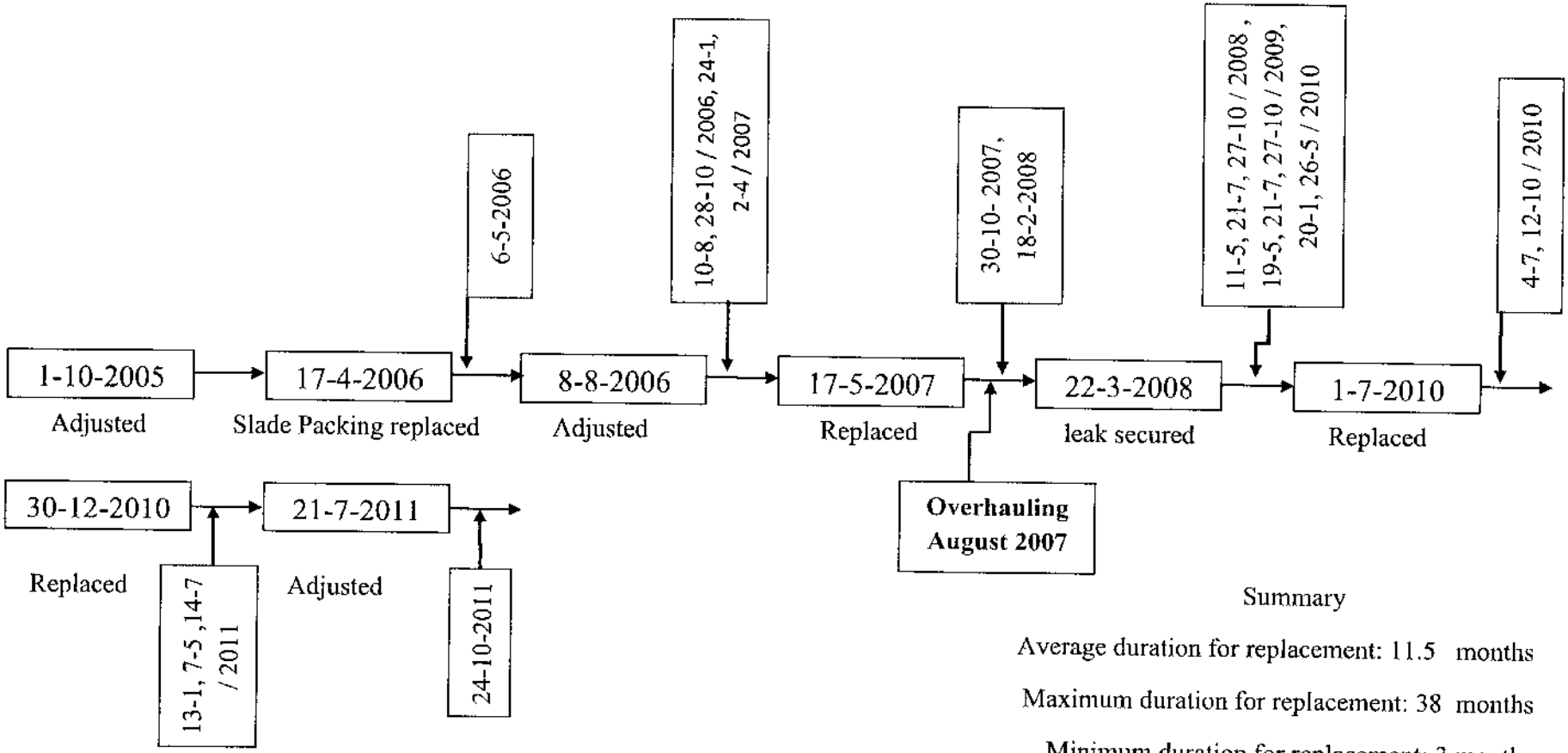



Chart 5 N– Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for HTD pump #2 at HTB

Type of Defect: (Gland Packing of the pump is leaking),

Station : HTBS, total numbers of gland packing defects (49)

Equipment : Ground water Pump # 2 – (8 defects for leaking of gland packing)




Summary

Average duration for replacement: 11.5 months

Maximum duration for replacement: 38 months

Minimum duration for replacement: 3 months

Total number of replacement: 4 times

Number of adjustment: 2 times

Table 6 N – Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for GW pump #2 at HTB

| PPM task number | Duration between planned preventive maintenance | No of corrective actions for gland packing defect between PPM tasks |
|---|---|---|
| 1 | 6-5-2006 to 10-8-2006 | 1 |
| 2 | 10-8-2006 to 28-10-2006 | 0 |
| 3 | 28-10-2006 to 24-1-2007 | 0 |
| 4 | 24-1-2007 to 2-4-2007 | 0 |
| 5 | 2-4-2007 to 1-8-2007 (Overhauling) | 1 |
| 6 | 1-8-2007 to 30-10-2007 | 0 |
| 7 | 30-10-2007 to 18-2-2008 | 0 |
| 8 | 18-2-2008 to 11-5-2008 | 1 |
| 9 | 11-5-2008 to 21-7-2008 | 0 |
| 10 | 21-7-2008 to 27-10-2008 | 0 |
| 11 | 27-10-2008 to 19-5-2009 | 0 |
| 12 | 19-5-2009 to 21-7-2009 | 0 |
| 13 | 21-7-2009 to 27-10-2009 | 0 |
| 14 | 27-10-2009 to 20-1-2010 | 0 |
| 15 | 20-1-2010 to 26-5-2010 | 0 |
| 16 | 26-5-2010 to 4-7-2010 | 1 |
| 17 | 4-7-2010 to 12-10-2010 | 0 |
| 18 | 12-10-2010 to 13-1-2011 | 1 |
| 19 | 13-1-2011 to 7-5-2011 | 0 |
| 20 | 7-5-2011 to 14-7-2011 | 0 |
| 21 | 14-7-2011 to 24-10-2011 | 1 |
| **Total** | **20** | **6** |

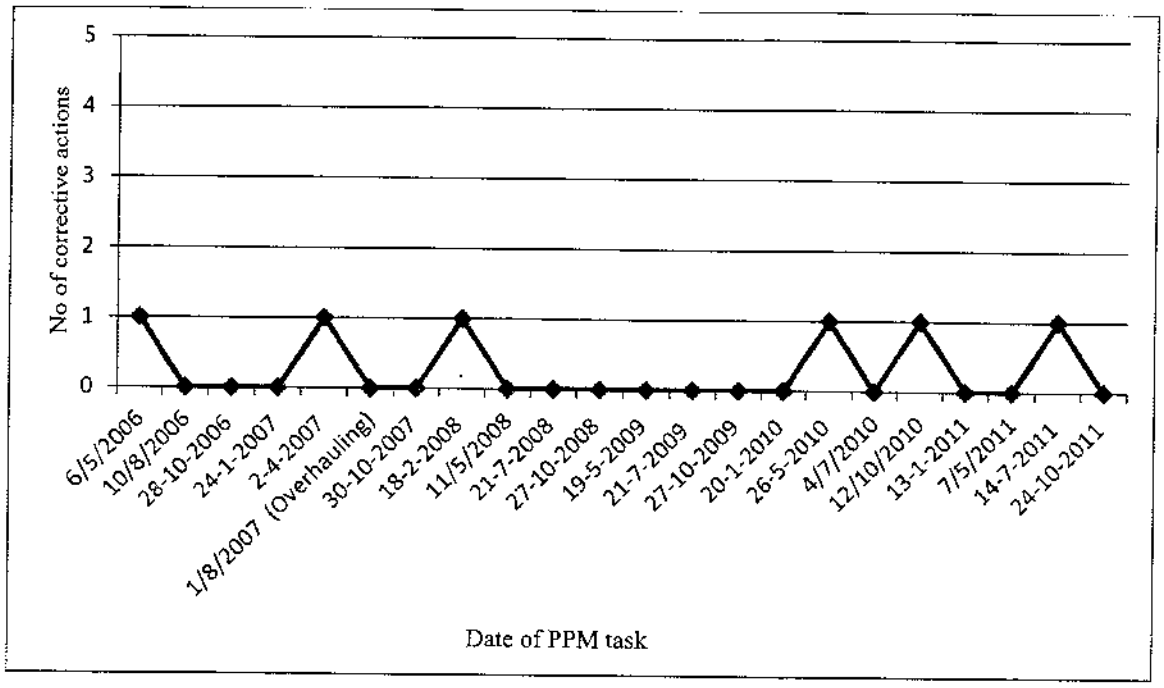
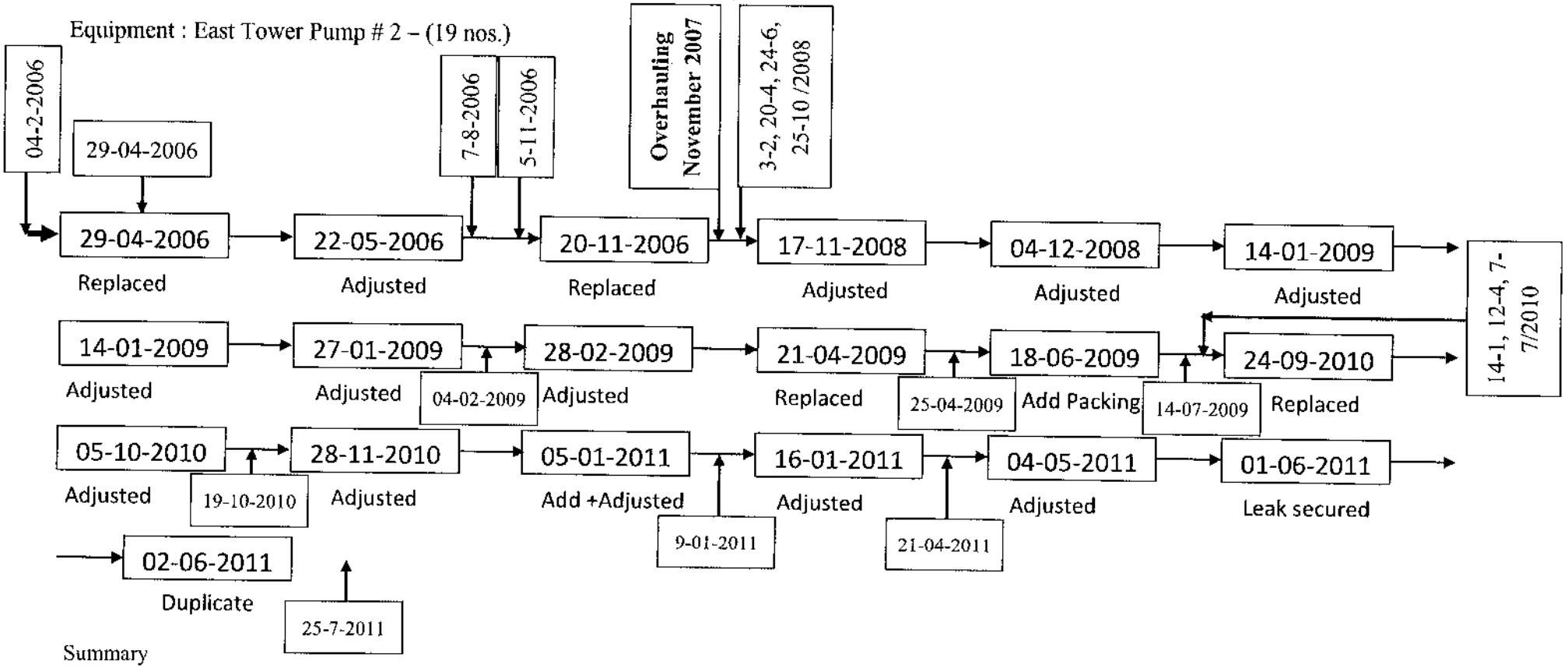



Chart 6 N– Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for GW pump #2 at HTB

Type of Defect: (Gland Packing of the pump is leaking),

Station : W.R#1, total number of gland packing defects (49)

Equipment : East Tower Pump # 2 – (19 nos.)




Summary

Average duration for replacement: 13.25 months

Maximum duration for replacement: 29 months

Minimum duration for replacement: 7 months

Total number of replacement: 4 times

Number of adjustment: 13 times

Table 7 N – Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for East tower pump #2 at WR#1 BS

| PPM task number | Duration between planned preventive maintenance | No of corrective actions for gland packing defect between PPM tasks |
|---|---|---|
| 1 | 4-2-2006 to 29-4- 2006 | 0 |
| 2 | 29-4-2006 to 7-8-2006 | 2 |
| 3 | 7-8-2006 to 5-11-2006 | 0 |
| 4 | 5-11-2006 to 1-11-2007 (overhauling) | 1 |
| 5 | 1-11-2007 to 3-2-2008 | 0 |
| 6 | 3-2-2008 to 20-4-2008 | 0 |
| 7 | 20-4-2008 to 24-6-2008 | 0 |
| 8 | 24-6-2008 to 25-10-2008 | 0 |
| 9 | 25-10-2008 to 4-2-2009 | 5 |
| 10 | 4-2-2009 to 25-4-2009 | 2 |
| 11 | 25-4-2009 to 14-7-2009 | 1 |
| 12 | 14-7-2009 to 14-1-2010 | 0 |
| 13 | 14-1-2010 to 12-4-2010 | 0 |
| 14 | 12-4-2010 to 7-7-2010 | 0 |
| 15 | 7-7-2010 to 19-10-2010 | 2 |
| 16 | 19-10-2010 to 9-1-2011 | 2 |
| 17 | 9-1-2011 to 21-4-2011 | 1 |
| 18 | 21-4-2011 to 25-7-2011 | 3 |
| **Total** | **18** | **19** |

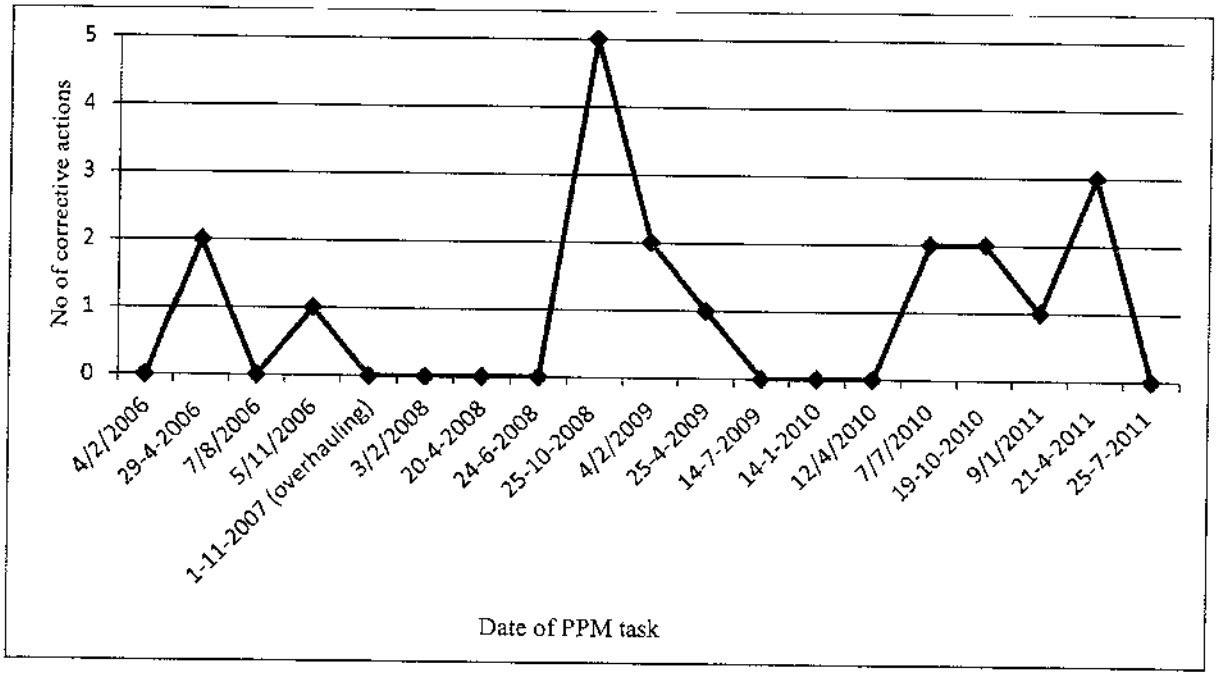
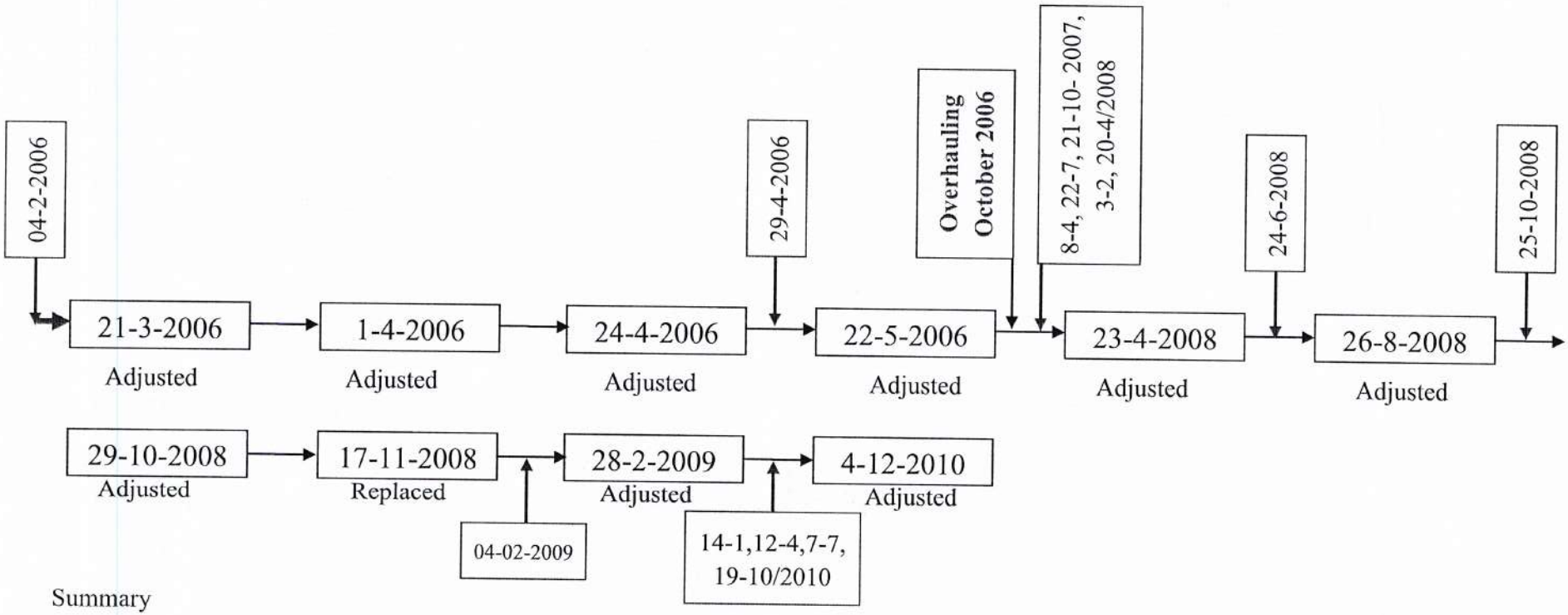



Chart 7 N– Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for East tower pump #2 at West Riff'a #1 BS

Type of Defect: (Gland Packing of the pump is leaking),

Station : W.R#1, total number of gland packing defects (49)

Equipment : East Tower Pump # 1 – (10 nos.)




Summary

Average duration for replacement: 12 months
Maximum duration for replacement: 24 months
Minimum duration for replacement: 24 months
Total number of replacement: 2 times
Number of adjustment: 9 times

Table 8 N – Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for East tower pump #1 at WR#1 BS

| PPM task number | Duration between planned preventive maintenance | No of corrective actions for gland packing defect between PPM tasks |
|---|---|---|
| 1 | 4-2-2006 to 29-4-2006 | 3 |
| 2 | 29-4-2006 1-10-2006 (overhauling) | 1 |
| 3 | 1-10-2006 to 8-4-2007 | 0 |
| 4 | 8-4-2007 to 22-7-2007 | 0 |
| 5 | 22-7-2007 to 21-10-2007 | 0 |
| 6 | 21-10-2007 to 3-2-2008 | 0 |
| 7 | 3-2-2008 to 20-4-2008 | 0 |
| 8 | 20-4-2008 to 24-6-2008 | 1 |
| 9 | 24-6-2008 to 25-10-2008 | 1 |
| 10 | 25-10-2008 to 4-2-2009 | 2 |
| 11 | 4-2-2009 to 25-4-2009 | 0 |
| 12 | 25-4-2009 to 14-7-2009 | 0 |
| 13 | 14-7-2009 to 25-10-2009 | 0 |
| 14 | 25-10-2009 to 14-1-2010 | 0 |
| 15 | 14-1-2010 to 12-4-2010 | 0 |
| 16 | 12-4-2010 to 7-7-2010 | 0 |
| 17 | 7-7-2010 to 19-10-2010 | 0 |
| 18 | 19-10-2010 9-1-2011 | 1 |
| **Total** | **18** | **9** |

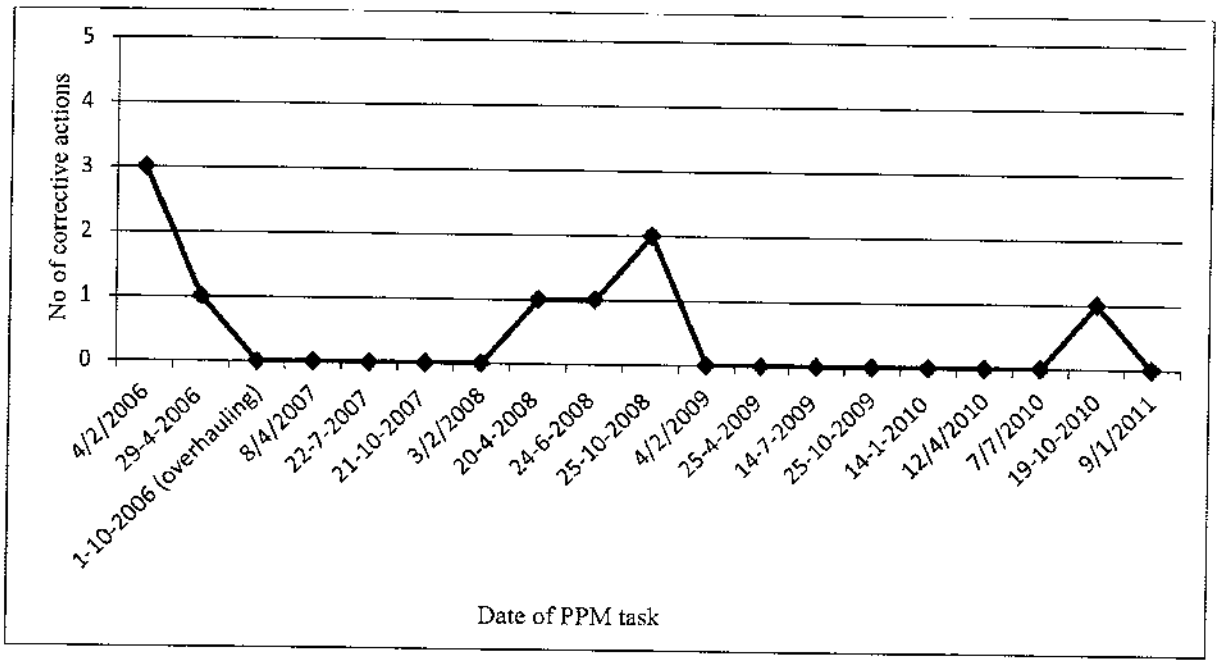
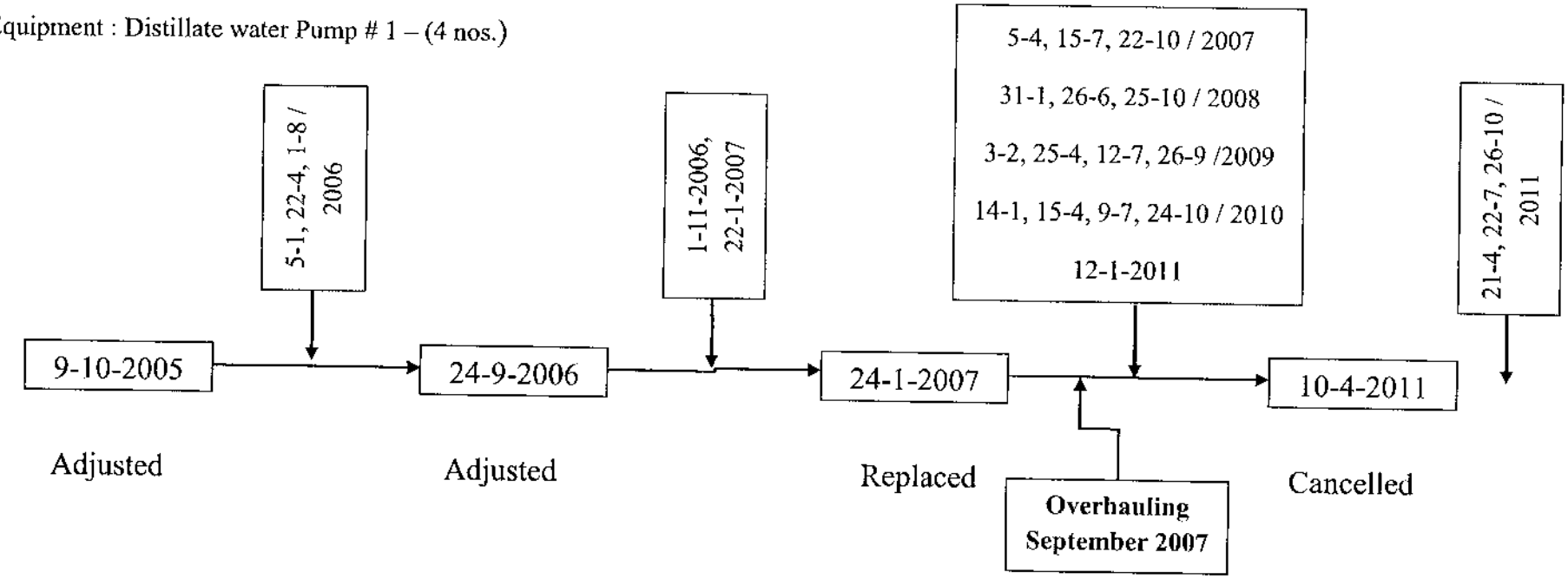



Chart 8 N– Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for East tower pump #1 at West Riff'a #1 BS

Type of Defect: (Gland Packing of the pump is leaking),

Station : W.R#1, total number of gland packing defects (49)

Equipment : Distillate water Pump # 1 – (4 nos.)




Summary

Average duration for replacement: unknown months

Maximum duration for replacement: unknown months

Minimum duration for replacement: unknown months

Total number of replacement: 1 times

Number of adjustment: 2 times

Table 9 N – Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for Distillate water pump #1 at WR#1 BS

| PPM task number | Duration between planned preventive maintenance | No of corrective actions for gland packing defect between PPM tasks |
|---|---|---|
| 1 | 5-1-2006 to 22-4-2006 | 0 |
| 2 | 22-4-2006 to 1-8-2006 | 0 |
| 3 | 1-8-2006 to 1-11-2006 | 1 |
| 4 | 1-11-2006 to 22-1-2007 | 0 |
| 5 | 22-1-2007 to 5-4-2007 | 1 |
| 6 | 5-4-2007 to 15-7-2007 | 0 |
| 7 | 15-7-2007 to 1-9-2007 (overhauling) | 0 |
| 8 | 1-9-2007 to 22-10-2007 | 0 |
| 9 | 22-10-2007 to 31-1-2008 | 0 |
| 10 | 31-1-2008 to 26-6-2008 | 0 |
| 11 | 26-6-2008 to 25-10-2008 | 0 |
| 12 | 25-10-2008 to 3-2-2009 | 0 |
| 13 | 3-2-2009 to 25-4-2009 | 0 |
| 14 | 25-4-2009 to 12-7-2009 | 0 |
| 15 | 12-7-2009 to 26-9-2009 | 0 |
| 16 | 26-9-2009 to 14-1-2010 | 0 |
| 17 | 14-1-2010 to 15-4-2010 | 0 |
| 18 | 15-4-2010 to 9-7-2009 | 0 |
| 19 | 9-7-2009 to 24-10-2010 | 0 |
| 20 | 24-10-2010 to 12-1-2011 | 0 |
| 21 | 12-1-2011 to 21-4-2011 | 1 |
| 22 | 21-4-2011 to 22-7-2011 | 0 |
| 23 | 22-7-2011 to 26-10-2011 | 0 |
| **Total** | **23** | **3** |

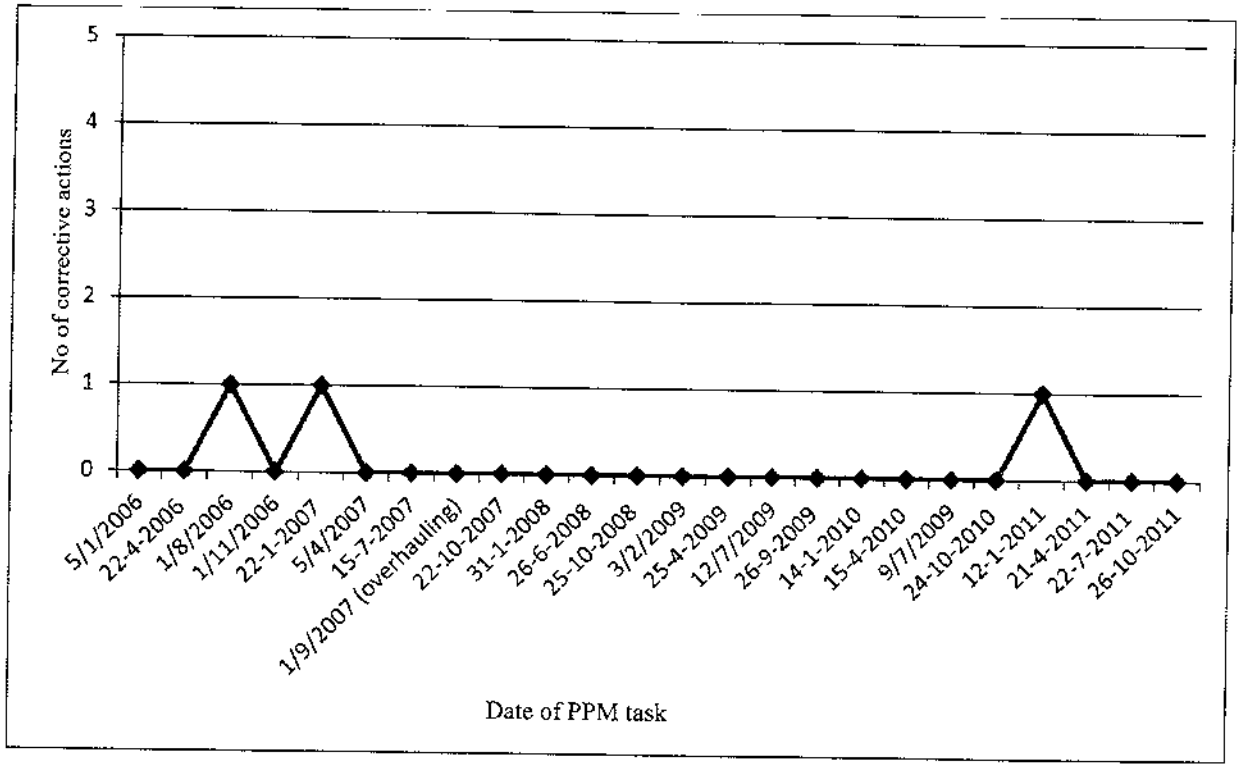
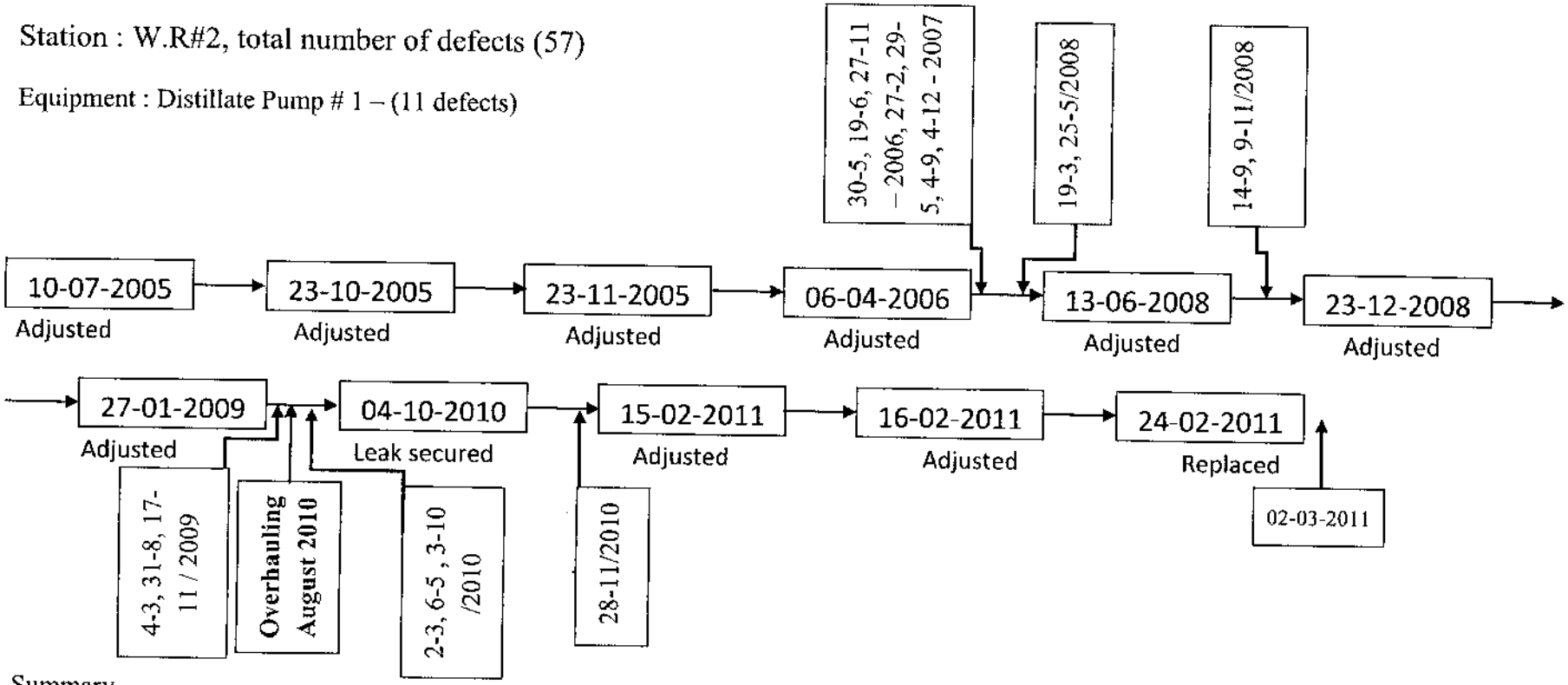



Chart 9 N– Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for Distillate water pump #1 at West Riff'a #1 BS

Type of Defect: (Gland Packing of the pump is leaking),

Station : W.R#2, total number of defects (57)

Equipment : Distillate Pump # 1 – (11 defects)




Summary

Average duration for replacement: 33 months

Maximum duration for replacement: 60 months

Minimum duration for replacement: 6 months

Total number of replacement: 2 times

Number of adjustment: 9 times

Table 10 N – Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for Distillate pump #1 at WR#2 BS

| PPM task number | Duration between planned preventive maintenance | No of corrective actions for gland packing defect between PPM tasks |
|---|---|---|
| 1 | 30-5-2006 to 10-9-2006 | 0 |
| 2 | 10-9-2006 to 27-11-2006 | 0 |
| 3 | 27-11-2006 to 27-2-2007 | 0 |
| 4 | 27-2-2007 to 29-5-2007 | 0 |
| 5 | 29-5-2007 to 4-9-2007 | 0 |
| 6 | 4-9-2007 to 4-12-2007 | 0 |
| 7 | 4-12-2007 to 19-3-2008 | 0 |
| 8 | 19-3-2008 to 25-5-2008 | 0 |
| 9 | 25-5-2008 to 14-9-2008 | 1 |
| 10 | 14-9-2008 to 9-11-2008 | 0 |
| 11 | 9-11-2008 to 4-3-2009 | 2 |
| 12 | 4-3-2009 to 31-8-2009 | 0 |
| 13 | 31-8-2009 to 17-11-2009 | 0 |
| 14 | 17-11-2009 to 2-3-2010 | 0 |
| 15 | 2-3-2010 to 6-5-2010 | 0 |
| 16 | 6-5-2010 to 1-8-2010 (overhauling) | 0 |
| 17 | 1-8-2010 to 3-10-2010 | 0 |
| 18 | 3-10-2010 to 28-11-2010 | 1 |
| 19 | 28-11-2010 to 2-3-2011 | 3 |
| 20 | 2-3-2011 to 1-5-2011 | 0 |
| 21 | 1-5-2011 to 6-9-2011 | 0 |
| **Total** | **21** | **7** |

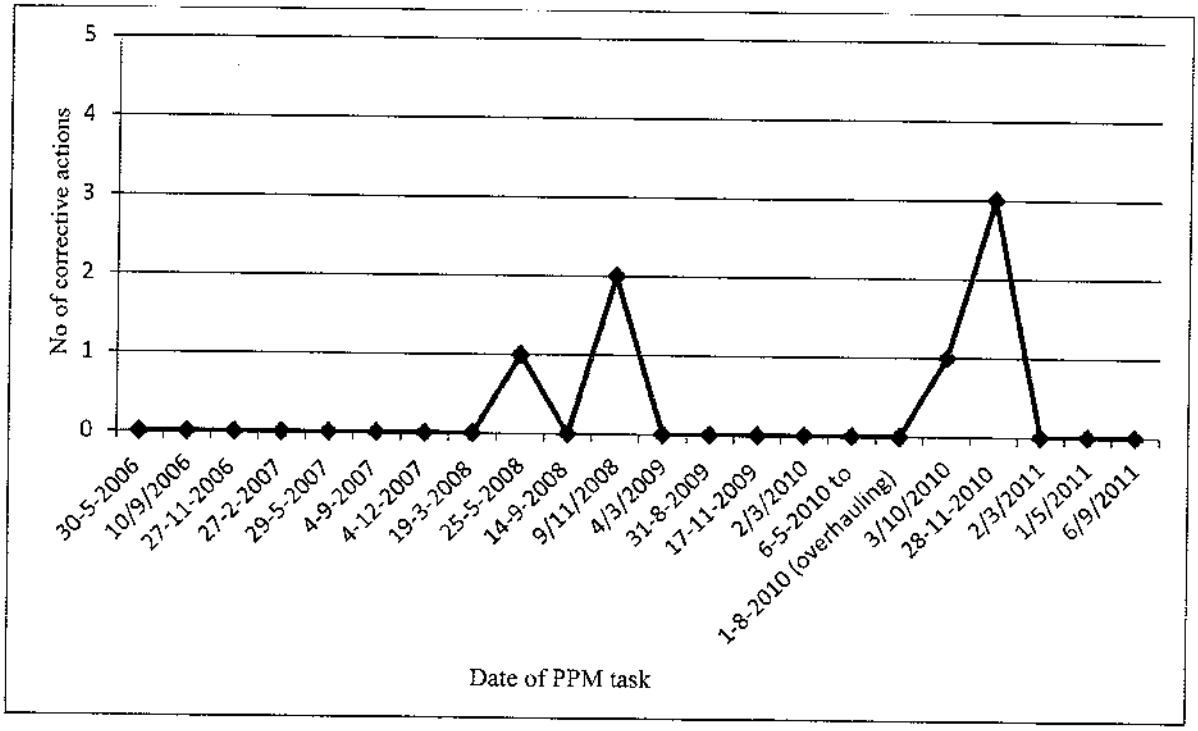
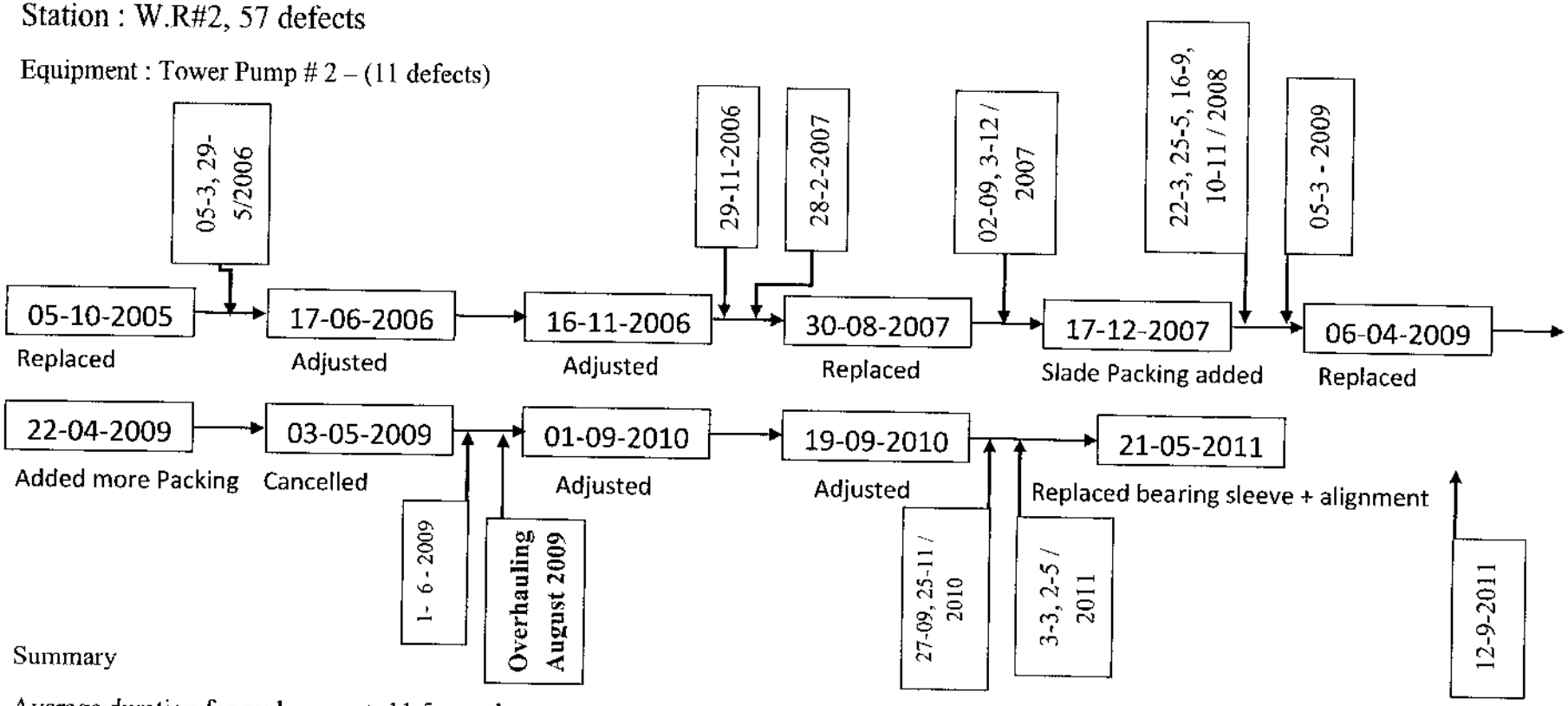



Chart 10 N– Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for Distillate water pump #1 at West Riff'a #2 BS

Station : W.R#2, 57 defects

Equipment : Tower Pump # 2 – (11 defects)




Summary

Average duration for replacement: 11.5 months

Maximum duration for replacement: 23 months

Minimum duration for replacement: 4 months

Total number of replacement: 4 times

Number of adjustment: 4 times

Table 11 N– Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for tower pump #2 at WR#2 BS

| PPM task number | Duration between planned preventive maintenance | No of corrective actions for gland packing defect between PPM tasks |
|---|---|---|
| 1 | 5-3-2006 to 29-5-2006 | 0 |
| 2 | 29-5-2006 to 29-11-2006 | 2 |
| 3 | 29-11-2006 to 28-2-2007 | 0 |
| 4 | 28-2-2007 to 2-9-2007 | 1 |
| 5 | 2-9-2007 to 3-12-2007 | 0 |
| 6 | 3-12-2007 to 22-3-2008 | 1 |
| 7 | 22-3-2008 to 25-5-2008 | 0 |
| 8 | 25-5-2008 to 16-9-2008 | 0 |
| 9 | 16-9-2008 to 10-11-2008 | 0 |
| 10 | 10-11-2008 to 5-3-2009 | 0 |
| 11 | 5-3-2009 to 1-6-2009 | 0 |
| 12 | 1-6-2009 to 1-8-2009 (overhauling) | 3 |
| 13 | 1-8-2009 to 6-9-2009 | 0 |
| 14 | 6-9-2009 to 16-11-2009 | 0 |
| 15 | 16-11-2009 to 4-3-2010 | 0 |
| 16 | 4-3-2010 to 27-9-2010 | 2 |
| 17 | 27-9-2010 25-11-2010 | 0 |
| 18 | 25-11-2010 to 3-3-2011 | 0 |
| 19 | 3-3-2011 to 2-5-2011 | 0 |
| 20 | 2-5-2011 to 12-9-2011 | 1 |
| 21 | 12-9-2011 to 14-11-2011 | 0 |
| **Total** | **21** | **10** |

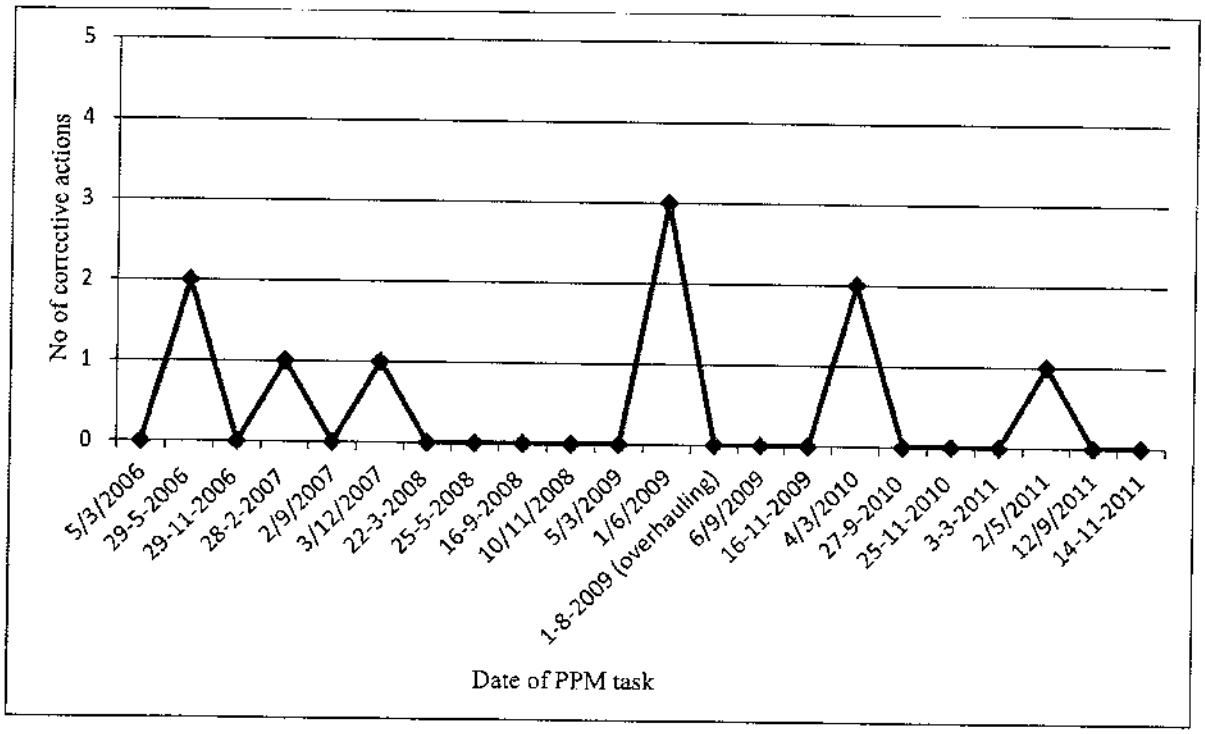



Chart 11 N– Relationship between preventive maintenance of pumps and corrective maintenance of gland packing for Tower pump #2at West Riff'a #2 BS

Appendix O

# Cost of corrective action (repair) for Gland packing leakage

## Appendix O

## Cost of corrective action (repair) for gland packing leakage

### 1. Hamala A2 GFS:

Table 1O - Cost of repairing for West Riff'a pump # 1 at Hamala A2 GFS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Replaced | 20 | 41 | 0 |
| 2 | Adjusted | 6 | 9.6 | 0 |
| 3 | Adjusted | 9.66 | 15.47 | 0 |
| 4 | Adjusted | 6 | 9.6 | 0 |
| 5 | Replaced | 24.5 | 56.1 | 175 |
| 6 | Replaced | 95 | 181.1 | 100 |
| 7 | Adjusted by contractor | 1.5 | 0 | 0 |
| 8 | Adjusted | 6.33 | 17.1 | 0 |
| 9 | Replaced by contractor | 18 | 57.47 | 0 |
| 10 | Adjusted | 33 | 82.69 | 0 |
| 11 | Adjusted | 6 | 12 | 0 |
| 12 | Replaced | 22 | 54.45 | 18 |
| 13 | Tightened | 5.5 | 14.85 | 0 |
| 14 | Repaired | 2.5 | 7.5 | 0 |
| 15 | Tightened | 21 | 58.8 | 0 |
| 16 | Repaired | 10 | 24 | 0 |
| 17 | Adjusted | 12 | 28.8 | 0 |
| 18 | No comment | 10 | 24 | 0 |
| Total | | 308.99 | 694.53 | 293 |

Cost of replacing gland packing = BD 387.12

Cost of adjusting gland packing = BD 307.41

Cost of material related to replacement of gland packing = BD 293

---

Table 2 O - Cost of repairing for West Riff'a pump # 2 at Hamala A2 GFS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Remove one packing | 2 | 3.2 | 0 |
| 2 | Adjusted | 6 | 9.6 | 0 |
| 3 | Adjusted | 5 | 10.25 | 0 |

| | | | | |
|---|---|---|---|---|
| 4 | Adjusted | 10 | 22 | 0 |
| 5 | Remove one packing | 26 | 49.4 | 18 |
| 6 | Adjusted | 6 | 14.1 | 0 |
| 7 | Adjusted | 2 | 5.4 | 0 |
| 8 | Add packing | 54 | 149.66 | 40 |
| 9 | Adjusted | 6 | 16.2 | 0 |
| 10 | Replaced | 10 | 32.06 | 0 |
| 11 | Completed | 4 | 10.8 | 0 |
| 12 | Add packing | 4 | 10.8 | 0 |
| 13 | Adjusted | 3 | 8.10 | 0 |
| 14 | Add packing | 34 | 95.51 | 6 |
| 15 | Adjusted | 10.5 | 25.2 | 0 |
| 16 | Replaced | 9 | 23.4 | 0 |
| 17 | Adjusted | 7 | 18.9 | 0 |
| 18 | Cancelled | 0 | 0 | 0 |
| 19 | Cancelled | 0 | 0 | 0 |
| 20 | Replaced | 14 | 35.7 | 0 |
| 21 | Adjusted | 6 | 16.2 | 40 |
| 22 | Replaced | 13.5 | 39.6 | 20 |
| Total | | 232 | 596.08 | 124 |

Cost of replacing gland packing = BD 130.76

Cost of adjusting gland packing = BD 465.32

Cost of material related to replacement of gland packing = BD 20

Cost of material related to adjustment of gland packing = BD 86

---

Table 3 O - Cost of repairing for West Riff'a pump # 3 at Hamala A2 GFS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Replaced | 28 | 46.3 | 30 |
| 2 | Adjusted | 0 | 15.93 | 0 |
| 3 | Add packing | 2 | 4 | 0 |
| 4 | Replaced | 58.5 | 105.3 | 231.6 |
| 5 | Adjusted | 5 | 10.6 | 0 |
| 6 | Adjusted | 5 | 11 | 0 |
| 7 | Adjusted | 19.5 | 37.5 | 0 |
| 8 | Adjusted | 14 | 32.9 | 0 |

| | | | | |
|---|---|---|---|---|
| 9 | Replaced | 38.5 | 106.15 | 30 |
| 10 | Add packing | 34 | 95.51 | 6 |
| 11 | Replaced | 12 | 28.8 | 0 |
| 12 | Adjusted | 1.5 | 4.05 | 0 |
| 13 | Adjusted | 3.5 | 8.4 | 0 |
| 14 | Adjusted | 7 | 19.95 | 0 |
| 15 | Add packing and adjust | 8 | 22.8 | 55 |
| 16 | Adjusted | 6 | 15.6 | 0 |
| 17 | Replaced | 12 | 31.2 | 80 |
| 18 | Adjusted | 1 | 2.7 | 0 |
| 19 | Replaced | 24 | 67.33 | 35 |
| Total | | 279.5 | 666.02 | 467.6 |

Cost of replacing gland packing = BD 385.08

Cost of adjusting gland packing = BD 280.94

Cost of material related to replacement of gland packing = BD 406.6

Cost of material related to adjustment of gland packing = BD 61

## 2. Hamad Town BS:

Table 4 O - Cost of repairing for Distillate water pump # 1 at HTBS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | New packing | 92.5 | 163.85 | 0 |
| 2 | Replaced | 12 | 21.6 | 247 |
| 3 | Adjusted | 3 | 5.55 | 0 |
| 4 | Adjusted | 5.25 | 8.58 | 0 |
| 5 | Replaced | 32 | 56.90 | 0 |
| 6 | Replaced | 13 | 13 | 40 |
| 7 | Adjusted | 11.25 | 24.84 | 0 |
| 8 | Replaced | 8 | 20 | 0 |
| 9 | Adjusted | 5 | 5 | 0 |
| 10 | Adjusted | 14 | 38.85 | 0 |
| 11 | Adjusted | 29 | 70.33 | 0 |
| 12 | Replaced | 4.5 | 14.10 | 0 |
| Total | | 229.5 | 442.6 | 287 |

Cost of replacing gland packing = BD 289.45

Cost of adjusting gland packing = BD 153.07

Cost of material related to replacement of gland packing = BD 287

---

Table 5 O - Cost of repairing for Hamad Town Distribution pump # 2 at HTBS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Adjusted | 9 | 27.3 | 0 |
| 2 | Adjusted | 29 | 70.33 | 0 |
| 3 | Tightened | 4 | 11.4 | 0 |
| 4 | Replaced | 4.5 | 12.15 | 0 |
| 5 | Replaced | 0 | 0 | 0 |
| Total | | 46.5 | 121.18 | 0 |

Cost of replacing gland packing = BD 12.15

Cost of adjusting gland packing = BD 109.03

Table 6O - Cost of repairing for ground water pump # 2 at HTBS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Adjusted | 2 | 37 | 0 |
| 2 | Slade packing replaced | 14 | 22.4 | 360 |
| 3 | Adjusted | 13 | 22.1 | 0 |
| 4 | Replaced | 29 | 70.33 | 64 |
| 5 | Leak secured | 3 | 4.05 | 0 |
| 6 | Replaced | 9 | 22.5 | 0 |
| 7 | Replaced | 6 | 14.4 | 15 |
| 8 | Adjusted | 3 | 8.1 | 0 |
| Total | | 79 | 200.88 | 439 |

Cost of replacing gland packing = BD 129.63

Cost of adjusting gland packing = BD 71.25

Cost of material related to replacement of gland packing = BD 439

### 3. West Riff'a #1 BS:

Table 7 O - Cost of repairing for East Tower pump # 2 at West Riff'a #1 BS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Adjusted | 3.5 | 5.6 | 0 |
| 2 | Adjusted | 15 | 28 | 0 |
| 3 | Adjusted | 4.5 | 7.65 | 0 |
| 4 | Adjusted | 5 | 8 | 0 |
| 5 | Adjusted | 12 | 32.4 | 0 |
| 6 | Adjusted | 7 | 18.9 | 0 |
| 7 | Adjusted | 11 | 31.35 | 20 |
| 8 | Replaced | 12 | 28.80 | 0 |
| 9 | Adjusted | 2 | 6 | 0 |
| 10 | Adjusted | 4 | 9.6 | 0 |
| Total | | 76 | 176.3 | 20 |

Cost of replacing gland packing = BD 28.8

Cost of adjusting gland packing = BD 147.5

Cost of material related to adjustment of gland packing = BD 20

---

Table 8 O - Cost of repairing for East Tower pump # 1 at West Riff'a #1 BS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Replaced | 13 | 26.5 | 31 |
| 2 | Adjusted | 2 | 3.2 | 0 |
| 3 | Replaced | 7 | 14 | 120 |
| 4 | Adjusted | 8 | 19.2 | 0 |
| 5 | Adjusted | 6 | 16.2 | 0 |
| 6 | Adjusted | 14 | 33.6 | 0 |
| 7 | Adjusted | 14 | 33.6 | 0 |
| 8 | Adjusted | 5 | 13.5 | 0 |
| 9 | Adjusted | 12 | 28.8 | 0 |
| 10 | Replaced | 13 | 31.2 | 0 |
| 11 | Add packing | 1 | 2.63 | 10 |
| 12 | Replaced | 4 | 9.6 | 10 |
| 13 | Adjusted | 10 | 24 | 0 |
| 14 | Adjusted | 6 | 17.1 | 0 |

| | | | | |
|---|---|---|---|---|
| 15 | Add and adjust | 6 | 14.4 | 15 |
| 16 | Adjusted | 10 | 24 | 0 |
| 17 | Adjusted | 12 | 28.8 | 0 |
| 18 | Leak secured | 5 | 13.5 | 0 |
| 19 | Duplicate | 0 | 0 | 0 |
| Total | | 148 | 353.83 | 186 |

Cost of replacing gland packing = BD 81.3

Cost of adjusting gland packing = BD 272.53

Cost of material related to replacement of gland packing = BD 161

Cost of material related to adjustment of gland packing = BD 25

---

Table 9 O - Cost of repairing for ground water pump # 1 at West Riffa #1 BS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Adjusted | 6 | 11.2 | 0 |
| 2 | Adjusted | 12 | 17.1 | 0 |
| 3 | Replaced | 16 | 42 | 0 |
| 4 | Cancelled | 0 | 0 | 0 |
| Total | | 34 | 70.3 | 0 |

Cost of replacing gland packing = BD 42

Cost of adjusting gland packing = BD 28.3

## 4. West Riff'a #2 BS:

Table 10 O - Cost of repairing for distillate water pump # 1 at West Riff'a #2 BS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Adjusted | 4.5 | 10.8 | 0 |
| 2 | Adjusted | 8 | 16.4 | 0 |
| 3 | Adjusted | 10.33 | 20.3 | 0 |
| 4 | Adjusted | 6 | 6 | 0 |
| 5 | Adjusted | 4 | 10.8 | 0 |
| 6 | Adjusted | 4 | 10.8 | 0 |
| 7 | Adjusted | 8 | 20.4 | 0 |
| 8 | Leak secured | 5 | 12.75 | 0 |
| 9 | Adjusted | 7 | 16.8 | 0 |
| 10 | Adjusted | 7.5 | 22.75 | 0 |
| 11 | Replaced | 8 | 21.6 | 0 |
| Total | | 72.33 | 169.4 | 0 |

Cost of replacing gland packing = BD 21.6

Cost of adjusting gland packing = BD 147.8

---

Table 11 O - Cost of repairing for Tower pump # 2 at West Riff'a #2 BS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Replaced | 6.83 | 16.4 | 0 |
| 2 | Adjusted | 7 | 14 | 0 |
| 3 | Adjusted | 6 | 9.6 | 0 |
| 4 | Replaced | 9.75 | 15.93 | 46 |
| 5 | Slade packing added | 5.5 | 10.18 | 64 |
| 6 | Replaced | 12 | 28.8 | 0 |
| 7 | Add more packing | 6 | 15 | 0 |
| 8 | Cancelled | 0 | 0 | 0 |
| 9 | Adjusted | 7 | 18.9 | 0 |
| 10 | Adjusted | 1 | 2.70 | 0 |
| 11 | Replaced | 126 | 365.38 | 402 |
| Total | | 187.08 | 496.89 | 512 |

Cost of replacing gland packing = BD 426.51

Cost of adjusting gland packing = BD 70.38

Cost of material related to replacement of gland packing = BD 448

Cost of material related to adjustment of gland packing = BD 64

---

Table 12 O - Cost of repairing for Tower pump # 3 at West Riffa #2 BS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Adjusted | 13.5 | 34.4 | 0 |
| 2 | Adjusted | 10 | 20.15 | 0 |
| 3 | Add and adjust | 13 | 24.05 | 0 |
| 4 | Add and adjust | 13 | 24.05 | 0 |
| 5 | Adjusted | 6 | 9.6 | 0 |
| 6 | Replaced | 7 | 14 | 32 |
| 7 | Replaced | 13.5 | 50.63 | 0 |
| 8 | Adjusted | 4 | 10.8 | 0 |
| Total | | 80 | 187.68 | 32 |

Cost of replacing gland packing = BD 64.63

Cost of adjusting gland packing = BD 123.05

Cost of material related to replacement of gland packing = BD 32

Appendix P

# Mean time between failure for leakage of discharge line defect

**Appendix P**

**Mean time between failure for leakage of discharge line defect**

**Assumption : Failure rate is constant for all pumps**

**Station: Hamala A2 GFS**

Type of defects: leakage from discharge header

Equipment Name: West Riffa pump #1

Frequency: 3

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs |
|---|---|---|---|
| 1 | 1-1-2005 | 0 | 0 |
| 2 | 16-3-2008 | 28080 | 4 |
| 3 | 6-4-2008 | 504 | 3.5 |
| 4 | 15-9-2010 | 21408 | 42 |
| **Total** | | **49992** | **49.5** |

MTBF = 49992 /3 = 16664 Hrs

MTTR = 49.5 / 3 = 16.5 Hrs

$\lambda$ = 1/ MTBF = 1/ 16664 = 0.00006 failure / hour

A = MTBF / MTBF+MTTR = 16664 / 16664+16.5 = 0.999

**Station: Hamala A2 GFS**

Type of defects: leakage from discharge header

Equipment Name: West Riffa pump #3

Frequency: 4

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs |
|---|---|---|---|
| 1 | 1-1-2005 | 0 | 0 |
| 2 | 9-8-2006 | 14040 | 30 |
| 3 | 1-1-2007 | 3480 | 7 |
| 4 | 16-3-2008 | 10560 | 3 |
| 5 | 30-12-2009 | 15696 | 35 |
| **Total** | | **43776** | **75** |

MTBF = 43776 /4 = 10944 Hrs

MTTR = 75 / 4 = 18.75 Hrs

$\lambda$ = 1/ MTBF = 1/ 5697 = 0.000092 failure / hour

A = MTBF / MTBF+MTTR = 10944 / 10944+18.75 = 0.998

**Station: Hamad Town Blending station**

Type of defects: leakage from discharge header

Equipment Name: Hamad Town pump #1

Frequency: 4

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs |
|---|---|---|---|
| 1 | 1-1-2005 | 0 | 0 |
| 2 | 26-10-2005 | 7152 | 7.5 |
| 3 | 5-4-2007 | 12624 | 26 |
| 4 | 17-1-2008 | 6888 | 6 |
| 5 | 29-6-2011 | 30216 | 10 |
| **Total** | | **56880** | **49.5** |

MTBF = 56880 /4 = 14220 Hrs

MTTR = 49.5 / 4 = 12.375 Hrs

$\lambda$ = 1/ MTBF = 1/ 14220 = 0.00007 failure / hour

A = MTBF / MTBF+MTTR = 14220 / 14220+12.375 = 0.999

**Station: Hamad Town Blending station**

Type of defects: leakage from discharge header

Equipment Name: Hamad Town pump #2

Frequency: 5

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs |
|---|---|---|---|
| 1 | 1-1-2005 | 0 | 0 |
| 2 | 24-11-2006 | 16608 | 5.5 |
| 3 | 17-1-2008 | 10056 | 4 |
| 4 | 18-1-2010 | 17568 | 21 |
| 5 | 1-2-2010 | 336 | 12 |
| 6 | 21-2-2011 | 9240 | 10 |
| **Total** | | **53808** | **52.5** |

MTBF = 53808 /4 = 10761.6 Hrs

MTTR = 52.5 / 5 = 10.5 Hrs

$\lambda$ = 1/ MTBF = 1/ 10761.6 = 0.000092 failure / hour

A = MTBF / MTBF+MTTR = 10761.6 / 10761.6+10.5 = 0.999

**Station: West Riff'a #1 Blending station**

Type of defects: leakage from discharge header

Equipment Name: Distillate water pump #1

Frequency: 4

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs |
|---|---|---|---|
| 1 | 1-1-2005 | 0 | 0 |
| 2 | 27-1-2008 | 26904 | 36.5 |
| 3 | 28-10-2008 | 6600 | 10 |
| 4 | 1-7-2010 | 14664 | 4 |
| 5 | 21-7-2011 | 9240 | 10 |
| **Total** | | **57408** | **60.5** |

MTBF = 57408 / 4 = 14352 Hrs

MTTR = 60.5 / 4 = 15.125 Hrs

$\lambda$ = 1/ MTBF = 1/ 14352 = 0.000069 failure / hour

A = MTBF / MTBF+MTTR = 14352 / 14352+15.125 = 0.998

**Station: West Riff'a #1 Blending station**

Type of defects: leakage from discharge header

Equipment Name: West Tower pump #1

Frequency: 6

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs |
|---|---|---|---|
| 1 | 1-1-2005 | 0 | 0 |
| 2 | 7-6-2008 | 30072 | 10 |
| 3 | 16-2-2009 | 6096 | 30 |
| 4 | 1-3-2009 | 312 | 42 |
| 5 | 17-7-2009 | 3312 | 24 |
| 6 | 4-8-2009 | 432 | 1 |
| 7 | 17-11-2010 | 11280 | 35 |
| **Total** | | **51504** | **142** |

MTBF = 51504 / 6 = 8584 Hrs

MTTR = 142 / 6 = 23.67 Hrs

$\lambda$ = 1/ MTBF = 1/ 8584 = 0.00011 failure / hour

A = MTBF / MTBF+MTTR = 8584 / 8584+23.67 = 0.997

Appendix Q

# Cost of corrective action (repair) for discharge header or valve leakage

## Appendix Q, Cost of corrective action (repair) for discharge header

### 1. Hamala A2 GFS:

Table Q1 - Cost of repairing for ground water pump # 1 at Hamala A2 GFS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Repaired | 4 | 10.8 | - |
| 2 | Repaired | 3.5 | 9.45 | - |
| 3 | Welded | 42 | 169.4 | 35 |
| Total | | 49.5 | 189.65 | 35 |

Table Q2 - Cost of repairing for ground water pump # 3 at Hamala A2 GFS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Repaired | 30 | 79.9 | 48 |
| 2 | Repaired | 7 | 7 | - |
| 3 | Welded | 3 | 8.1 | - |
| 4 | Repaired | 35 | 90.3 | 2 |
| Total | | 75 | 185.3 | 50 |

### 2. Hamad Town BS:

Table Q3 - Cost of repairing for HTD pump # 1 at HTBS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Repaired | 7.5 | 12.25 | - |
| 2 | Repaired | 26 | 56.06 | 15.10 |
| 3 | repaired | 6 | 17.10 | - |
| 4 | Welded | 10 | 44.58 | - |
| Total | | 49.5 | 129.99 | 15.1 |

Table Q4 - Cost of repairing for HTD pump # 2 at HTBS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Welded | 5.5 | 8.8 | - |
| 2 | Welded | 4 | 11.4 | - |
| 3 | Welded | 21 | 58.8 | - |
| 4 | Welded | 12 | 38.51 | - |
| 5 | Welded | 10 | 28.5 | - |
| Total | | 52.5 | 146.01 | - |

## 3. West Riff'a #1 BS:

Table Q5 - Cost of repairing for distillate water pump # 1 at West Riff'a #1 BS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Remove spool, weld and reinstall | 36.5 | 75.7 | 70 |
| 2 | Welded | 10 | 40.5 | - |
| 3 | Welded | 4 | 12 | - |
| 4 | Welded | 10 | 25.5 | - |
| Total | | 60.5 | 153.7 | 70 |

Table Q6 - Cost of repairing for West Tower pump # 2 at West Riff'a #1 BS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Completed | 10 | 29.36 | - |
| 2 | Repaired | 30 | 99.17 | - |
| 3 | Welded | 42 | 111.30 | - |
| 4 | Welded | 24 | 73.50 | - |
| 5 | Cancelled | 1 | 3.4 | - |
| 6 | Welded | 35 | 94.5 | - |
| Total | | 142 | 411.23 | - |

Appendix R

# Mean time between failure for drain valve is blocked or broken

**Appendix R**

**Mean time between failure for drain line and valve leakage, blockage or breakage**

**Assumption : Failure rate is constant for all pumps**

**Station: Hamad Town Distribution station**

Type of defects: drain valve is blocked or broken

Equipment Name: Tower pump #2

Frequency: 7

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs |
|---|---|---|---|
| 1 | 1-1-2005 | 0 | 0 |
| 2 | 15-5-2005 | 3216 | 9 |
| 3 | 15-5-2005 | 0 | 9 |
| 4 | 17-9-2006 | 11760 | 14 |
| 5 | 12-11-2006 | 1344 | 5 |
| 6 | 13-11-2006 | 24 | 0 |
| 7 | 27-11-2009 | 26640 | 4 |
| 8 | 16-9-2011 | 15792 | 6 |
| **Total** | | **58776** | 47 |

MTBF = 58776 / 7 = 8396.6 Hrs

MTTR = 47 / 7 = 6.7 Hrs

$\lambda$ = 1/ MTBF = 1/ 8396.6 = 0.00012 failure / hour

A = MTBF / MTBF+MTTR = 8396.6 / 8396.6 + 6.7 = 0.999

**Station: West Riff'a #2 BS**

Type of defects: drain valve is blocked or broken

Equipment Name: GW pump #2

Frequency: 5

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs |
|---|---|---|---|
| 1 | 1-1-2005 | 0 | 0 |
| 2 | 7-2-2005 | 888 | 6.5 |
| 3 | 23-6-2005 | 3264 | 2 |
| 4 | 8-7-2005 | 360 | 6 |
| 5 | 29-11-2005 | 3456 | 13 |
| 6 | 10-7-2007 | 14112 | 9 |
| **Total** | | **22080** | **36.5** |

MTBF = 22080 /5 = 4416 Hrs

MTTR = 36.5 / 3 = 7.3 Hrs

$\lambda$ = 1/ MTBF = 1/ 4416 = 0.00022 failure / hour

A = MTBF / MTBF+MTTR = 4416 / 4416+7.3 = 0.998

**Station: West Riff'a #2 BS**

Type of defects: drain valve is blocked or broken

Equipment Name: Tower pump #2

Frequency: 5

| Serial no. | Date of failure | Time to failure (TTF)in Hrs | Time to repair (TTR) in Hrs |
|---|---|---|---|
| 1 | 1-1-2005 | 0 | 0 |
| 2 | 23-6-2005 | 4152 | 2 |
| 3 | 30-7-2005 | 888 | 10 |
| 4 | 21-11-2005 | 11496 | 6.5 |
| 5 | 26-7-2006 | 5928 | 6 |
| 6 | 20-4-2008 | 15216 | 4 |
| **Total** | | **37680** | **28.5** |

MTBF = 37680 / 5 = 7536 Hrs

MTTR = 28.5 / 5 = 5.7 Hrs

$\lambda$ = 1/ MTBF = 1/ 7536 = 0.00013 failure / hour

A = MTBF / MTBF+MTTR = 7536 / 7536+5.7 = 0.999

Appendix S

# Cost of corrective action (repair) for drain valve leakage, blockage or broken

Appendix S

**Cost of corrective action (repair) for drain line and valve leakage, blockage or breakage**

1. **Hamad Town DS:**

Table 1S - Cost of repairing for Tower pump # 1 at HTDS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Repaired | 9 | 13.5 | 0 |
| 2 | Repaired | 9 | 13.5 | 0 |
| 3 | Replace old line with new pipes | 14 | 20.3 | 0 |
| 4 | Replaced | 5 | 11 | 0 |
| 5 | Duplicate | 0 | 0 | 0 |
| 6 | Replaced | 4 | 16.2 | 1.5 |
| 7 | Replaced with new one | 6 | 24 | 1.5 |
| Total | | 47 | 98.5 | 3 |

2. **West Riff'a #2 BS:**

Table 2S - Cost of repairing for ground water pump # 2 at West Riff'a #2 BS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | Repaired | 6.5 | 14.3 | 0 |
| 2 | De-clogged | 2 | 2.9 | 0 |
| 3 | Repaired | 6 | 10.6 | 0 |
| 4 | Made free | 13 | 28.6 | 0 |
| 5 | Cleaned | 9 | 16.65 | 0 |
| Total | | 36.5 | 73.05 | 0 |

Table 3S - Cost of repairing for Tower pump # 2 at West Riff'a #2 BS

| No. | Action by Maintenance | Man-hours (Hrs) | Manpower ( BD) | Material (BD) |
|---|---|---|---|---|
| 1 | De-clogged | 2 | 2.9 | 0 |
| 2 | Cleaned | 10 | 14.8 | 0 |
| 3 | Made free | 6.5 | 13 | 0 |
| 4 | Cleaned | 6 | 8.7 | 0 |
| 5 | Cleaned | 4 | 10.8 | 0 |
| Total | | 28.5 | 50.2 | 0 |

Appendix T

# Mechanical Maintenance practices for repairing pumps defects

Appendix T

Mechanical Maintenance practices for repairing pumps defects

| No. | Mechanical Defect description | Frequency of Defects (Cost in BD) | Practices implemented to Repair the defect from MMS |
|---|---|---|---|
| 1 | Gland packing of the pump is leaking | 238 (Cost = BD 19818.03) | 1. Packing replaced: (38)<br>2. Packing adjusted: (147)<br>3. Slade packing replace: (5)<br>4. Tightened: (7)<br>5. Leak secured: (3)<br>6. Checked and leak repaired: (3)<br>7. Add packing and tightened: (14)<br>8. Repaired :(8)<br>9. Remove one packing: (1)<br>10. Replace packing sleeve and pump bearings as well the packing:(1)<br>11. Replace pump bearings and packing: (3)<br>12. Top casing opened, clean the impeller and aligned: (1)<br>13. Duplicate: (5)<br>14. Cancelled : (2) |
| 2 | leakage from discharge line /valve | 76 (Cost = BD 4813.92) | 1. Welding repair: (28)<br>2. Leak repaired: (26)<br>3. Replace existing spool: (1)<br>4. Pin hole patched: (5)<br>5. Welding square metal (100 mm)on header: (3)<br>6. Remove spool (400x300mm) weld and fix back: (1)<br>7. Repair using clamp: (4)<br>8. Elbow repaired: (3)<br>9. Duplicate : (2)<br>10. Cancelled: (3) |
| 3 | Drain valve is blocked /leaking/broken | 63 | 1. De-clogged : (8) |

| | | | |
|---|---|---|---|
| | | (Cost = BD 1530.56) | 2. Cleaned and made free : (23)<br>3. Pipe replaced : (14)<br>4. Replace broken pieces : (7)<br>5. Leak secured : (6)<br>6. Drain line welded : (1)<br>7. Fabricate new drain line: (1)<br>8. Replace damage elbow : (1\|)<br>9. Duplicate : (2) |
| 4 | Check valve is not working properly (Passing or Hammering) | 58<br>(Cost = BD 7018.02) | 1. Repair loose nozzle: (2)<br>2. Re-fix NRV weight: (2)<br>3. Internal parts cleaned: (3)<br>4. Top cover of valve removed-repaired : (1)<br>5. Repaired : (14)<br>6. Normal : (9)<br>7. NRV disc repaired, and the valve painted :(1)<br>8. Overhauled : (1)<br>9. Load adjusted :(3)<br>10. Replace with reconditioned valve : (3)<br>11. By pass valve replaced : (2)<br>12. Valve exercised : (8)<br>13. Stopper welded : (2)<br>14. Adjust the shaft of the NRV : (3)<br>15. NRV cleaned and exercised : (4) |
| 5 | Check valve is leaking | 45<br>(Cost = BD 1553.55) | 1. Leak secured: (3)<br>2. O ring of leaver replaced : (12)<br>3. Leak is minor, no need for shutdown : (1)<br>4. No leak : (1)<br>5. Repaired : (15)<br>6. Shuttering door gear repaired: (1)<br>7. Replace valve spindle seal: (2)<br>8. Remove valve disc and shaft for cleaning : (1)<br>9. New shaft seal provided: (1)<br>10. Remove for repairing and fixed back : (1) |

| | | | |
|---|---|---|---|
| | | | 11. Replace NRV : (1)<br>12. Adjust packing: (5)<br>13. Duplicate : (1) |
| 6 | Inboard bearing is noisy | 45<br>(Cost = BD 6730.37) | 1. Apply grease : (13)<br>2. Top cover lifted, wear ring cleaned and lateral ring cleaned : (1)<br>3. Normal reading within limit: (16)<br>4. Pump sent for overhauling : (3)<br>5. Cleaned and lubricated: (5)<br>6. Liquid assembly replaced, inboard bearing is rotating inside bearing housing:(1)<br>7. Alignment done for the pump : (1)<br>8. Repaired: (5) |
| 7 | Gland packing of the pump is smoking | 29<br>(Cost = BD 1302.62) | 1. Gland packing adjusted : (16)<br>2. Gland packing replaced: (10)<br>3. Adjusted by contractor: (2)<br>4. Repaired: (1) |
| 8 | Motor inboard bearing is noisy | 29<br>(Cost = BD 1590.09) | 1. Apply grease : (16)<br>2. Motor overhauled : (2)<br>3. Replace grease : (2)<br>4. Both bearings were noisy, motor replaced : (1)<br>5. Sensor was loosed, adjusted : (1)<br>6. Noise from pump: (1)<br>7. Normal, within limit: (4)<br>8. Repaired by contractor (under warranty) : (1)<br>9. Cancelled : (1) |
| 9 | Motor outboard bearing is noisy | 14<br>(Cost = BD 2875.43) | 1. Apply grease : (6)<br>2. Motor disconnected, sent for overhaul : (1)<br>3. Lubricated both bearings : (1)<br>4. Normal, within limit : (6) |
| 10 | Gland packing of the suction valve is leaking | 9<br>(Cost = BD 243.48) | 1. Packing adjusted : (3)<br>2. Packing replaced: (2)<br>3. Gland follower adjusted: (2) |

| | | | |
|---|---|---|---|
| | | | 4. Tightened: (2) |
| 11 | Outboard bearing is noisy | 9 (Cost = BD 540.19) | 1. Bearing replaced : (1)<br>2. Checked : (3)<br>3. Contractor replace the bearings: (1)<br>4. Within limit: (4) |
| 12 | Relieve valve is blocked | 8 (Cost = BD 144.6) | 1. Cleaned : (7)<br>2. Replaced : (1) |
| 13 | Gland packing of the discharge valve is leaking | 7 (Cost = BD 505.27) | 1. Packing adjusted :(5)<br>2. Gland follower adjusted : (2) |
| 14 | Inboard bearing temperature is high | 6 (Cost = BD 146.15) | 1. Remove extra grease from inboard bearings : (1)<br>2. Normal : (2)<br>3. Repaired:(3) |
| 15 | Outboard bearing temperature is high | 6 (Cost = BD 598.31) | 1. Normal : (4)<br>2. Apply grease : (2) |
| 16 | Coupling is damaged | 4 (Cost = BD 1023.61) | 1. Rubber bush replaced: (1)<br>2. Gland packing adjusted: (1)<br>3. Gland packing replaced: (1)<br>4. Replace bearings: (1) |
| 17 | Casing is leaking from pin hole | 4 (Cost = BD 2118.8) | 1. Replace the plug : (2)<br>2. Replace the casing : (1)<br>3. Top cover removed, problem from the stuffing box : (1) |
| 18 | Shaft is jammed | 3 (Cost = BD 153.54) | 1. Remove shaft and repair parts: (1)<br>2. Pump coupling made free : (1)<br>3. Made free : (1) |
| 19 | Inboard bearing grease is coming out | 3 (Cost = BD 93.46) | 1. Replace grease : (3) |
| 20 | Pump is not sucking water | 2 (Cost =BD 46) | 1. Wrong defect , no problem: (1) |
| 21 | Suction / discharge valve is jammed | 1 (Cost = BD 101.725) | 1. Valve made free: (1) |
| 22 | Coupling cove to be re-fixed | 1 (Cost = BD 29) | 1. Coupling bolts replaced: (1) |
| | **Total** | 660 (Cost = BD **52976.725**) | |