ANALYSIS OF OPERATIONAL FACTORS AFFECTING BOILER PERFORMANCE: KUWAIT AS A CASE STUDY

BY

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ABSTRACT

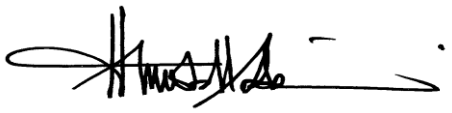
A boiler is a closed vessel used to heat fluid (typically water). The heat or vapours expelled by the boiler's fluid are employed in various heating techniques or applications, including sanitation, boiler-based power production, central heating, cooking, and water heating. According to the ASME performance test code (PTC), there are two techniques for determining the efficiency of a boiler: the Input-Output Method (Direct method), and the Heat Loss Method (Indirect method). Diverse studies on boiler efficiency have been undertaken over the last few decades using various methodologies, including experimental analysis and optimization methods. It is critical to monitor boiler efficiency to increase overall plant production. As a result, numerous approaches are employed to enhance boiler efficiency. Similarly, another research found that a boiler consumes approximately eighty percent of the boiler's energy and operational cost. As a result, it is noted that a variety of undesirable impacts might result in additional losses; such losses are mainly caused by unburned fuel, tube gas accumulation, convective, and radiative heat loss. As a result, this research aims to investigate boiler performance and increase boiler efficiency in the Kuwait oil and gas industries using a design optimization technique. This research thesis examined several elements to enhance the boiler's efficiency using the analysis of variance approach, including pre-heater design, economizer design, an efficient heating system design, and so on. For this objective, we used the design optimization technique to examine the feasibility and probability of boiler performance and efficiency under various conditions using empirical data from respondents in Kuwait's oil and gas business. According to the findings of this study, around 30% of heat energy is lost during the process of discharging flue gas from the boiler. As a result, the requirement for boiler design transformation is critical for improving boiler performance.

ملخص البحث

الغلاية عبارة عن وعاء مغلق يستخدم لتسخين السوائل (عادة الماء). يتم استخدام الحرارة أو الأبخرة التي يطردها سائل الغلاية في مجموعة متنوعة من تقنيات أو تطبيقات التدفئة، بما في ذلك الصرف الصحي، وإنتاج الطاقة المعتمد على الغلايات، والتدفئة المركزية، والطهي، وتسخين المياه. وفقًا لرمز اختبار أداء **(ASME (PTC**، هناك طريقتان لتحديد كفاءة المرجل: طريقة الإدخال والإخراج (الطريقة المباشرة) وطريقة فقدان الحرارة (الطريقة غير المباشرة). تم إجراء دراسات متنوعة حول كفاءة المراجل على مدى العقود القليلة الماضية باستخدام منهجيات مختلفة، بما في ذلك التحليل التجريبي وطرق التحسين. من الأهمية بمكان مراقبة كفاءة المرجل من أجل زيادة الإنتاج الكلي للمصنع. نتيجة لذلك، يتم استخدام العديد من الأساليب لتعزيز كفاءة المرجل. وبالمثل، وجد بحث آخر أن المرجل يستهلك ما يقرب من ثمانين بالمائة من طاقة الغلاية بالإضافة إلى التكلفة التشغيلية. نتيجة لذلك، لوحظ أن مجموعة متنوعة من الآثار غير المرغوب فيها قد تؤدي إلى خسائر إضافية؛ هذه الخسائر ناتجة بشكل رئيسي عن الوقود غير المحترق، وتراكم غاز الأنبوب، والحمل الحراري، وفقدان الحرارة الإشعاعي. نتيجة لذلك، فإن الغرض من هذا البحث هو التحقق من أداء الغلايات وزيادة كفاءة الغلايات في صناعات النفط والغاز الكويتية باستخدام تقنية تحسين التصميم. فحصت أطروحة البحث هذه عدة عناصر لتعزيز كفاءة الغلاية باستخدام تحليل نهج التباين، بما في ذلك تصميم السخان المسبق ، وتصميم الموفر، وتصميم نظام التدفئة الفعال، وما إلى ذلك. لتحقيق هذا الهدف، استخدمنا تقنية تحسين التصميم لفحص جدوى واحتمالية أداء المرجل وكفاءته في ظل ظروف مختلفة باستخدام البيانات التجريبية من المشاركين في أعمال النفط والغاز في الكويت. وفقًا لنتائج هذه الدراسة، يتم فقدان حوالي 30٪ من الطاقة الحرارية أثناء عملية تفريغ غاز المداخن من المرجل. نتيجة لذلك ، فإن الحاجة إلى تحويل تصميم الغلاية أمر بالغ الأهمية لتحسين أداء المرجل.

APPROVAL PAGE

The thesis of Faisal M Sh F Alazemi. has been approved by the following:



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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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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 Merciful

Allah - beginning with the name of - the Most Gracious, the Most Merciful Most Auspicious is he in whose control is the entire kingship; and he is able to do all things [67:1]. All Praise to Allah, the Lord of the creation, and countless blessings and peace upon our Master Mohammed, the leader of the Prophets.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVATIONS

AEC	Architecture, Engineering and Construction
AHP	Analytical hierarchy process
ASME	American Society of Mechanical Engineering
BCMPs	Best Co-Management Practices prioritization
BIM	Building information modelling
BMPs	Best Management Practices
GBC	Green building construction
KW	Kilowatt
HR	Human Recourse
MAUT	Multi attribute utility technique
MCDM	Multiple-criteria decision-making
MCDM	Multi-criteria decision-making
SPSS	Statistical Package for the Social Sciences
PMBOK	Project Management Body of Knowledge
PTC	Performance Test Code

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 current research are covered in this chapter. First, a summary, including a brief description of the subject, is introduced and 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 quickly explained. Objectives are laid down with a specific goal to answer the problem statement. Then, in the research methodology, the critical flow of the current study is explained. Finally, the thesis's description is presented.

1.2 INTRODUCTION

As it suggests, the term boilers are hot water or steam generating and dispensing units where the hot water and steam are supplied and passed through the heating pipes or the process included in the use. A boiler is a closed, giant metal reservoir or chamber built so that it is possible to use the chemical energy used as the fuel and a heating element and to use it as heating and other power-related methods. The said process can be accomplished if the water is heated above the tolerance level and the desired ambient pressure and temperature. The boiler supplied the required or desired type of steam under pressure and vacuum to the process after reaching the desired temperature and its threshold limit and can therefore be referred to as the water to steam converter/producer. Any uniform liquid or fluid that later converts into vapor form by phase and can be considered the whole evaporation process may be the boiler's input.

Many fuels are used as the firing factor in the boiler and act as the boiler's input/feed, which may be either fossil fuels or non-fossil fuels, but most widely used as feeds are oil, coal, and natural gases.

1.3 BACKGROUND OF THE STUDY

Complex geometry is utilized in a boiler design because it has multiple inputs and multiple outputs. This method is of a non-linear form that has no function for self-balancing. In terms of both physical and chemical processes, the combustion process of a boiler is also complex. A boiler is used for various food factories, cement industries, etc. Due to different factors, such as energy consumption, low maintenance costs, environmental protection, etc., the performance of a boiler must be increased. In recent days, on the impulse of urgent environmental concerns such as global warming, everybody is designing a design that will assist in energy conservation. Boilers are primarily used to generate steam or produce hot water in several industries and power plants. Several studies have shown that energy consumption is significant in boilers (Barama et al., 2017). Therefore, improving the boiler performance will save a substantial amount of energy, even in limited amounts. This will also boost greenhouse emissions, which would be a big step for environmental safety.

By definition, a boiler is a pressure vessel that, depending on the requirements, is used to produce electricity or supply the industry with hot water to provide heating facilities. Boilers supply hot water or steam services for domestic and industrial uses in commercial and residential buildings (Jaymaha, 2006). Electricity, coal, gas, etc., and nuclear power are mainly used for generation. Boilers are suitable options for converting energy generated by these resources, such as thermal energy, into electricity. Day by day, the supplies of fossil fuels are depleted, and demand for other

energy resources, such as oil, gas, coal, etc., for electricity generation is growing. According to a report, by the end of 2030, demand for certain energy services will cross 47.5 percent-94.7 percent (Barma et al., 2017; Som and Dutta, 2008). Improvements in boiler efficiency are also critical.

With fuel combustion in the furnace, chemical energy derived from the fuel is converted into thermal energy in a steam boiler (Figure 1.1). The architecture of a boiler is becoming more complicated these days as a more significant number of devices are connected, such as heat exchangers, pre-heaters, economizers, etc.

1.3.1 Methods to Increase the Energy Efficiency of the Boiler

Boilers are essential in many manufacturing plants, supplying hot water and steam for different purposes, from sterilization and washing to mechanical operation. There are significant benefits to be achieved by operating these boilers at maximum efficiency as an integral weapon, delivering the highest possible output, protection, and energy efficiency.

Boilers are also parts of manufacturing installations that are energy-consuming. Steam generation systems account for 34% of the electricity used in manufacturing in the United States, and up to one-third of all energy consumption in the United Kingdom is used to heat water. This illustrates that increasing boiler systems' energy efficiency will significantly change business running costs and the climate (Barama et al., 2017).

Most boilers have three elements: a burner that transforms heat to fuel, a heat exchanger that transfers heat to steam or hot water, and a boiler vessel. A chimney stack pulls out the combustion by-products (flue gases), and the steam and hot water flow to their final uses into a delivery system. The most common fuel used in boilers

is natural gas and oil, while electric boilers are typically used where combustion boilers pose a fire risk and where reducing emissions is necessary.

Via the following ways, boilers face heat and energy losses:

- Flue gas losses: These heat losses are due to the flue gas temperature and result from the excess air and combustion air temperature.
- Feedwater: Poor consistency of feedwater contributes to increased blowdown rate and other losses due to scale build-up in the delivery chain.
- Loss of radiation: The radiant loss of heat from the boiler casing.
- Blowdown losses: To monitor the concentration of suspended solids and avoid sludge formation, heated water is regularly discharged from boilers.

Figure 1.1 In an industrial application, boilers (Boilers, 2020).

The above sources of heat and energy losses can each be tackled by the following means to maximize boiler energy efficiency and reduce the heat lost by boilers and maximize their energy efficiency (Bhatia 2012):

- Regulation of boiler combustion: This helps minimize the combustion of waste air, so the hotter oxygen and nitrogen that emerges from the flue, the more energy is wasted. The flue gas oxygen concentration is measured and controlled, and modified.

Flue gas temperature is also a good boiler efficiency predictor. Boiler performance can be controlled by calculating flue temperature and comparing its modifications against steam load, atmospheric temperature, and oxygen content. The flue gas temperature should be kept as low as possible (Figure 1.2).

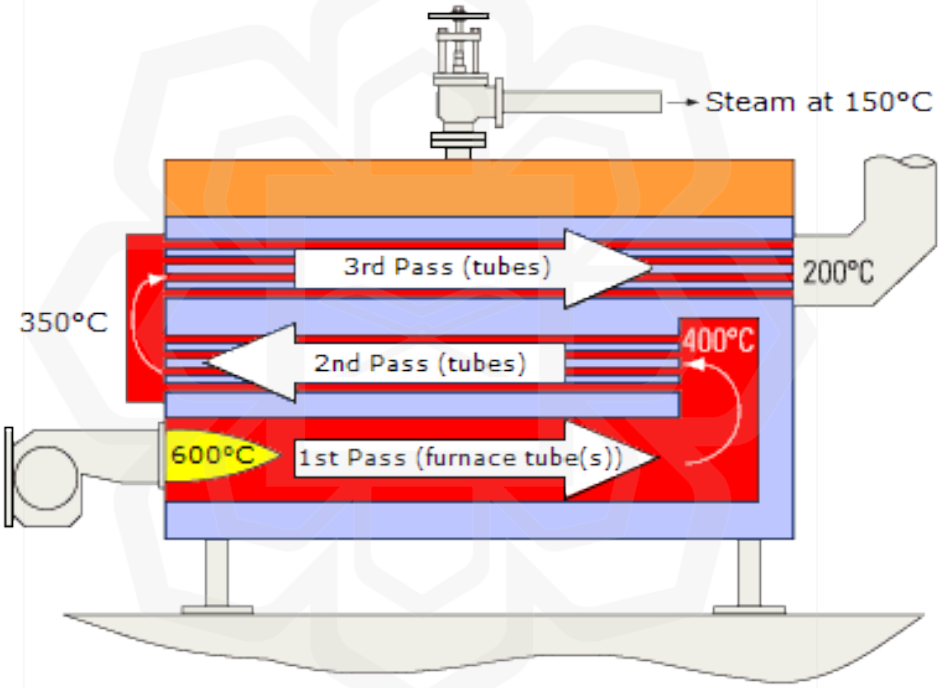

Figure 1.2 Shows the diagram of an industrial boiler process (Thermodyne, 2021).

- Pre-treatment of feedwater: Feedwater treatment includes eliminating impurities that can induce boiler sludge build-up and delivery system scale build-up. Feedwater clarification and filtration remove suspended material, while demineralization eliminates dissolved impurities.

- Boiler casing insulation: Proper insulation techniques and the preservation of insulation layers are needed to reduce heat loss by radiant heat loss from the boiler casing. Insulation must be assured that it is free from water or other liquid contaminants that may impair its ability to preserve heat.
- Recovery of blow-down heat: Blow-down water produces valuable energy that can be recovered. There are two critical approaches used. Flash steam is generated when blowdown occurs, and the flash steam can be recovered for low-pressure steam applications if the blowdown stream is directed to a flash steam vessel.

For pre-heating feedwater using a heat exchanger, blowdown water from either the blowdown stream or the liquid drain of the flash steam vessel may also be used.

By implementing an economizer, the energy efficiency of a boiler can also be improved. This heat exchanger pre-heats the boiler feedwater using the waste heat from the flue gas, thus minimizing the amount of input heat needed to get the feedwater temperature to the required degree (Figure 1.3).

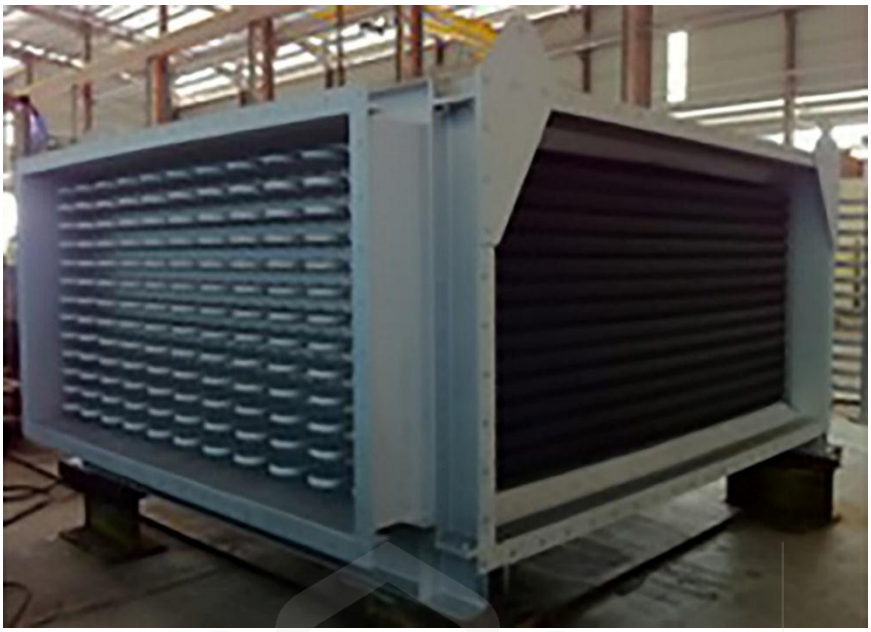

Figure 1.3 Boiler economizer (Mackenzie Industries, 2021)

Because of intrinsic constraints in boiler architecture, the approaches highlighted above can help to reduce energy and heat loss. Ultimately, it is based on the system configuration to improve further the performance of steam, hot water, or process heating systems. Owners of facilities will have to ensure the boilers are sized according to process needs and bear in mind that instead of one oversized boiler, they will need a range of interconnected smaller boilers to accommodate peak demand and future expansion. By implementing these practices and techniques, operators of manufacturing facilities would benefit from increased boiler energy efficiency and reduced running costs.

1.4 STATEMENT OF THE PROBLEM

Steam boilers are primarily used in various industries in Kuwait, such as the cement industry, chemical plants, etc. Energy efficiency is one of the main factors that will lead to the potential adoption of many energy policies. This will also aid with cost savings. A boiler uses a large volume of fuel. Therefore, boiler efficiency needs to be

improved. A slight performance improvement will further cause significant savings in fuel and operational costs. A successful maintenance program such as a preventive maintenance program or an optimization of the boiler configuration will improve the boiler's performance.

Four variables are essential for determining energy quality in the global giant that provides energy to manufacture goods in a highly dynamic international marketplace for the benefit of consumers (Ahamed et al., 2010). These four considerations include (a) Type of fuel, (b) Disadvantages of the combustion system, (c) Machinery configuration (d) Specifications for steam system service. Since the last century, boilers have been used in many applications of human life. Boilers play a crucial role in the oil and gas industry in various uses. Boiler quality, however, varies from one type to another and from application to application. In addition, the material used to build the boiler and the type of fuel used influence the boiler's performance due to complete or partial combustion. In addition, the boiler creates gases that are very harmful to nature and human beings. Many other issues and drawbacks can arise due to the losses during combustion, limiting performance, and adding to many fuel costs. By improving the performance of the operating boilers, these issues can be addressed.

Different factors are studied in many kinds of literature to boost the boiler performance, but optimization in the boiler design is not performed. Different kinds of fuels are analyzed, and the performance of a boiler is stated for each kind of fuel. The existence of excess air often has a significant effect on the boiler performance of certain other variables, such as flue gas temperature or stack temperature. Based on previous literature results, it is crucial to optimize the design of a boiler to function.

A successful boiler will help conserve electricity, one of the most significant issues these days, and will decrease carbon emissions. To minimize the environmental damage, low carbon emissions are required.

1.5 RESEARCH MOTIVATION

Due to many reasons, including the type of fuel, excess air, stack temperature, incomplete combustion, etc., the efficiency of a boiler is greatly affected. Because of a boiler's bad efficiency, the fuel intake increased a tone and began to emit carbon dioxide and carbon monoxide throughout the setting. Other variables must be defined and evaluated to monitor each factor's effect on the boiler's performance, regardless of the form and scale of the boiler. These studies can aid in analyzing heat losses due to many variables, such as radiation heat loss, conduction heat loss, convective heat loss. A proper boiler efficiency review can help decrease the critical cause of a boiler's output, such as dry flue gas production, excess air presence, carbon dioxide accumulation, bottom ash accumulation due to unburnt fuel, etc.

Poor efficiency and irregular behavior will arise because of proper boiler design optimization. When employed in industries where a boiler's performance is low, and there is a lack of maintenance and concern for the operational state of a boiler, it can be an all-time hazard. Due to identifying the root cause of boiler performance suffering, there is still a lack of different dynamic control techniques.

It is stated in the literature that the entire plant's productivity is decreased mainly due to heat loss. The only way to address this issue is through good maintenance practices and optimizing the different boiler designs and parts. In much of the available literature, only such essential criteria are found to have been used by