ANALYSIS ON LOSSES AND BOILER EFFICIENCY TO FIND OPTIMUM COOLING WATER FLOWRATE

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ABSTRACT

Steam power plant is using fuel to generate electrical power. The used of the fuel must be efficient so the boiler can generate for the maximum electrical power. By the time the steam cycle in the boiler, it also had heat losses through some parts and it effect on the efficiency of the boiler. This project will analyze about the parts losses and boiler efficiency to find the optimum cooling water flowrate. By using the CUSSONS P7690/SP steam power plant in mechanical laboratory in UMP the data is collect by using 4 types of cooling water flowrate that is 3000l/h, 4000l/h, 5000l/h and 6000l/h. Result of the analysis show that the optimum cooling water flowrate for superheated steam is 6000l/h that give lowest losses, 6.1 kW and maximum efficiency that is 78.99%. This study is fulfilling the objective of analysis to find the optimum cooling water fowrate for steam power plant in UMP.

ABSTRAK

Stesen janakuasa stim menggunakan bahan bakar untuk menjana tenaga elektrik. Penggunaan bahan bakar tersebut mestilah efisien supaya dandang dapat menjana tenaga elektrik yang maksimum. Dalam ketika kitaran stim berlaku di dalam pendandang, haba telah terbebas pada sesuatu bahagian dan memberi kesan kepada kecekapan penggunaan pendandang tersebut. Projek ini akan menganalisis tentang kehilangan haba pada sesuatu bahagian dan kecekapan pendandang untuk mencari aliran air sejuk yang paling optimum. Dengan menggunakan CUSSONS P7690/SP stesen janakuasa stim di makmal mekanikal dalam UMP data telah diambil bagi 4 jenis aliran air sejuk iaitu 3000l/h, 4000l/h, 5000l/h and 6000l/h. Keputusan dari analisis menunjukan aliran air sejuk yang optimum ialah pada 6000l/h yang memberi kehilangan haba terendah, 6.1 kW dan maksimum kecekapan iaitu 78.99%. Kajian ini memenuhi objektif analisis iaitu untuk mencari aliran air sejuk yang paling optimum untuk stesen janakuasa stim di UMP.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURE

LIST OF SYMBOLS

mf - boiler fuel pulses

UCV - Upper calorific value

$Q_{superheater}$ - input electrical energy for superheater

m_{air} - estimate air flow

Cp_{air} - approximates to 1.005 kJ/(kgK)

T_{air} - ambient air temp

$(mh)_{feedwater}$ - influx of enthalpy with feedwater

m_s - mass flow rate

h_1 - enthalpy of water

$W_{turbine}$ - power output from turbine

N - rotational speed of turbine, RPM

T - net output on output shaft

$(mh)_{ex\ st.}$ - enthalpy efflux through the exhaust stack

$(m_a + m_f)$ - sum of fuel and air mass flow

Cp_{ex} - specific heat at constant pressure for exhaust gas

T_{ex} - exhaust gas temperature measured at stack outlet

P_a - absolute ambient inlet pressure

T_a - absolute ambient inlet temperature

$(mh)_{condensate}$ - enthalpy efflux through the condenser

h_c - enthalpy of condensate leaving condenser

h_s - enthalpy of boiler saturated vapors hfw - enthalpy of feedwater

ρf - density of fuel

CVf - gross calorific value of fuel

LIST OF APPENDICES

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, all the important information related of this project is stated. Besides that, the literature review can give a brief explanation about the steam power plant and its operation also the effect of the cooling water flow rate. Some of the points in this chapter can give extra information which is useful while doing this project.

2.2 The Use of Steam

Steam is a critical recourse in today's industrial world. It is essential for cooling and heating of large buildings, driving equipment such as pump and compressors and for powering ships. However, its most importance priority remains as source of power for the production of electricity.

Steam is extremely valuable because it can be produced anywhere in this world by using the heat that comes from the fuels that are available in this area. Steam also has unique properties that are very important in producing energy. Steam is basically recycled, from a steam to water and then back to steam again, all in manner that is nontoxic in nature.

The steam plant of today are a combination of complex engineered system that work to produce steam in the most efficient manner that is economically feasible. Whether the end product of this steam is electricity, heat or a steam process required to develop a needed product such as paper, the goal is to have that product produced at the lowest cost possible. The heat required to produce the steam is a significant operating cost that affects the ultimate cost of the end product. (Everett, 2005)

2.2.1 Steam is Efficient and Economic to Generate

Water is plentiful and inexpensive. It is non-hazardous to health and environmentally sound. In its gaseous form, it is a safe and efficient energy carrier. Steam can hold five or six times as much potential energy as an equivalent mass of water.

When water is heated in a boiler, it begins to absorb energy. Depending on the pressure in the boiler, the water will evaporate at a certain temperature to form steam. The steam contains a large quantity of stored energy which will eventually be transferred to the process or the space to be heated.

It can be generated at high pressures to give high steam temperatures. The higher the pressure, the higher the temperature. More heat energy is contained within high temperature steam so its potential to do work is greater.

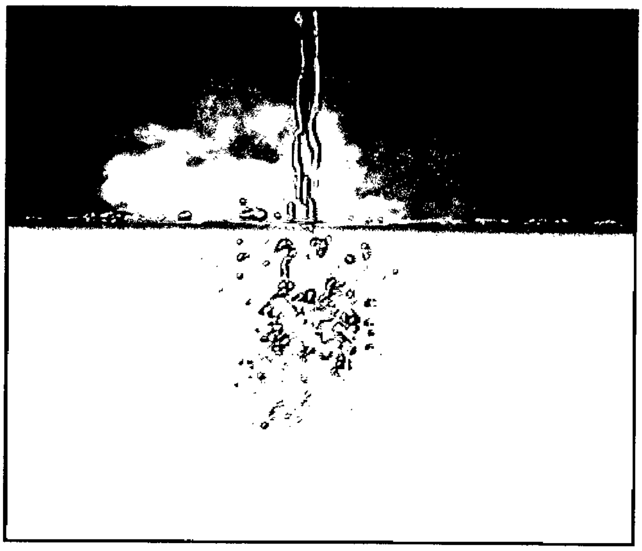

Figure 2.1: Heated water

i. Modern shell boilers are compact and efficient in their design, using multiple passes and efficient burner technology to transfer a very high proportion of the energy contained in the fuel to the water, with minimum emissions.
ii. The boiler fuel may be chosen from a variety of options, including combustible waste, which makes the steam boiler an environmentally sound option amongst the choices available for providing heat. Centralized boiler plant can take advantage of low interruptible gas tariffs, because any suitable standby fuel can be stored for use when the gas supply is interrupted.
iii. Highly effective heat recovery systems can virtually eliminate blowdown costs, return valuable condensate to the boiler house and add to the overall efficiency of the steam and condensate loop.

The increasing popularity of Combined Heat and Power (CHP) systems demonstrates the high regard for steam systems in today's environment and energy-conscious industries. (Everett, 2005)

2.2.2 Energy is Easily Transferred to the Process

Steam provides excellent heat transfer. When the steam reaches the plant, the condensation process efficiently transfers the heat to the product being heated.

Steam can surround or be injected into the product being heated. It can fill any space at a uniform temperature and will supply heat by condensing at a constant temperature; this eliminates temperature gradients which may be found along any heat transfer surface - a problem which is so often a feature of high temperature oils or hot water heating, and may result in quality problems, such as distortion of materials being dried.

Because the heat transfer properties of steam are so high, the required heat transfer area is relatively small. This enables the use of more compact plant, which is easier to install and takes up less space in the plant. A modern packaged unit for steam heated hot water rated to 1200 kW and incorporating a steam plate heat exchanger and all the controls, requires only 0.7 m^2 floor spaces. In comparison, a packaged unit incorporating a shell and tube heat exchanger would typically cover an area of two to three times that size.

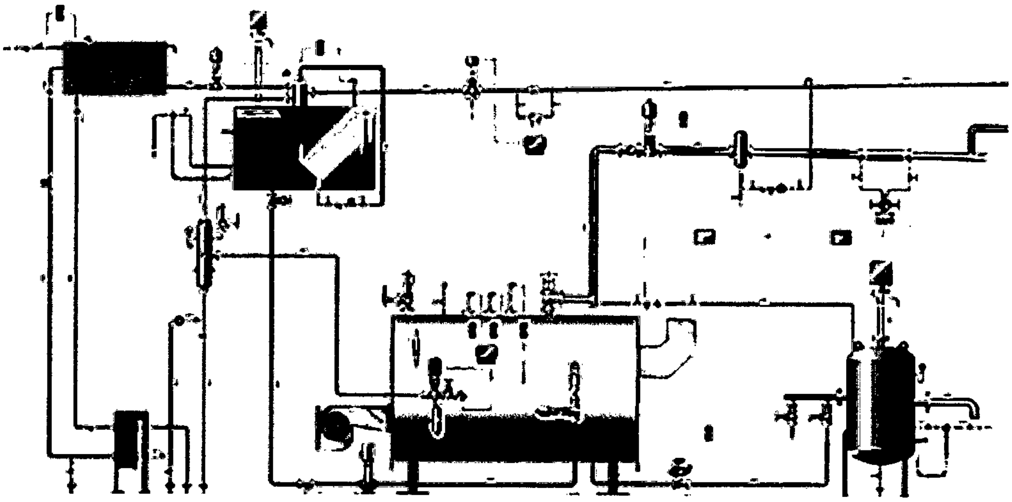

Figure 2.2: A modern boiler house package

Table 2.1: Comparison of heating media with steam

Steam	Hot Water	High Temperature Oils
High heat content Latent heat approximately 2100 kJ/kg	Moderate heat content Specific heat 4.19 kJ/kg°C	Poor heat content Specific heat often 1.69-2.93 kJ/kg°C
Inexpensive Some water treatment costs	Inexpensive Only occasional dosing	Expensive
Good heat transfer coefficients	Moderate coefficients	Relatively poor Coefficients
High pressure required for high temperatures	High pressure needed for high temperatures	Low pressures only to get high temperatures
No circulating pumps required Small pipes	Circulating pumps required Large pipes	Circulating pumps required Even larger pipes

Easy to control with two way valves	More complex to control - three way valves or differential pressure valves may be required	More complex to control - three way valves or differential pressure valves may be required.
Temperature breakdown is easy through a reducing valve	Temperature breakdown more difficult	Temperature breakdown more difficult
Steam traps required	No steam traps required	No steam traps required
Condensate to be handled	No condensate handling	No condensate handling
Flash steam available	No flash steam	No flash steam
Boiler blowdown necessary	No blowdown necessary	No blowdown necessary
Water treatment required to prevent corrosion	Less corrosion	Negligible corrosion
Reasonable pipework required	Searching medium, welded or flanged joints usual	Very searching medium, welded orilanged joints usual
No fire risk	No fire risk	Fire risk
System very flexible	System less flexible	System inflexible

2.3 The Steam-Plant Cycle

The simplest steam cycle of practical value is called the Rankine cycle, which originated around the performance of the steam engine. The steam cycle is important because it connects processes that allow heat to be converted to work on a continuous basis. This simple cycle was based on dry saturated steam being supplied by a boiler to a power unit such as a turbine that drives an electric generator. Dry saturated steam is at the temperature that corresponds to the boiler pressure, is not superheated, and does not contain moisture. The steam from the turbine exhausts to a condenser, from which the condensed steam is pumped back into the boiler. It is also called a condensing cycle, and a simple schematic of the system is shown in Fig. 2.3.

This schematic also shows heat (Qin) being supplied to the boiler and a generator connected to the turbine for the production of electricity. Heat (Qout) is removed by the condenser, and the pump supplies energy (Wp) to the feedwater in the form of a pressure increase to allow it to flow through the boiler.

A higher plant efficiency is obtained if the steam is initially superheated, and this means that less steam and less fuel are required for a specific output. (Superheated steam has a temperature that is above that of dry saturated steam at the same pressure and thus contains more heat content, called enthalpy, Btu/lb.) If the steam is reheated and passed through a second turbine, cycle efficiency also improves, and moisture in the steam is reduced as it passes through the turbine. This moisture reduction minimizes erosion on the turbine blades.

When saturated steam is used in a turbine, the work required rotating the turbine results in the steam losing energy, and a portion of the steam condenses as the steam pressure drops. The amount of work that can be done by the turbine is limited by the amount of moisture that it can accept without excessive turbine blade erosion. This steam moisture content generally is between 10 and 15 percent. Therefore, the moisture content of the steam is a limiting factor in turbine design.

With the addition of superheat, the turbine transforms this additional energy into work without forming moisture, and this energy is basically all recoverable in the turbine. A reheater often is used in a large utility. (Kenneth, 2005)

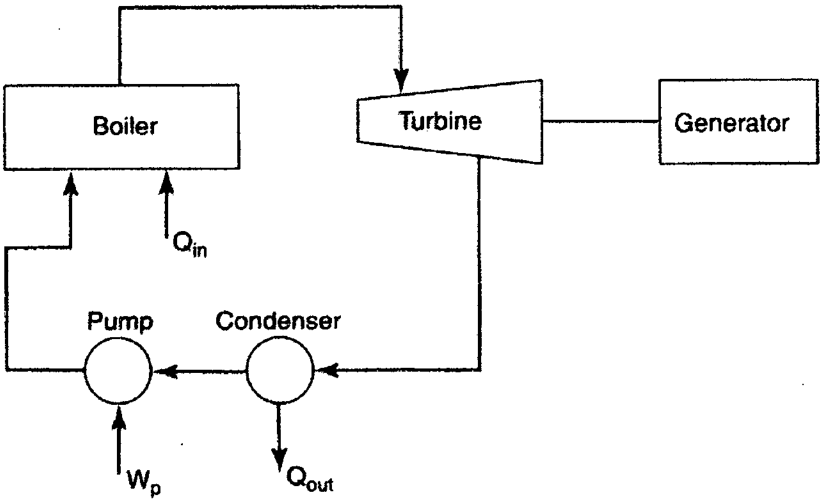

Figure 2.3: Boiler basic cycle

2.4 Feedwater

The feedwater system requires accessories to supply the correct amount of water in the proper condition to the boiler. A feedwater accessory is equipment that is not directly attached to the boiler that controls the quantity, pressure, and/or tore of water supplied to the boiler. Maintaining the correct level of water in the boiler is critical for safety and efficiency. If the water level in the boiler is too high, water can be carried over into steam lines, which can lead to water hammer and line rupture. If the water level in the boiler is too low, heat from the furnace cannot be properly transferred to the water. This can cause overheating and damage to boiler tubes and heating surfaces. Significant damage from over heating can lead to a boiler explosion.

Feedwater is treated and regulated automatically to meet the demand for steam.

Valves are installed in feedwater lines to permit access for maintenance and repair. The feedwater system must be capable of supplying water to the boiler in all circumstances and includes feedwater accessories required for the specific boiler application, In a steam heating system.) Heat necessary for providing comfort in the building starts at the boiler. Water in the boiler is heated and turns to steam. Steam leaves the boiler through the main steam line (boiler outlet) where it enters the main steam header-. From the main steam header, main branch lines direct the steam up a riser to the heating unit (heat exchanger).

Heat is released to the building space as steam travels through the heating unit,

Steam in the heating unit coals and turns into condense. The condensate is separated fromt the steam by a steam trap that allows condensate, but not steam to pass. The condensate is directed through the condenser return line to the condensate return tank. The feedwater pump pumps the condensate and/or water back to the boiler through check valves and stop valves on the feedwater line. Feedwater enters the boiler and is turned to steam to repeat the process. (Kenneth, 2005)

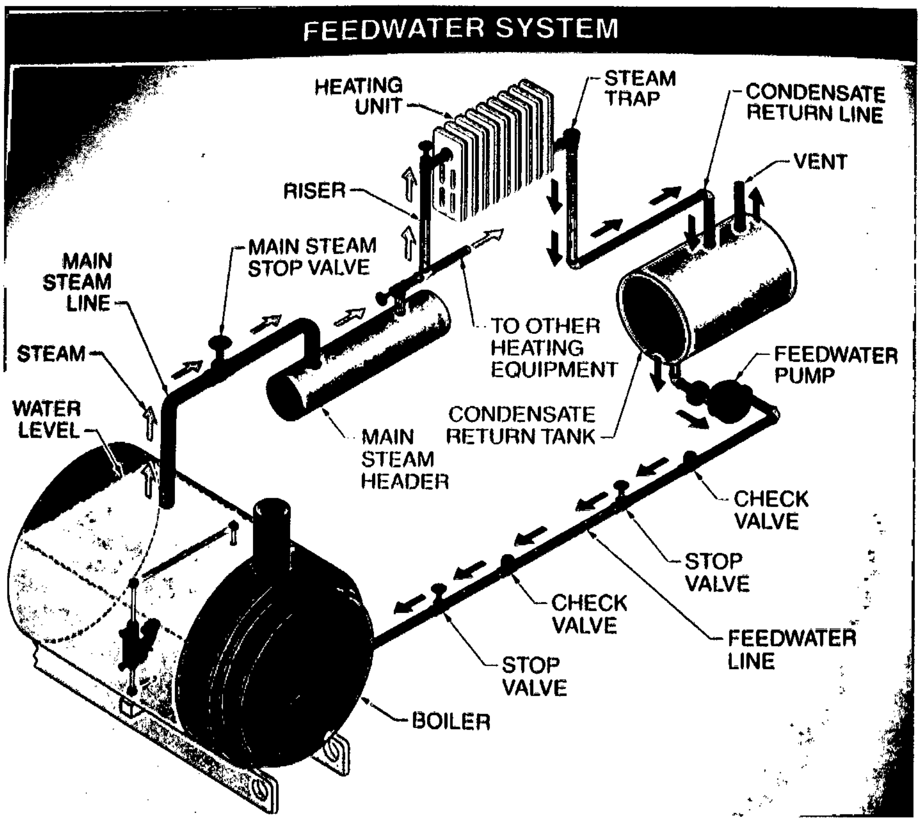

Figure 2.4: The flow in the boiler

2.5 Boiler Efficiency

Boiler Efficiency may be indicated by

i. Combustion Efficiency - indicates the burners ability to burn fuel measured by unburned fuel and excess air in the exhaust
ii. Thermal Efficiency - indicates the heat exchangers effectiveness to transfer heat from the combustion process to the water or steam in the boiler, exclusive radiation and convection losses
iii. Fuel to Fluid Efficiency - indicates the overall efficiency of the boiler inclusive thermal efficiency of the heat exchanger, radiation and convection losses - output divided by input.

Boiler Efficiency is in general indicated by either Thermal Efficiency or Fuel to Fluid Efficiency depending the context. (Chattopadhyay, 2005)

2.5.1 Gross Calorific Value

This is the theoretical total of the energy in the fuel. However, all common fuels contain hydrogen, which burns with oxygen to form water, which passes up the stack as steam.

The gross calorific value of the fuel includes the energy used in evaporating this water. Flue gases on steam boiler plant are not condensed; therefore the actual amount of heat available to the boiler plant is reduced.

Accurate control of the amount of air is essential to boiler efficiency:

i. Too much air will cool the furnace, and carry away useful heat.
ii. Too little air and combustion will be incomplete, unburned fuel will be carried over and smoke may be produced.

Table 2.2: Fuel oil data

Oil Type	**-Grade**	**Gross calorific value (MJ/l)**
Light	-E	40.1
Medium	-F	40.6
Heavy	-G	41.1
Bunker	-H	41.8

Table 2.3: Gas data

Gas Type	**Gross calorific value (MJ/m at NTP)**
Natural	38.0
Propane	93.0
Butane	122.0

2.5.2 Net Calorific Value

This is the calorific value of the fuel, excluding the energy in the steam discharged to the stack, and is the figure generally used to calculate boiler efficiencies. In broad terms:

Net calorific value ≈ Gross calorific value - 10%

The combustion process: $\overset{\text{Fuel}}{\boxed{C + H}} + \overset{\text{Air}}{\boxed{O_2 + N_2}} \xrightarrow{\text{Combustion}} \overset{\text{Heat}}{\boxed{CO_2 + H_2O + N_2}}$

Where:

C = Carbon

H = Hydrogen

O = Oxygen

N = Nitrogen

Accurate control of the amount of air is essential to boiler efficiency:

1. Too much air will cool the furnace, and carry away useful heat.
2. Too little air and combustion will be incomplete, unburned fuel will be carried over and smoke may be produced.

In practice, however, there are a number of difficulties in achieving perfect (stoichiometric) combustion:

i. The conditions around the burner will not be perfect, and it is impossible to ensure the complete matching of carbon, hydrogen, and oxygen molecules.
ii. Some of the oxygen molecules will combine with nitrogen molecules to form nitrogen oxides (NO_x).

To ensure complete combustion, an amount of 'excess air' needs to be provided. This has an effect on boiler efficiency. The control of the air/fuel mixture ratio on many existing smaller boiler plants is 'open loop'. That is, the burner will have a series of cams and levers that have been calibrated to provide specific amounts of air for a particular rate of firing.

Clearly, being mechanical items, these will wear and sometimes require calibration. They must, therefore, be regularly serviced and calibrated. On larger plants, 'closed loop' systems may be fitted which use oxygen sensors in the flue to control combustion air dampers.

Air leaks in the boiler combustion chamber will have an adverse effect on the accurate control of combustion. (Nag, 2005)

2.6 Heat Losses

Having discussed combustion in the boiler furnace, and particularly the importance of correct air ratios as they relate to complete and efficient combustion, it remains to review other potential sources of heat loss and inefficiency. (Nag, 2005)

2.6.1 Heat Losses in the Flue Gases

: This is probably the biggest single source of heat loss, and the Engineering Manager can reduce much of the loss. The losses are attributable to the temperature of the gases leaving the furnace. Clearly, the hotter the gases in the stack, the less efficient the boiler. The gases may be too hot for one of two reasons

1. The burner is producing more heat than is required for a specific load on the boiler:
    i. This means that the burner(s) and damper mechanisms require maintenance and re-calibration.
2. The heat transfer surfaces within the boiler are not functioning correctly, and the heat is not being transferred to the water:
    i. This means that the heat transfer surfaces are contaminated, and require cleaning.

Some care is needed here - Too much cooling of the flue gases may result in temperatures falling below the 'dew point' and the potential for corrosion is increased by the formation of:

i. Nitric acid (from the nitrogen in the air used for combustion).
ii. Sulphuric acid (if the fuel has a sulphur content).
iii. Water.

2.6.2 Radiation Losses

Because the boiler is hotter than its environment, some heat will be transferred to the surroundings. Damaged or poorly installed insulation will greatly increase the potential heat losses. A reasonably well-insulated shell or water-tube boiler of 5 MW or more will lose between 0.3 and 0.5% of its energy to the surroundings.

This may not appear to be a large amount, but it must be remembered that