A GENERIC PREVENTIVE MAINTENANCE FRAMEWORK OF INDUSTRIAL BOILER CORROSION

BY

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ABSTRACT

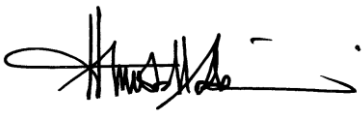
In the oil and gas industries, numerous factors affect boiler performance and one of the more critical ones is corrosion. In addressing this particular problem, a number of related studies have been conducted, such as statistical analysis, analysis of variance, and optimisation techniques. In this study, the corrosion problems affecting the oil and gas industries in Kuwait were looked into, since it is one of the major global producers and exporters of crude oil, used as fuels for the source of energy, during the steam generation in the industrial boilers. However, the presence of various chemical substances on the boiler surface creates problems of corrosion, attributed to losses worth billions of dollars, every year, in various organisations. Much effort has been taken by many researchers and practitioners, in finding out efficient solutions. Every industry has different responsibilities and structures, and applying one solution for every industry is complex. Therefore, this study aimed to fill this research gap and build up a new prevention system that shows the generalised results. In this study, a systematic literature review, based on preliminary studies in corrosion, was conducted, to examine all the contributing factors, sources of corrosion, and the present corrosion prevention systems. After determining all the contributing factors and identifying shortcomings in previous studies, a five-point Likert scale boiler corrosion survey was conducted, along with an empirical validation and a convenience sampling, in the oil and gas industries, in Kuwait. Statistical Package for the Social Sciences (SPSS 2.0) was used to find the skewness and the set of main factors for the problem. Using the design science approach, a new corrosion prevention management framework was successfully developed, which could be applied to each industry. This new corrosion prevention management framework represents generalised results for all the present corrosion problems, and is to be used to validate the relevance and rigours of any relevant research, using the Hevner's seven-step approach, to provide a viable artefact for various research problems. An analysis of variance was used to determine the data optimisation, with predictable results. This shows the numerous factors that affect the corrosion performance of boilers in Kuwait's specific gas and oil industries. This framework is efficient, in terms of both managerial and technical perspectives, as proven by its cost-based analysis.

ملخص البحث

بالذات، تم إجراء عدد من الدراسات ذات الصلة، مثل التحليل الإحصائي، وتحليل التباين، وتقنيات التحسين. في هذه الدراسة، تم النظر في مشاكل التآكل التي تؤثر على صناعات النفط والغاز في الكويت، حيث أنها واحدة من المنتجين والمصدرين العالميين الرئيسيين للنفط الخام المستخدم كوقود لمصدر الطاقة أثناء توليد البخار في الغلايات الصناعية. ومع ذلك، فإن وجود مواد كيميائية مختلفة على سطح الغلاية يخلق مشاكل تآكل تُعزى إلى خسائر تقدر بمليارات الدولارات كل عام في مختلف المجالات. يبذل العديد من الباحثين والمهنيين جهودًا كبيرة لإيجاد حلول فعالة لهذه المشكلة. لكل صناعة مسؤولية وهيكل مختلف، ومن المعقد تطبيق حل واحد لكل الصناعات. لذلك هدفت هذه الدراسة إلى سد هذه الفجوة البحثية وبناء نظام وقائي جديد لإظهار النتائج العامة. في هذه الدراسة، تم إجراء مراجعة منهجية على أبحاث التآكل الأولية للتحقيق في جميع العوامل المساهمة في التآكل ومصادره وأنظمة منعه. بعد تحديد جميع العوامل المساهمة وتحديد أوجه القصور في الدراسات السابقة، تم إجراء مسح تآكل غلاية على مقياس ليكرت من خمس نقاط جنبًا إلى جنب مع التحقق التجريبي وأخذ العينات الملائمة في صناعات النفط والغاز في الكويت. تم استخدام الحزمة الإحصائية للعلوم الاجتماعية (SPSS 2.0) لإيجاد الانحراف ومجموعة العوامل الرئيسية للمشكلة. تم تطوير إطار جديد لإدارة منع التآكل بنجاح باستخدام نهج علم التصميم والذي يمكن تطبيقه على كل الصناعات. يمثل هذا الإطار الجديد لإدارة التآكل نتيجة عامة لجميع مشاكل التآكل الحالية وسيتم استخدامه للتحقق من ملاءمة ودقة أي بحث ذي صلة باستخدام نهج هيفنر المكون من سبع خطوات لتوفير أداة قابلة للتطبيق لمشاكل البحث المختلفة.تم استخدام تحليل التباين لتحديد تحسين البيانات والتنبؤ بالنتائج. يدل هذا على أن هناك العديد من العوامل التي تؤثر على مقاومة التآكل للغلايات في صناعات النفط والغاز في الكويت. يُعتبر هذا الإطار فعال من حيث المنظورين الإداري والفني كما ثبت من خلال تحليله القائم على التكلفة.

APPROVAL PAGE

The thesis of Nader S Th O S Alazemi has been approved by the following:



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This thesis is dedicated to my parents and family for their endless love, support, and encouragement

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In the Name of Allah, the Most Compassionate, the Most Gracious and the Most Merciful, in whose hands is all sovereignty, and He has power over all things. [67:1]. All Praise be to Allah, the Lord of the creations, and countless blessings and peace upon our Prophet Muhammed SAW.

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LIST OFABBREVIATIONS

EDS	Energy Dispersive Spectroscopy
RAIM	Rosin Amide Imidazoline
SPSS	Statistical Package for Social Sciences
VCI	Volatile Corrosion Inhibitors
AFM	Atomic Free Microscopy
SEM	Scanning Electron Microscope
TFHA	Transport Federal Highway Administration
CC	Cubical Crystal
GDP	Gross Domestic Product
KCI	Potassium Chloride

LIST OF SYMBOLS

psi	pascals
kw	kilowatt
t	temperature
p	pressure
ρ	density

CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW

The introduction, study background, research questions, research hypothesis, problem statement, research philosophy, scope, methodology, and goals of the current research are covered in this chapter. First, a summary, including a brief description of the subject, is introduced, followed by the research dilemma and logic to the solution based on the work's philosophy. At this point, the nature of the study is briefly explained. Objectives of the study are laid down with a specific end goal to answer the problem statement. Meanwhile, in the research methodology, the critical flow of the current study is explained.

1.2 BACKGROUND OF THE STUDY

At one of its refineries, a major oil and gas company faces a corrosion crisis related to its boilers. A process engineer normally uses Knovel's digital graphing method to solve the corrosion problem, by increasing the alkalinity of the water solution used in the boilers. The boiler efficiency can be improved, by modifying the solution. A typical fully corroded industrial boiler can be seen in Figure 1.1.

Figure 1.1 Corroded Industrial Boiler

A boiler is a vessel generally made of steel or alloy steel in a closed form, and its primary purpose is to heat the fluid (usually water). The fluid does not necessarily boil; it is also used to heat or vaporise the existing liquid, besides being used in various heating processes and applications, such as central heating, boiler-based power generation, cooking, and sanitation (Frederick M. Steingress,2001). So, the boiler is also a steam generation unit, designed to use the chemical energy present in a fuel that raises the energy content of the water used for power application and heating purposes. Many kinds of fuels are boiled; they may be either fossil or non-fossils fuels. The most common types of fuels include coal, oil, and natural gas. Steam could be generated by heating water in the boiler above the atmospheric pressure (Alazemi et al., 2019). Many industries, such as for food, oil, textile, dairy, garment, paper mills, commercial building, and breweries extensively use industrial boilers. Other types of boilers are used for many other applications, including office buildings, apartments, hotels, restaurants, schools, hospitals, government buildings, and airports.

A boiler is classified based on the content in the tubes, the number of tubes, the position of a furnace, an axis of shells, methods of water circulation, and steam. All types of boilers are suffering from the problem of corrosion, which is generally termed boiler corrosion.

Boiler corrosion is defined as the ongoing destruction of the surface of boiler metals, due to the pitting action of dissolved oxygen, which is present in the boiler water. This heavily defects the inner metallic exterior of the boiler, which often leads to the formation of deep holes in the metal, which may be self-protected by other corrosion products, such as scabs or blisters over the holes, thus allowing the chemical reaction to continue further. Generally, the surface of the boiler is built of heavy metals, that consist of many layers, but the oxygen pitting site can develop a deep penetration hole through the boiler metal surface, which causes ultimate failures. Oxygen dissolved in the water inside the boiler is often untreated and highly corrosive to the steam boiler. Deaerator and preheated water will reduce the dissolved oxygen content of raw water, so it is necessary to attain adequate chemical reserve of an effective oxygen scavenger, to avoid the damage of costly boiler metal corrosion and downtime. Boiler corrosion leads to a serious damage, in terms of both operational and financial aspects.

Kuwait is a significant producer and exporter of crude oil in the world. Due to the extensive presence of oil, they have been using oil sources for the generation of electricity and other applications. There is always a need for an industrial boiler to accomplish numerous operations, using crude oil. The ability of a boiler to use oil as a source of energy in evaporating water and converting it into steam allows it to create electricity and execute many application processes. Therefore, an industrial boiler is excellent; it is used for different processes and applications in food, oil and gas,

chemical, textile, pharmaceutical, and the power plant for energy generation (Tuffner, 2014). Figure 1.2 shows the section of the boiler in an animated form.

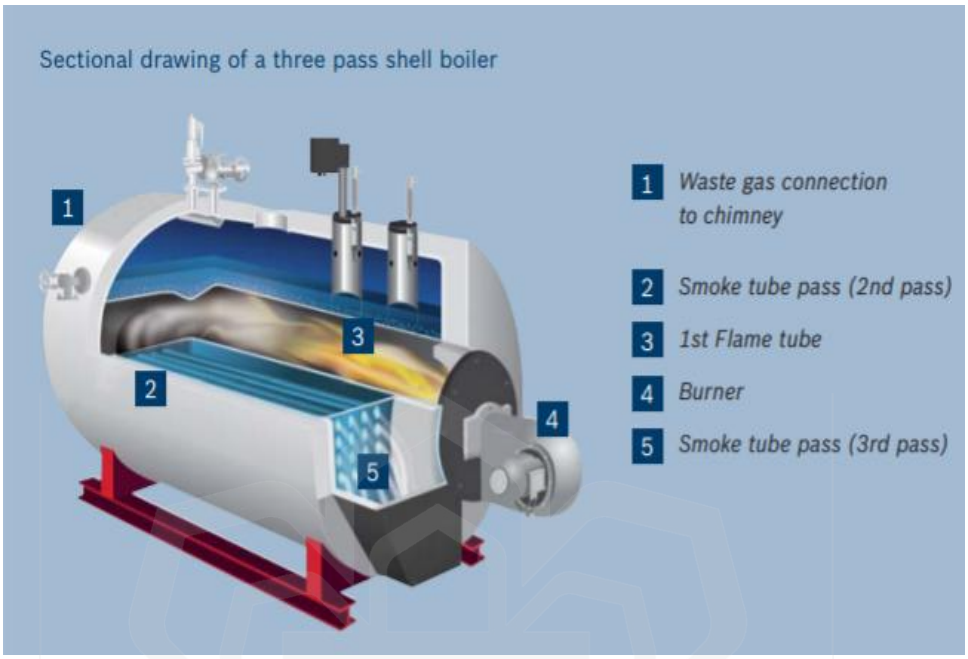

Figure 1.2 Industrial Boiler (Markus Tuffner, 2014)

1.3 COMMON ISSUES

Heat is an essential element for many operations in the industrial process. To transfer heat from one place to another, there will always be the availability of a process. Water or steam is considered as one of the best forms of heat transfer agents, because it contains some desirable properties, such as higher energy absorption, or easy transportability. It is readily available everywhere and not harmful to the environment. The atmospheric pressure of water is also lower. An industrial boiler operates on the same concept as a cooker, but its capability is far greater than that of the cooker in every way, allowing it to withstand far higher pressure than does a pressure cooker. An industrial boiler is welded with many layers of thick steel plates up to 35mm thick, able to take the pressure of 30 bar or higher. A reliable or robust

design for the boiler is necessary. Otherwise, there is always the possibility of the boiler collapsing and releasing explosive forces, equivalent to a tonne of gelatinate.

Different design measurements make it possible for the single boiler to generate about 38 MW of thermal output, which is approximately equal to the power of 500 average VW golf cars. The basic designs of hot water or steam boilers are relatively similar with each other. The boiler pressure vessel is a horizontal, cylindrical tube, closed at both sides with an end plate and insulated all around. A flame tube (1st pass) in this pressure vessel fires through a burner, and an internally situated reversing chamber reverses the flue gases and leads them back in the second smoke tube passes. On the front of the boiler is an external reversing chamber, which again reverses the flue gases and leads them to the end of the boiler in the third smoke tube pass. Hot water boilers are usually filled with water during the operation process. On the other hand, Steam boilers are only 3/4 filled with water; the upper quarter is the steam space, due to this vast design, which can store a massive amount of water and multi-stage lead through the flue gases is also the three-pass shell boiler.

All functions of an industrial boiler system are based on hot water or steam boiler that is powered by a specific type of fuel. Fuel undergoes a specific combustion process, which provides some energy, which is subsequently utilised to evaporate the water and transfer steam to the user, via the piping system. When all the steam is used, the remaining water flows back through the pipe, for reheating. Flue gases, created with the combustion of fuels, are transferred back to the atmosphere, through the chimney.

1.3.1 Boiler Corrosion

The main reason for corrosion occurring on the boiler surface is the presence of atmospheric oxygen in the air, or water that reacts with a metallic surface and performs the oxidation reaction. Meanwhile, in cases of industrial boilers, corrosion takes place due to oxygen, which dissolves into water present inside the boiler, and reacts with the metals of the steam boilers. The surface of the boiler is built of various metal or alloy metals, and a ferrous component of metals reacts with atmospheric oxygen in the water and undergoes the oxidation reaction. This oxidation chemical reaction leads to the formation of ferrous oxides. Ferrous oxides cause the formation of cavities and deep holes into the surface of metals. The formation of deep holes and cavities on the surface of the metallic element is termed pitting, the primary host for corrosion.

Leading Causes of Boiler Corrosion

1. Boiler maintenance is unscheduled and improper.
2. Presence of CO2 in the boiler water.
3. The pH level of boiled water is unbalanced.
4. Presence of oxygen in the boiler water.
5. Exposure of metals to dissolved gases.

The primary corrosion problem is cracking of metal surface, whereas cracking in the boiler metal may occur due to two different mechanisms. The first mechanism, cyclic stress, is due to rapid heating and cooling and it occurs on the metallic surface of the boiler. If the process is concentrated on a certain point only, it results in roughened corrosion or pitted metallic surfaces. It generally occurs due to improper corrosion prevention. The second type of corrosion, fatigue, started suing to the presence of a

thick protective oxide film on the surface of metals, which continues the cyclic stresses. Fatigue corrosion results in cracks, which are generally blunt and thick in shape. Based on the different types of chemical reactions, corrosion can be classified further.

Types of Corrosion in Industrial Boilers

1. Acidic corrosion
2. Caustic corrosion
3. Hydrogen embrittlement
4. Oxygen attack
5. Carbon dioxide attack
6. Galvanic corrosion

1.3.2 Effects of Boiler Corrosion

Corrosion can damage the boiler in two ways, general and pitting. General corrosion damages the overall system, whereas pitting only damages the minor part of the boiler surface. Corrosion of boilers affects the operation process and causes economic losses to the processing holder. Some of the effects of boiler corrosion are as follows.

Lost Efficiency- corrosion and scale deposits directly or indirectly affect the efficiency of an operation. Products of corrosion also lead to the scale deposit. Hence, if the amount of corrosion is not scaled up, there are more chances of corrosion in the future. More likely, into the pulled off the metal that will cause efficiency-robbing deposit. Corrosion that damages the surface of the boiler leads to the reduction of the system efficiency. Holes in the metals cause leaks that can cause various operational problems and could potentially result in the boiler shut down.

Shorter System Lifespan- failure in controlling corrosion will lead to shortening the lifespan of the entire system. If chemical composition within the water system does not receive attention timely, then corrosion will worsen with time and lead to the overall loss in efficiency experience, continuing to degrade until the system shuts down.

Higher Costs- the cost of repairing the damaged parts or replacing them, due to corrosion, is excessively costly. In many cases, replacing the overall system or pitted tubes is required, instead of repairs. To replace the damaged parts, it will need to shut down the system for some time, affecting the overall plant productivity. Even after replacing the damaged parts of the system, attaining the previous level of productivity is not guaranteed.

Holes- the formation of holes occurs when the boiler is continued to be used for further processing, when pitting has already taken place, and any other prevention has not been taken. A hole will be gradually damaging the whole surface of the boiler.

Pitting-pitting is the major corrosion problem; it occurs on the surface part, in the presence of a prominent level of oxygen, and the oxygen reacts with metals, causing pits on the surface. If any maintenance or prevention is not undertaken, pitting worsens and causes more holes on the surface.

1.4 PROBLEM STATEMENT

A lot of research work have already been done in the field of boiler corrosion and its prevention. Every method has its own anomalies and to find out the best approach to prevent corrosion, studying the boiler corrosion is required. This research examined the corrosion problems in boilers used in the Kuwait's oil and gas industry. Kuwait is a giant producer and exporter of crude oil, and various organisations have been using