STUDY THE ENERGY RECOVERY IN ACRYLIC BOILER

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ABSTRACT

Boiler is widely used in industry as a utility which generate steam or hot water in a plant. Since, boiler involve heat exchange in the process, thus, it will involve energy loss in boiler. The loss can be caused by flue gas, surface radiation and convection and also because of blow down process. Therefore, this study is aimed to study the energy recovery of Acrylic Boiler. About 24% energy lost in this boiler. Thus, energy balance will be constructed by considering first law thermodynamics, calculating the energy loss based on flue gas stream based on ASME formulae and minimizing the energy loss. 77% of the losses due to flue gas lost. Heat recovery to minimize the lost will be considered. The recovered heat is used to preheat the boiler feed water until 93.3 °C. The loss can be minimized efficiently until 64%. Besides, the boiler efficiency is increased significantly. Hence superheated steam generated also can be increased up to 11%. Economic analysis should be done as to compare the effectiveness of heat recovery and energy saving for the boiler system.

ABSTRAK

Pendidih digunakan secara meluas dalam industri sebagai utiliti yang menjana stim atau air panas dalam loji. Oleh itu, pendidih melibatkan proses pertukaran haba. Justeru, ia akan melibatkan kehilangan tenaga dalam dandang. Kerugian yang boleh disebabkan oleh gas serombong, radiasi permukaan dan olahan dan juga kerana proses *blow down* . Oleh itu, kajian ini bertujuan untuk mengkaji pemulihan tenaga Pendidih Akrilik. Kehilangan tenaga sebanyak 24% dalam pendidih ini. Oleh itu, keseimbangan tenaga akan dibina dengan mengaplikasikan analisis hukum termodinamik pertama, mengira kehilangan tenaga berdasarkan aliran gas serombong berdasarkan formula ASME serta meminimumkan kehilangan tenaga. 77% daripada kehilangan tenaga yang disebabkan oleh pelepasan gas serombong ke atmosfera. Pemulihan haba untuk meminimumkan kehilangan tenaga akan dipertimbangkan. Haba pulih digunakan untuk memanaskan dahulu air masuk ke pendidih sehingga 93,3 °C. Kerugian ini boleh dikurangkan dengan tepat sehingga 64%. Selain itu, kecekapan pendidih meningkat dengan ketara. Oleh itu panas lampau dijana juga boleh meningkat sehingga 11%. Analisis ekonomi perlu dilakukan untuk membandingkan keberkesanan pemulihan haba dan penjimatan tenaga untuk sistem pendidih.

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LIST OF SYMBOLS

°C	degree Celcius
°F	Fahrenheit
kg/h	Mass Flow Rate
t/ hr	Mass Flow Rate
%	Percentage
kg/m^3	Density
kJ/kg °C	Specific Heat
kJ/kg	Enthalpy Difference
kg/kg	Ratio in Fuel

LIST OF ABBREVIATIONS

USD	US Dollar
CO	Carbon Monoxide
DG	Dry Gas
CO_2	Carbon Dioxide
O_2	Oxygen
N_2	Nitrogen

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Boiler plays an important role in processing industrial. It is used to generate basic needs for industrial operation. It is constructively combining several devices into a complex as to produce steam either in saturated or superheated steam and also hot water. In various processes or heating applications are depended on heated or vaporized exit of the boiler. It designs depends on type of fuel used, steam production unit, temperature and pressure of producing steam, and also combustion method.

Steam is either mist (as seen from a kettle), or the gas phase of water (water vapor). In common speech, steam most often refers to the visible white mist that condenses above boiling water as the hot vapor mixes with the cooler air. This mist consists of tiny droplets of liquid water. Pure steam emerges at the base of the spout of a steaming kettle where there is no visible vapor.

Pure steam is a transparent gas. At standard temperature and pressure, pure steam (unmixed with air, but in equilibrium with liquid water) occupies about 1,600 times the volume of an equal mass of liquid water. In the atmosphere, the partial pressure of water is much lower than 1 atm, therefore gaseous water can exist at temperatures much lower than 100 °C (212 °F).

The industrial used for steam such as steam engines and steam turbines. A steam engine uses the expansion of steam to drive a piston or turbine to perform mechanical work. The ability to return condensed steam as water-liquid to the boiler at high pressure with relatively little expenditure of pumping power is important. Engineers use an idealized thermodynamic cycle, the Rankine cycle, to model the behavior of steam engines. Steam turbines are often used in the production of electricity. Condensation of steam to water often occurs at the low-pressure end of a steam turbine, since this maximizes the energy efficiency, but such wet-steam conditions have to be limited to avoid excessive turbine blade erosion.

In other industrial applications steam is used for energy storage, which is introduced and extracted by heat transfer, usually through pipes. Steam is a capacious reservoir for thermal energy because of water's high heat of vaporization.

In the U.S., more than 86% of electricity is generated using steam as the working fluid, nearly all by steam turbines.

In electric generation, steam is typically condensed at the end of its expansion cycle, and returned to the boiler for re-use. However in cogeneration, steam is piped into buildings through a district heating system to provide heat energy after its use in the electric generation cycle. The world's biggest steam generation system is the New York City steam system which pumps steam into 100,000 buildings in Manhattan from seven cogeneration plants.

An autoclave, which uses steam under pressure, is used in microbiology laboratories and similar environments for sterilization. Steam is used in piping for utility lines. It is also used in jacketing and tracing of piping to maintain the uniform temperature in pipelines and vessels. Steam is generated for the following plant uses:

1. Turbine drive for electric generating equipment, blowers and pumps
2. Process for direct contact with products, direct contact sterilization and noncontact for processing temperatures
3. Heating and air conditioning for comfort and equipment

The efficiency achievable with steam generation relies heavily on the system's ability to return condensed steam to the operating cycle. Many of the systems described above return a significant portion of the condensed steam to the generation cycle.

A waste heat boiler is one of the devices which generally employed to recover energy from high temperature furnace gases. It may contain unburnt combustibles that are burnt to complete the combustion and to extract a significance fraction of waste energy under some operating condition

Regularly wastes are used for combustion as to generate steam for the plant usage. Waste heat is a heat produced by way of fuel combustion and will dump to the environment. However it still can be used for economic and environmental purpose. Thus, temperature of the waste heat gases and economics involved the strategy to recover the heat. Hot flue gasses in large quantity are generated from boilers, furnaces, kilns and oven. (Bureau of Energy Efficiency, n.d).

BASF Petronas Chemicals which located in Gebeng Kuantan, Pahang is a company in which facing a problem through the energy loss in Acrylic Boiler. Thus, this assessment is one part in solving the problem. This company basically offers high quality of products, such as Acrylic Monomer, Oxo Alcohol, and Butanediol & Derivatives. In producing super- absorbent polymers, acrylic acid is the main precursor to absorb liquid many times their own weight. It is widely used in diapers and other hygienic products. Plus, it is also used as a polymer flocculants that separates water from wastes. (BASF Petronas Chemicals, n.d)

1.2 PROBLEM STATEMENT

The Acrylic Boiler is used for the combustion of liquid and gaseous wastes from OAA and OAE plants along with some natural gas and also to generate steam about 85,000 kg/h at 50 barg for the plant usage. In addition, the superheaters (two stages) of waste heat recovery boiler are used to superheat the saturated 50 bar steam from AA plant. However, currently only maximum 65t/hr of steam is produced since it was designed without process steam and it requires 88t/hr of 50 bar superheated steam should be produced.

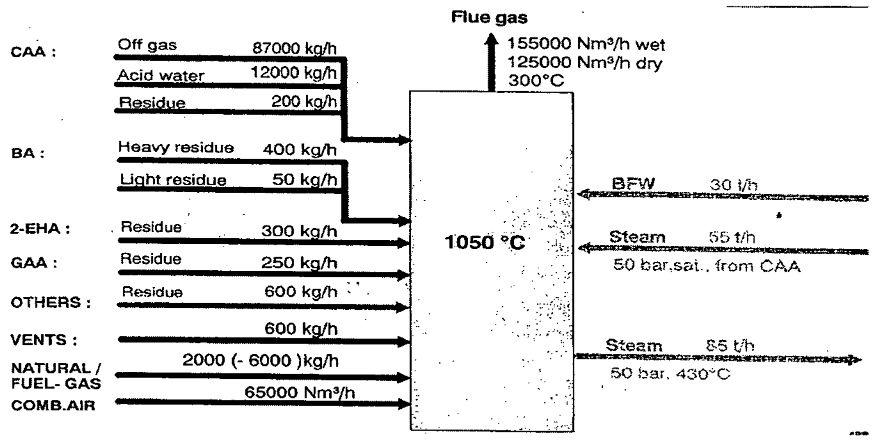


Figure 1.1: Acrylic Boiler of BASF Petronas Chemicals in Gebeng, Kuantan.

1.3 RESEARCH OBJECTIVE

The objectives are based on energy balance, energy loss and minimizing the energy loss in Acrylic Boiler. The objectives as followed:

1) To study the energy balance
2) To calculate the energy loss in the boiler flue gas stream
3) To minimize the energy loss

1.4 SCOPE OF STUDY

Based on the problems in which occurs from Acrylic Boiler in BASF Chemicals located in Gebeng, about 24% of energy has lost, since the boiler was designed to produce up to 85 000 kg/h of steam, however only 65 000 kg/h can be produced. Plus, objectives obtained must focus more in minimizing the energy loss. By recovering the energy loss due to flue gas, it is expected to reduce the total energy loss of the boiler. Hence increased the boiler efficiency and also increase the superheated steam generated.

1.5 RATIONAL AND SIGNIFICANCE

This study will offer the improvement on boiler efficiency, minimization of energy loss in which will produce optimum steam generation for other plant, and also energy cost can be reduced. (J. Francisco & A. Mario 1992) have found that, after minimizing the loss in boiler operations, since the combustion was improved, with saving $85,517.24 USD per year because of several reasons such as, cleanness in internal boiler is increased so that boiler maintenance diminished in one day with saving about $ 41,379.31 USD, and about 3 till 0.8 per month of boiler shoot- down had decreased during 1990 with saving about $13,103.45 USD.

1.6 DEFINITION KEY OF TERM

Table 1.1: Definition Key of Term

Terms	**Definition**
Waste Heat Recovery Boiler	Boiler in which heat that would otherwise be discarded is used to make steam
Dry Flue Gas Loss	The sensible heat energy in the flue gases due to the flue gas temperature.
Wet Flue Gas Loss	The latent energy in the steam in the flue gas stream due to the water produced by the combustion reaction being vaporized from the high flue gas temperature.

CHAPTER 2

LITERATURE REVIEW

2.1 OVERVIEW

Waste heat energy is generated widely in industrial processes. A continuously circulate of water is placed inside a waste heat recovery boiler with series of tube. On the hot side the wasted heat has been recovered and is transferred to the water inside the tubes of the boiler. The steam then generated to a steam turbine generator which is used to generate power. The boiler is usually placed on top of stack or heat source. (Waste Heat Recovery Boiler, n.d).

2.2 ENERGY ANALYSIS

(R. Saidur et al , 2010)has reported that the first law thermodynamic is conventional used to analyze the energy utilization, but it is unable to account quality of aspect of energy. Hence, exergy analysis becomes significance. Exergy is consequent of Second Law of Thermodynamics. It is property that enable to determine the useful work potential of a given amount of energy at some specified state. As a complement to the present materials and energy balances, exergy calculation can provide increased and deeper insight into the process, as well as unforeseen ideas for improvement. Consequently it can be highlighted that the potential usefulness of exergy analysis in sectoral energy utilization is substantial and that the role of exergy in energy policy making activities is crucial. (Dincer et. al. 2004). An understanding on energy efficiencies is essential in designing, analyzing, optimizing, and improving energy systems through appropriate energy policies and strategy.

2.3 HEAT LOSS IN BOILER

(Vashist, n.d) has presented about factors which will contribute to heat loss in boiler. Firstly, heat loss due to unburned carbon. Larger amounts of carbon than burnt fuel, is possible to leave in the ash and constitute a loss of potential heat in the fuel. Secondly, dry flue gas which is the major energy loss in a boiler that came out at high temperature of flue gas. Moisture in flue is one of the factors that caused the heat loss; this is due to absorption and moisture leaving in the air heater at gas temperature. During changing the enthalpy of water vapour due to moisture in the fuel constitutes a loss. Unburned carbon loss occurred when not all the available carbon comes in contact with combustion air. It may caused by insufficient grinding of the fuel. Surface radiation and convection represent the heat loss from boiler surface to the surrounding. Plus, it is difficult to measure.

2.3.1 Flue Gas as Major Source of Heat Loss

The greatest heat losses which occur in boiler by far are flue gas losses. The flue gas contains considerable latent and sensible heat. Flue is occurred through the wasted heat when too much air is added. (Beggs , 2009). Besides (Doty and C. Turner, 2009) also stated that energy loss in boiler might be occurred because of flue gas. Therefore its temperature must be controlled properly. At lower temperature, the acid condensation will occur in the flue. Meanwhile, at higher temperature it carries out too much thermal energy. A significance amount of energy is lost through flue gases as all the heat produced by the burning fuel cannot be transferred to water or steam in the boiler. Typically, temperature leaving the stack gas in range between 150- 250 °C. Thus, about 10- 30 % of the heat energy lost through it. Since most energy lost from boiler appear in the flue gas, the recovery of this heat can result in substantial energy saving. (Jayamaha 2008, Beggs, 2002)

2.4 ENERGY RECOVERY

(R. Saidur et al, 2010) has identified ways to reduce boiler energy consumption by using variable speed drive and nanofluids application to enhance the heat transfer.

It may be noted that a boiler energy used can be reduced by many alternatives such as excess air controlling, enhancing heat transfer rate, improving combustion efficiency, use of more environmental friendly fuel, recovering waste heat, recovering condensate, optimizing blow down process, preventing leakge and providing proper insulation.

2.4.1 Energy Recovery on Dry Flue Gas Loss

The dry flue gas loss can be reduced by reducing the amount of dry flue gas and by reducing the difference between flue gas temperature and combustion air temperature, but only up to a point; insufficient excess air leads to increased emissions of CO and hydrocarbons, even a risk of furnace explosion. The lower limits of excess air are determined by the ability of the burner to mix the fuel and air, and by the accuracy of the burner controls in metering the two fluids. Good burners with good controls should be able to operate with about 10% excess air at full load, perhaps 30 % excess air at 20 % of full load.

Reducing excess air has a moderate effect on reducing the value of DG. This can be explored by substituting different values for CO_2 , O_2 and N_2 into the formula for dry flue gas. It is necessary to maintain the correct relationship in composition. While reducing excess air only moderately reduces dry gas, the effect on reducing loss dry flue gas is greater, because reducing dry flue gas also reduces the flue gas temperature The reduced volume of flue gas passing over the same heat exchange surface results in a lower end temperature, but the reduction in flue gas temperature is not easy to predict, and is best determined by experiment.

Flue gas temperature can also be reduced by exposing more heat exchange surface to the flue gas, such as an economizer, which heats the feedwater, or an air heater which heats the combustion air. One can assume a lower value for flue gas temperature, calculate its effect on loss in dry flue gas , and then determine whether the improvement in efficiency, and corresponding fuel savings, justify the cost of the additional heat exchanger.

It should be noted that when an air heater is employed, the combustion air temperature is measured where the air enters the air heater, not at the burners. When adding heat exchange surface it is important that the final flue gas temperature be kept above the dewpoint, to avoid condensation, unless the heat exchanger is designed to accommodate it. Condensing flue heat exchangers can offer substantial gains in efficiency, but are beyond the scope of this discussion. When firing natural gas, a minimum temperature of the heat exchanger surface to avoid condensation is about 105 °C .

2.4.2 Energy Recovery on Wet Flue Gas Loss

In the process of combustion the hydrogen content of the fuel is converted to H_2O, which normally leaves the stack as water vapor, carrying with it the heat required to convert it from liquid to vapor. With fuels high in hydrogen, such as natural gas, this is a significant loss, upwards of 10 % of the energy in the fuel, depending on flue gas temperature.

Much of this loss can be recovered by employing condensing flue heat exchangers. In conventional systems, minimizing latent heat is a matter of reducing flue gas temperature but staying above the dewpoint to avoid condensation. Safe minimum temperatures for heat exchanger surfaces handling flue gas from natural gas are about 105 °C

2.5 Mathematical Modelling and Computational Approach

Furnace is one of the most important processes which will influence thermal efficiency on boiler. The models which constructed based on rudimentary principle of physics were used to analyze and predict heat exchange in boiler. (Huang et al, 1988)has presented a model to examines thermal efficiency on fire- tube boiler. The modelling includes heat exchange between flue gases and boiling water, and heat exchange between the external surface of the boiler and the environment. Based on this type of model, the efficiency of boiler at different loads can be simulated. (Claus and Stephen, 1985)had determined steam boiler heat parameters by using the indirect method for testing its efficiency by computer simulation. Therefore, the study enables people to study the boiler work and fuel consumption at different parameters.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Generally, hot water or saturated steam or superheated is a demand industry which is used for technology purposes. Energy balance for the Acrylic Waste Boiler is determined based on first law analysis. Meanwhile for energy losses, indirect method will be used as to specify the loss due to flue gas. This study is divided into three major scopes of study which are analytical approaches for a boiler analysis, mathematical tools for analysis thermal efficiency, and energy saving for a boiler

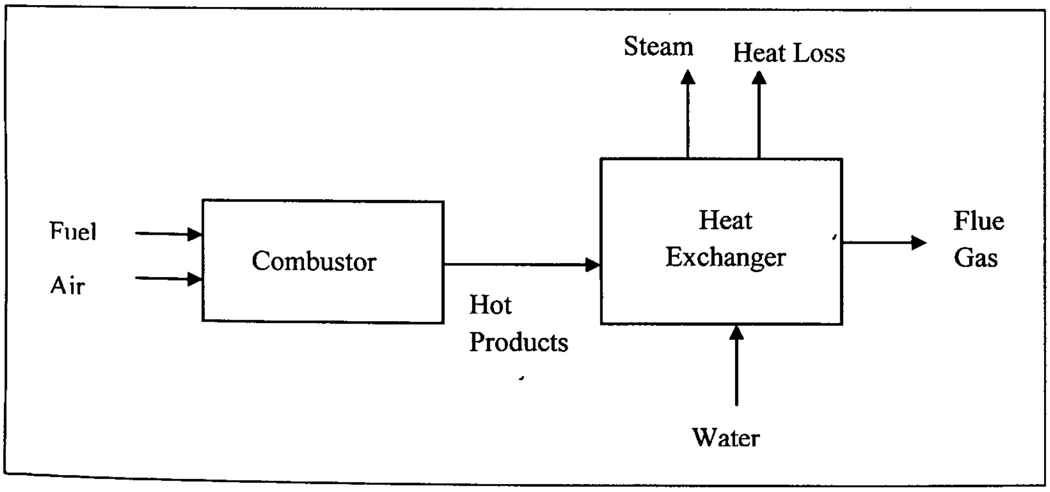
3.2 ANALYTICAL APPROACHES

This section describes about the method used to estimate the energy use and efficiency for a boiler.

3.2.1 Energy Analysis for a Boiler

A boiler is divided into two equipments such as, heat exchanger and combustor as shown in Figure 3.1. The energy analysis of these two parts has been discussed below. Besides, necessary data for the boiler has been taken from BASF Petronas Chemicals. It is tabulated in Table 3.1 and Table 3.2. Meanwhile, data in Table 3.3 is obtained from Table B6 and Table B7 from Ref: Felder and Rousseau (2005). For density and specific heat of flue gas data is shown in Table 3.4.

Figure 3.1: Schematic Diagram of Combustor and Heat Exchanger in a Boiler



Source: Changel and Boles, 2006

Table 3.1: Data for Mass Flow Rate, Temperature, Enthalpy, Density and Specific Heat

Substances	Mass Flow Rate, kg/h	Temperature 1, °C	Temperature 2, °C	Density, kg/m^3	Specific Heat, kJ/kg °C	Enthalpy Difference , kJ/kg
CAA:						
Off Gas	87000	30	907.90	1.14	n/a	5.57
Acid Water	12000	32	907.90	977.8	n/a	40.656
Residue	200	130	907.90	1048.42	1.12	n/a
BA:						
Heavy Residue	400	100.28	907.90	862	2.71	n/a
Light Residue	50	113.40	907.90	845.9	62.38	n/a
2- EHA Residue	300	99.81	907.90	886.2	n/a	5470.7
Atomizing Steam	5200	300	907.90	1.35	10.32	n/a
Vents	600	45	907.90	n/a	5.578	5.58
Natural Gas	800	47.81	907.90	0.78	8.77	53265
Air	75894	28.85	907.90	1.17	1.01	n/a

Source: BASF Petronas Chemicals (2011)

Table 3.2: Data for Flow Rate, Pressure, and Temperature

Substances	Volumetric Flow Rate, m^3/h	Mass Flow Rate, kg/h	Pressure, bar	Temperature , °C	Temperature , °C
Sat. Steam	n/a	55000	50	n/a	430
BFW	n/a	30000	n/a	30	252
Superheated Steam	n/a	65000	50	252	430
Flue Gas:					
Wet	126000	n/a	n/a	300	n/a
Dry	154000	n/a	n/a	300	n/a

Source: BASF Petronas Chemicals (2011)

Table 3.3: Data for Temperature, Density, Specific Heat, and Enthalpy Difference

Substances	Temperature 1, °C	Temperature 2, °C	Density, kg/m^3	Specific Heat, kJ/kg °C	Enthalpy Difference , kJ/kg
Sat. Steam	263.9	430	166.10	8.99	475.2
BFW	30	252	995.68	4.18	666.7
Superheated Steam	252	430	n/a	8.94	2183.6

Source: Felder and Rousseau (2005)