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

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SUPERVISOR DECLARATION

I hereby declare that the project paper of this has been read and I have the opinion that the project paper is appropriate in terms of scope coverage and quality for the award of degree of Bachelor of Mechanical Engineering and Manufacturing Engineering.

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Date : 16 November 2007

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

MOHD SHAHRULNIZAM BIN ABU SEMAN

A project report submitted in partial fulfillment of the requirement for the award of degree of Mechanical Engineering

Faculty of Mechanical Engineering
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NOVEMBER 2007

STUDENT DECLARATION

I declare that this thesis entitled "Analysis on Losses and Boiler Efficiency to Find Optimum Cooling Water Flowrate" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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To Beloved Late Father, Mother and Brothers

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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.

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mf	- boiler fuel pulses
UCV	- Upper calorific value
$Q_{superheater}$	- input electrical energy for superheater
m_{air}	- estimate air flow
$C_{p air}$	- 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
$C_{p ex}$	- 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_e	- 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

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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.

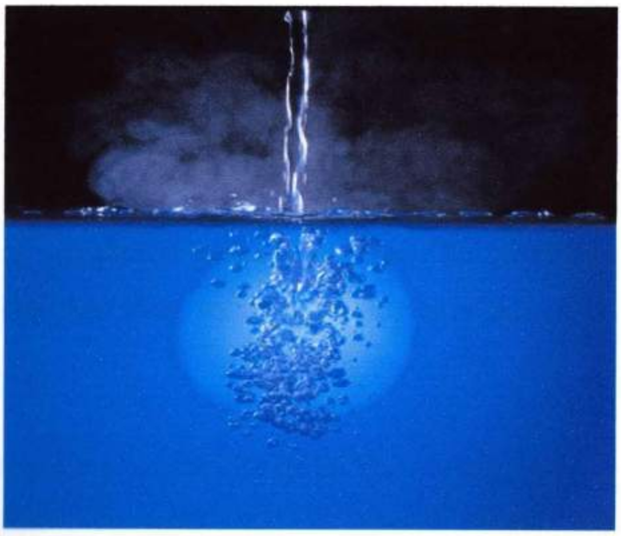

Figure 2.1: Heated water

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.

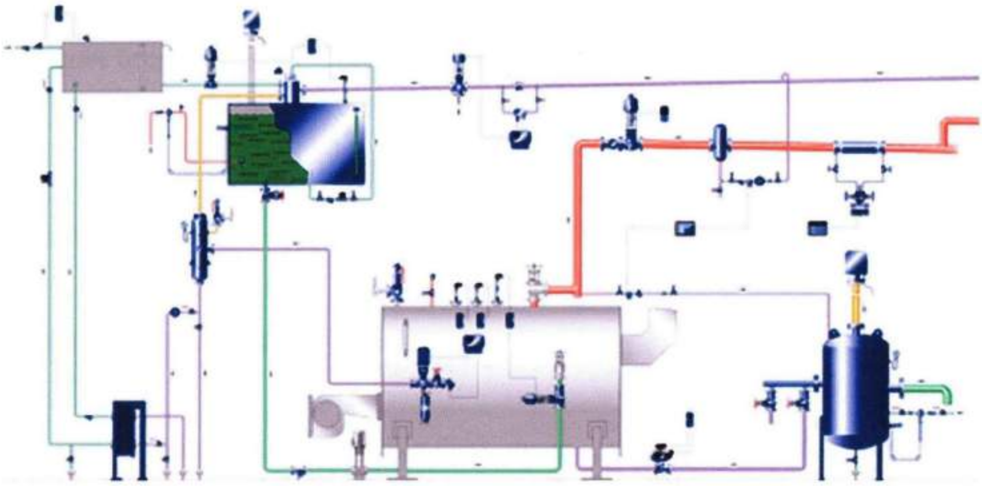

Figure 2.2: A modern boiler house package

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)

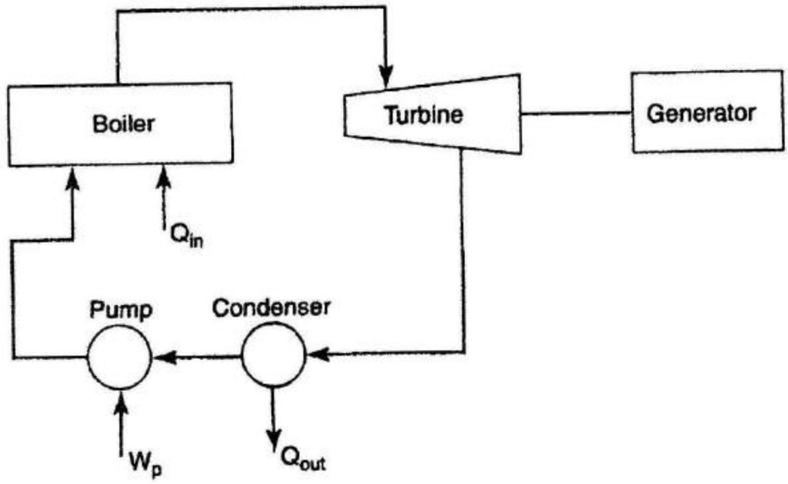

Figure 2.3: Boiler basic cycle

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)

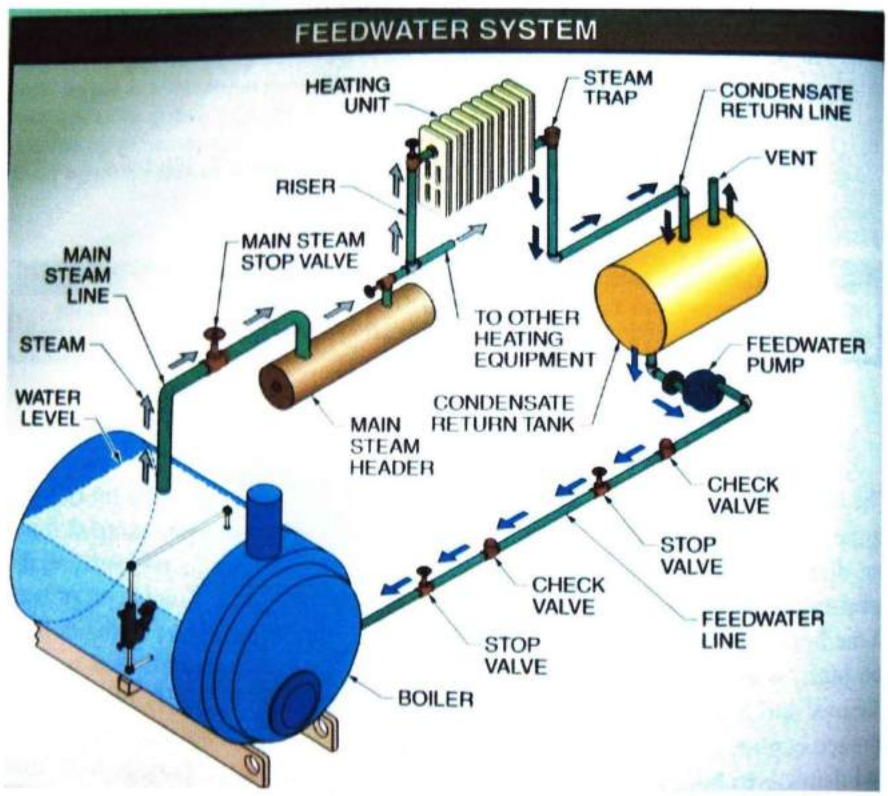

Figure 2.4: The flow in the boiler

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:

$$\underset{\text{Fuel}}{\boxed{C + H}} + \underset{\text{Air}}{\boxed{O_2 + N_2}} \xrightarrow{\text{Combustion}} \underset{\text{Heat}}{\boxed{CO_2 + H_2O + N_2}}$$

Where:

C = Carbon

H = Hydrogen

O = Oxygen

N = Nitrogen

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

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.

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 this is 0.3 to 0.5% of the boiler's full-load rating and this loss will remain constant, even if the boiler is not exporting steam to the plant, and is simply on stand-by.

This indicates that to operate more efficiently, a boiler plant should be operated towards its maximum capacity. This, in turn, may require close co-operation between the boiler house personnel and the production departments. (Chattopadhyay, 2005)

2.7 Fuel for Boilers

The three most common types of fuel used in steam boilers, are coal, oil, and gas. However, industrial or commercial waste is also used in certain boilers, along with electricity for electrode boilers. (Chattopadhyay, 2005)

2.7.1 Coal

Coal is the generic term given to a family of solid fuels with high carbon content. There are several types of coal within this family, each relating to the stages of coal formation and the amount of carbon content. These stages are:

i. Peat.
ii. Lignite or brown coals.
iii. Bituminous.
iv. Semi bituminous.
v. Anthracite.

The bituminous and anthracite types tend to be used as boiler fuel.

2.7.2 Oil

Oil for boiler fuel is created from the residue produced from crude petroleum after it has been distilled to produce lighter oils like gasoline, paraffin, kerosene, diesel or gas oil. Various grades are available, each being suitable for different boiler ratings; the grades are as follows:

i. Class D - Diesel or gas oil.
ii. Class E - Light fuel oil.
iii. Class F - Medium fuel oil.
iv. Class G - Heavy fuel oil.

Oil began to challenge coal as the preferred boiler fuel in the UK during the 1950s. This came about in part from the then Ministry of Fuel and Power's sponsorship of research into improving boiler plant. The advantages of oil over coal include:

i. A shorter response time between demand and the required amount of steam being generated.
ii. This meant that less energy had to be stored in the boiler water. The boiler could therefore be smaller, radiating less heat to the environment, with a consequent improvement in efficiency.
iii. The smaller size also meant that the boiler occupied less production space.
iv. Mechanical stokers were eliminated, reducing maintenance workload.
v. Oil contains only traces of ash, virtually eliminating the problem of ash handling and disposal.
vi. The difficulties encountered with receiving, storing and handling coal were eliminated.

Approximately 15 kg of steam can be produced from 1 kg of oil, or 14 kg of steam from 1 litre of oil.

2.7.3 Gas

Gas is a form of boiler fuel that is easy to burn, with very little excess air. Fuel gases are available in two different forms:

i. Natural gas - This is gas that has been produced (naturally) underground. It is used in its natural state, (except for the removal of impurities), and contains a high proportion of methane.
ii. Liquefied petroleum gases (LPG) - These are gases that are produced from petroleum refining and are then stored under pressure in a liquid state until used. The most common forms of LPG are propane and butane.

In the late 1960s the availability of natural gas (such as from the North Sea) led to further developments in boilers.

The advantages of gas firing over oil firing include:

i. Storage of fuel is not an issue; gas is piped right into the boiler house.
ii. Only a trace of sulphur is present in natural gas, meaning that the amount of sulphuric acid in the flue gas is virtually zero.

Approximately 42 kg of steam can be produced from 1 Therm of gas (equivalent to 105.5 MJ) for a 10 bar g boiler, with an overall operating efficiency of 80%.

2.7.4 Waste as the Primary Fuel

There are two aspects to this:

1. Waste material - Here, waste is burned to produce heat, which is used to generate steam. The motives may include the safe and proper disposal of hazardous material. A hospital would be a good example:
   i. In these circumstances, it may be that proper and complete combustion of the waste material is difficult, requiring sophisticated burners, control of air ratios and monitoring of emissions, especially

particulate matter. The cost of this disposal may be high, and only some of the cost is recovered by using the heat generated to produce steam. However, the overall economics of the scheme, taking into consideration the cost of disposing of the waste by other means, may be attractive.

ii. Using waste as a fuel may involve the economic utilisation of the combustible waste from a process. Examples include the bark stripped from wood in paper plants, stalks (bagasse) in sugar cane plants and sometimes even litter from a chicken farm.

The combustion process will again be fairly sophisticated, but the overall economics of the cost of waste disposal and generation of steam for other applications on site, can make such schemes attractive.

2. Waste heat - here, hot gases from a process, such as a smelting furnace, may be directed through a boiler with the objective of improving plant efficiency. Systems of this type vary in their level of sophistication depending upon the demand for steam within the plant. If there is no process demand for steam, the steam may be superheated and then used for electrical generation.

   This type of technology is becoming popular in Combined Heat and Power (CHP) plants:

i. A gas turbine drives an alternator to produce electricity.
ii. The hot (typically 500°C) turbine exhaust gases are directed to a boiler, which produces saturated steam for use on the plant.

Very high efficiencies are available with this type of plant. Other benefits may include either security of electrical supply on site, or the ability to sell the electricity at a premium to the national electricity supplier. (Mohammad, 2004)

2.8 Boiler Design

The boiler manufacturer must be aware of the fuel to be used when designing a boiler. This is because different fuels produce different flame temperatures and combustion characteristics.
For example:

i. Oil produces a luminous flame, and a large proportion of the heat is transferred by radiation within the furnace.
ii. Gas produces a transparent blue flame, and a lower proportion of heat is transferred by radiation within the furnace.

On a boiler designed only for use with oil, a change of fuel to gas may result in higher temperature gases entering the first pass of fire-tubes, causing additional thermal stresses, and leading to early boiler failure.

2.8.1 Boiler Types

The objectives of a boiler are:

i. To release the energy in the fuel as efficiently as possible.
ii. To transfer the released energy to the water, and to generate steam as efficiently as possible.
iii. To separate the steam from the water ready for export to the plant, where the energy can be transferred to the process as efficiently as possible.

A number of different boiler types have been developed to suit the various steam applications.

2.9 CUSSONS P7690/SP Steam Power Plant

Figure 2.5: Cussons steam power plant

Cussons P7690/SP Steam Power Plant is designed as a comprehensive self-contained unit with all relevant items of equipment factory mounted on a common steel bedplate. This modular construction and assembly greatly reduces space and installation requirements. The plant can operate as a steam boiler, turbo generator or complete power plant, and has been specifically designed to facilitate student comprehension and operation. This is achieved through relaying all instrumentation and controls to a central console incorporating a schematic diagram of the complete Steam Power Plant System. A student work surface is provided to allow for manual recording of required parameters, with all variables additionally available as signals suitable for data logging.

A complete self contained I KW steam power plant built up for laboratory scale with normal steam pressure 7 to 8 bar and steam output 90 to 120 kg / hr from and at 100 ° C. Steam Turbine Output Power is 750 to 850 Watt. The Main Components of the Power Plant shall comprise of the following equipment:

i. Steam Boiler Unit
ii. Electrical Superheater
iii. Steam Turbine Set
iv. Water Cooled Condenser Unit
v. Condensate collecting tank
vi. Vacuum and condensate Pump
vii. Cooling Tower
viii. Daily Water Tank
ix. Daily Oil Tank
x. Water Treatment System
xi. Separating and Throttling Calorimeter Unit
xii. Additional item
xiii. PC Data Acquisition System
xiv. PLC for safety function & Plant Control.

Dimension:	Length	: 3.0 - 4.0 m
	Width	: 2.0 - 3.0 m
	Height	: 2.0 - 3.0 m

2.9.1 Diesel Fired Steam Boiler Unit

Steam Boiler

Specifications:-

i. Fully automatic diesel fired steam boiler.

ii.	Water content	: 80 - 120 liters.
iii.	Normal steam pressure	: 7 bar - 8 bar.
iv.	Max. steam pressure	:10-12bar.
v.	Design Pressure	: 15 bar to 18 bar G.
vi.	Nominal steam output	: 90 kg/h - 120 kg/h.
vii.	Fuel consumption	: 7 kg/h - 10 kg/h.

viii.	Max. steam temperature	: 150°C - 200°C
ix.	Flue pipe diameter	: 120 mm - 150 mm.
x.	Boiler size	: Diameter 700-900 mm
		: Height 1700-1900 mm

a) Single Stage impeller Steam Turbine

Shall be completed with Dynamometer to load turbine. Fitted with stainless steel blade and direct flexible coupled by a flexible coupling to a dynamometer.

Specifications:-

i.	Maximum power output	: 1.0 kW
ii.	Operating Power	: I kW at 3000 rpm
iii.	Inlet pressure at operating point (OP)	: 7 8 bar
iv.	Inlet temperature; (OP)	: 220°C - 250°C.
v.	Flowrate (OP)	: 45-55.0 kg/h.
vi.	Exhaust pressure (OP)	: 0. I ~ 0.3 bar.
vii.	Design to operate at nominal	: 3000 to 4000 rpm

b) Instrumentation and Control Panel

Control panel fitted by following instruments:-

i. 10 way temperature indicator
ii. Tachometer
iii. Dynamometer field voltmeter
iv. condensate tuner
v. Torque meter
vi. Steam supply pressure
vii. Nozzle steam pressure
viii. Electrical supply: 3 ph, 415 V, 50 Hz and 1 ph, 240 V, 50 Hz,.
ix. Temperatures individually selected on MIMIC diagram on front panel.

2.10 Types of Blowdown

Bottom blowdown is the process of periodically draining part of the boiler water to remove heavy sludge that settles to the bottom of the boiler. The amount and the frequency of bottom blowdown depend on the types and amount of impurities in the power, the types of water treatment program, and the practice that produce the best results. Bottom blowdown in modern boilers is not necessary as in years past because of significant advance in pretreatment process and chemical technologies.

Continuous blowdown is the process of continuously draining water from a boiler to control the quantity of impurities in the remaining water. Because impurities in the boiler water are left behind when the steam separates from the water, the greatest concentration of these impurities is a few inches below the NOWL. Continuous blowdown is normally controlled with an automatic valve and conductivity controller or with a manual valve with a position-indicating scale on the side.

Surface blowdown is the process intermittently removing water from the boiler to control the quantity of impurities in the remaining water or to move a film of impurities on the water. The term "surface blowdown" is used in two content in modern boiler technology. In most cases, surface blowdown is exactly the same in the configuration as continuous blowdown, but it is used intermittently rather than continuously. This type of surface blowdown is often referred to as a skimmer for this reason. This type of blowdown is also intermittent and manually controlled.

2.10.1 Boiler Blowdown Purpose

1. Blowdown removes sludge and impurities from the boiler water.
2. Blowdown is used to completely drain the boiler. This is also known as dumping the boiler.

3. Blowdown is used to control the concentration of chemicals in the water. If the treatment chemicals become too heavily concentrated, blowing down the boiler and adding fresh feedwater can reduce the chemical concentration.
4. Blowdown can be used to lower a high boiler water level.

2.11 Efficiency Measurement

Efficiency is the ratio of energy output to energy input in a piece of equipment or in a system. The term "efficiency" is used in a number of contexts with regard to boiler systems. Energy can take multiple forms and the expression of efficiency often reflects those forms. Combustion efficiency is the percentage of the Btu content of fuel that is liberated as heat by the boiler fuel-burning equipment. Boiler thermal efficiency is the percentage of the heat liberated that is transferred into the boiler water. It is possible to have high combustion efficiency but low thermal efficiency and vice versa.

When combustion efficiency and thermal efficiency are combined, the result is fuel-to-steam efficiency. Fuel-to-steam efficiency is the percentage of the heat content of the fuel that is transferred into the boiler water. However, some boiler manufacturers use this term to refer to the performance of a particular boiler at its most efficient fixed firing rate.

The steam rate of a boiler is the combination of combustion efficiency and thermal efficiency at the full range of loads and conditions that the boiler encounters over a typical period of time. The steam rate of a boiler is normally expressed as the average number of pounds of steam produced by that boiler per unit of fuel. One boiler manufacturer uses the term "in-service efficiency" in much the same way as steam rate. However, inservice efficiency is expressed as a percentage. (Ronald, 1997)

2.11.1 Cost Measurement of Steam Efficiency

The industry standard used in expressing the cost of steam production is dollars per thousand pounds of steam generated. This basic measurement of the cost of steam generally takes into account the cost of the fuel, the water, and the chemicals used to treat the water. However, in specific discussions at the plant level, it is necessary to clarify the measurement being used. For example, some facilities that burn coal also consider the cost of coal storage and handling, flue gas cleaning, ash disposal, and other associated costs. Others use accounting formulas that consider the cost of boiler room labor, equipment depreciation, and other factors. (Ronald, 1997)

2.11.2 Method to Gauge Efficiency

The two standard methods of measuring boiler efficiency are the input-output method and the heat loss method. Both are spelled out in ASME Power Test Code 4.1. The input-output method records all the energy that is provided to and exits from the boiler from all sources. The input-output method is a direct method of testing boiler efficiency, but often is not feasible in industrial and commercial boiler plants due to the lack of accurate metering equipment. The input-output method requires the accurate measurement of many flows and conditions including the following (Ronald, 1997):

i. fuel flow
ii. fuel temperature
iii. steam pressure and temperature
iv. steam flow
v. feedwater temperature
vi. stack temperature
vii. combustion air temperature

The heat loss method identifies the efficiency losses from the boiler and subtracts them from 100% to obtain the overall percent efficiency. See Figure 10-1. This method is recognized as the standard method of determining efficiency where measuring instrumentation is otherwise inadequate. In addition to identifying the losses, this method helps quantify the losses. This allows for assessment of potential improvements. The losses that are typically measured include the following (Ronald, 1997):

i. heat loss due to combustible fuel not burned
ii. heat loss in blowdowns
iii. heat loss due to radiation
iv. heat loss due to moisture in the fuel
v. heat loss due to the formation of water vapor when hydrogen is burned
vi. heat loss due to dry stack gases

2.11.3 Efficiency for Low-cost Fuel

The operation of the equipment involved in the generation of steam results in costs to the facility beyond the cost of the fuel. Unneeded operation of the equipment increases the need for maintenance services and parts and shortens the life of the equipment. In addition, combustion of the fuel creates stack emissions. This creates unnecessary pollutants and increases costs associated with environmental compliance. If the capacity of the steam system is marginal, inefficient use of steam can result in periods when the steam system cannot meet the steam demand. By operating the steam system more efficiently, boiler operators help the plant avoid or delay the large expense of installing additional boilers. (Ronald, 1997)

2.11.4 Steam Efficiency

Steams system efficiency is a measurement of steam usage that takes into account both the equipment supplying the steam and the equipment demanding the steam. It is important to remember that steam system efficiency is not the same thing as the fuel-to-steam efficiency of the boilers. All the equipment one either the supply side or the demand side should be evaluated for potential efficiency improvements. The supply side of the steam system consists of the boilers and the equipment that supports the operation of the boilers. The demand side of the steam consists of all equipment that uses steam.

The steam system consists of both the supply side and the demand side. Both should be monitored for efficient operation. (Ronald, 1997)

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will describe about how the experiment been done and the method used to get the data and then how to used the data given to solve the problem by using energy balance analysis and experiment on different types of cooling water flowrate.

3.2 Boiler Starts up and Shutdown Procedure

Boiler operation safety procedure must be followed at all times. The power plant produces high steam pressure at high temperature, so the consequences that may happen to the user are very critical if the user did not follow the boiler operation.

These are the step must be follow to running the boiler:

3.2.1 Starts up Procedure

1. Ensure all valves are closed.
2. Ensure compressed air supply is connected and switched on.
3. Ensure mains water supply is connected and turned on.
4. Turn on Electrical wall isolator.
5. Check that Water Tank Drain Valve - valve 25 - is closed.

6. Open Mains Water Supply Valve - valve 10.
7. Open Water Treatment Bypass Valve - valve 11
8. Set Water Treatment Mixing Valve - valve 12 - to required position as previously determined by water analysis
9. Open Water Feed Valve to pump - valve 8. 10. Open Water Feed Valve to boiler - valve 9.
11. Open Sight Glass steam connection valve - valve 18 12. Open Sight Glass water connection valve - valve 19. 13. Open Pressure Gauge Valve - valve 28.
14. Open Boiler Level Chamber steam connection valve - valve 15.
15. Open Boiler Level Chamber water connection valve - valve 16.
16. Open Boiler Steam Valve - valve 1.
17. Open Turbine Steam Inlet Valve - valve 3.
18. Open Turbine Exhaust Valve - valve 5.
19. Set Condense Directing Valve - valve 7 - to "TO DRAIN"' position. 20. Open water supply to liquid ring extraction pump - valve 43 21. Open Cooling Water Flow Valve - valve 6.
22. Turn ON Air Isolator Valve - valve 38 - and check regulator is set to approximately bar.
23. Turn ON Door Isolator on electrical cubicle.
24. Fill fuel tank using hand pump and check level using gauge on front panel. 25. Open Fuel Oil Supply Valve - valve 27.
26. Ensure Fire Valve - valve 22 - is in the Open position.
27. Set Pressure Controller stepping to 0.00 bar - refer to Wallow manual.
28. Set Superheated Temperature Controller stepping to 100°C - refer to Wallow manual.
29. Press Green "SYSTEM ON" button - Boiler will till with water - Red light goes out, Green light will illuminate.
30. Insert key into keyswitch and turn "TURBINE:;" position - Cooling Water Circulation Pump starts, Boiler will start. Note: Water level in sight glass will start to rise as temperature starts to increase.
31. When boiler pressure reaches 1 bar open Slowdown Valve - valve 13 - allow level to fall in sight glass and then close again.

32. At approximately 4 bar pressure the Dynamometer will start up the Steam Control
Valve and Superheated will be enabled and the Condense pump will start.

Note: When the boiler reaches approximately 7.5 bar its burner will cut out and then cut in again as it drops to 7 bar and will then cycle continuously between these two pressures.

At this stage Experiments can now be performed at various temperatures and pressures

The pressure been set while running the experiment is reduced steam temperature (T4) at 200C, reduced steam pressure (P5) at 5.5bar and steam flow (ms) 170kJ/hr.

33. To achieve vacuum conditions - valve 42 - must be partially open to admit steam to turbine gland seals.
34. After the boiler has been running for a period of time sufficient to remove any scale from the pipes, set the Condense Diverting Valve - valve 7 - to "TO TANK" position.
35. Whilst running plant carry out Slowdown Procedure - see Boiler manual - Appendix B.
36. One turbine nozzle is always open, if additional nozzles are required open nozzle handvalves.

Note: Opening both handvalves will allow steam to pass through 3 nozzles and will result in too much steam being used, which will reduce the steam boiler pressure.

3.2.2 Shutdown Procedure.

1. Reduce Superheated Stepping to 100°C.
2. Reduce Steam Pressure Stepping to 0.00 bar.
3. When indicated pressure on controller is <0.5bar, turn Keyswitch to "STOP" position - Turbine stops, Condense pump stops, Boiler stops, Steam valve closes and Cooling water circulation pump runs on for 4 minutes before stopping.
4. Whilst boiler pressure is reducing carry out boiler and sight glass slowdown procedure - see Boiler manual - Appendix B.
5. When pressure reaches <2 bar, press red system OFF button on control panel. Green light goes out, Red light illuminates.
6. Close Boiler Feedwater Valve - valve 9.
7. Close Feed Pump Supply Valve - valve 8.
8. Close Air Supply Valve - valve 38. -
9. Close Fuel Oil Supply Valve - valve 27. 10. Close De-loniser Bypass Valve - valve 11.
11. Close Main Water Feed Valve - valve 10.
12. Turn door isolator OFF.
13. Turn well isolator OFF.
14. Turn OFF mains water supply

3.3 Energy Balance Analysis

These are the theory for using the energy balance to determine the efficiency of the power plant. For and overall energy balance for a plant such as this, a simple "box , type" "system and surrounding" model will be used. This system is shown schematically, below:

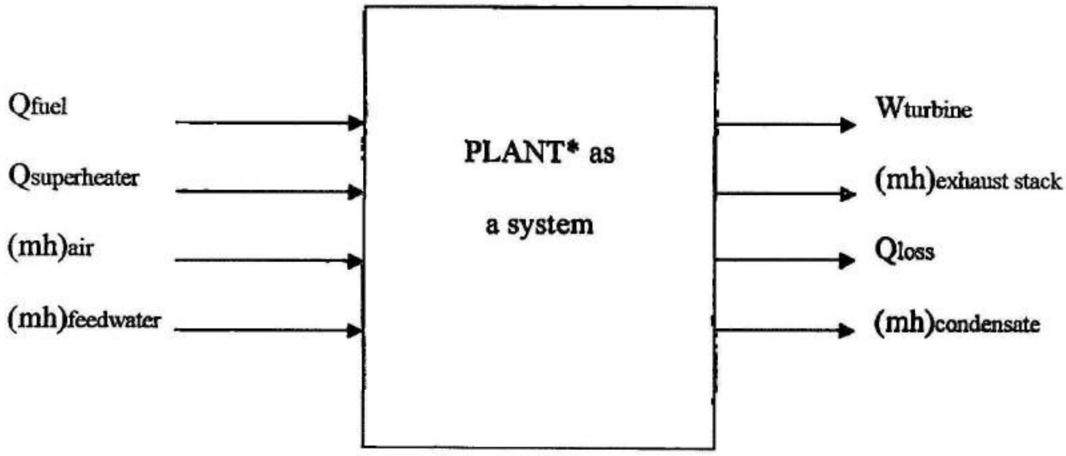

Figure 3.1: Simple energy balance box

By using this method we can calculate the input energy

1. Q_{fuel} = fuel oil
2. $Q_{superheater}$ = superheater
3. $(mh)_{air}$ = air influx
4. $(mh)_{feedwater}$ = feed-water

The output energy that can be calculate are

1. $W_{turbine}$ = turbine output
2. $(mh)_{exhaust\ stack}$ = exhaust stack loss
3. Q_{loss} = other losses
4. $(mh)_{condensate}$ = energy in condensate

From the result we can determine the main losses for the main part in the power plant. Most of all the data is taken many times so we can get the average and right data.

3.3.1 Calculation and Data Analysis

For the calculation, the equation for all the Input Energy and Output Energy are given by the power plant manufacturer. Just follow according the equation to gets the result. This is the basic equation to use the data:

$$\sum \text{Input energies} = \sum \text{Output energies}$$

$Q_{fuel} + Q_{superheater} + (mh)_{air} + (mh)_{feedwater} = W_{turbine} + (mh)_{exhaust\ stack} + Q_{loss} + (mh)_{condensate}$

Thus, Q_{loss} is determining by the following energy equation:

$Q_{loss} = (Q_{fuel} + Q_{superheater} + (mh)_{air} + (mh)_{feedwater}) - (W_{turbine} + (mh)_{exhaust\ stack} + (mh)_{condensate})$

Q_{loss} = the sum of all losses from the plant aggregated and comprising:

i. Convection, conduction and radiation losses from all hot surfaces exposed (even when lagged) to the surrounding atmosphere
ii. Sound emissions (small)
iii. Slight leaks of fluid (rare)

3.4 Cooling Water Flowrate Analysis

Method for this analysis is by doing 4 time experiments with different cooling water flowrate that is 3000l/h, 4000l/h, 5000l/h and 6000l/h for 10 minutes. Set the parameter that then compares the result of the experiment. Then plot the graph from the result and discussion will be made through the graph and result.
Procedure

1. Run the boiler
2. Set the parameter for reduced steam temperature (T4) at 200C, reduced steam pressure (P5) at 5.5bar and steam flow (ms) 170kg/hr.
3. Get data for 10 minutes of boiler
4. Do the experiment for 3000l/h, 4000l/h, 5000l/h and 6000l/h cooling water flowrate.
5. Interprets the result and plot graph from the efficiency.
6. Compare and discuss about the result
7. Conclude the optimum cooling water flowrate.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this chapter, we will analysis the result from the experiment. We calculate the losses and the efficiency of the boiler to know which is cooling water flowrate that give the most efficiency to the boiler between 3000 l/h, 4000 l/h, 5000 l/h or 6000 l/h.

This analysis is including graph to make the result easier to be observe.

4.2 Energy Balance Analysis

Q_{fuel} = energy input from fuel = mf x UCV ÷ 3600 (kW) (assumes 100% for combustion efficiency) and UCV = 45.5MJ/kg for class D (4.1)

$Q_{superheater}$ = input electrical energy for superheater
= (kW – hr) net reading from meter on panel ÷ time elapsed during test

$(mh)_{air}$ = influx of enthalpy with ambient air for combustion (kW)
= m_{air} Cp_{air} T_{air} (4.2)

m_{air} = estimate air flow(kg/s)

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

T_{air} = ambient air temp. (°C)

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

= $m_s h_1$ (4.3)

m_s = mass flow rate (kg/s)

h_1 = enthalpy of water, determined at temperature T_1, using properties tables.

$W_{turbine}$ = power output from turbine (kW)

= wT = angular velocity x output torque

= $\frac{2\pi N T}{60}$ (kW) (4.4)

N = rotational speed of turbine, RPM

T = net output on output shaft (Nm)

$(mh)_{exhaust\ stack}$ = enthalpy efflux through the exhaust stack (W)

$(mh)_{ex\ st.}$ = $(m_a + m_f)\ Cp_{ex}\ T_{ex}$ (4.5)

$(m_a + m_f)$ = sum of fuel and air mass flow (kg/s)

Cp_{ex} = specific heat at constant pressure for exhaust gas, 1.15kJ/(kgK)

T_{ex} = exhaust gas temperature measured at stack outlet, (°C)

Calculation of m_f and m_a

m_f = v_f (fuel flowrate litres/s) x p_{fuel} (4.6)

p_{fuel} = 870 kg/m3

The estimation of ambient air flow, ma, into the unit is achieved by:

i. Using a anemometer to measure the velocity, Ua, of air at boiler intake grill
ii. Measure the effective area A_g at the boiler air intake grill (m2)
iii. Calculate air density using perfect gas law:

$$p = \frac{P_a}{RT_a}$$

P_a = absolute ambient inlet pressure (kPa)

T_a = absolute ambient inlet temperature (K)

R = 0.287 kJ/(kgK) for air

$$m_a = \frac{P_a}{RT_a} \times A_g \times U_a \text{ (kg/s)} \quad (4.7)$$

$(mh)_{condensate}$ = $m_s h_c$

m_s = steam mass flowrate, kg/s

h_c = enthalpy of condensate leaving condenser, kJ/kg

Boiler Losses Calculation.

4.2.1 Calculation for 3000l/h Cooling Water Flowrate Losses

Q_{fuel} = 1L x 45.5 MJ ÷ 3600

= 12.64 kW

$Q_{superheater}$ = 1.5 x 3600 x (60 ÷ 10)

= 0.25 kW

$(mh)_{air}$ = 3.68 x 1.005 x 40.8

= 150.89 W

$(mh)_{feedwater}$ = 65.8543 x 147.9 ÷ 10

= 973.98 W

$$W_{turbine} = \frac{2\pi (3)(1.3)}{60} \text{ (kW)}$$

= 0.408 kW

$(mh)_{ex\ st.}$ = (0.87 + 3.68)x 1.15 x 265.9

= 1391.3 W

m_f = 1/1000 x 870

= 0.87

$$m_a = \frac{0.103 \text{ Pa}}{0.287 \text{ kJ/ (kgK)}(30.7)} \times 0.175 \text{ m2} \times 1.8 \text{ (kg/s)}$$

= 3.68 (kg/s)

$(mh)_{condensate}$ = 65.8543 x 310.2 ÷ 3600

= 5.67 kW

$Q_{loss} = (Q_{fuel} + Q_{superheater} + (mh)_{air} + (mh)_{feedwater}) - (W_{turbine} + (mh)_{exhaust\ stack} + (mh)_{condensate})$

Q_{loss} = (12.64 kW + 0.25 kW + 150.89 W + 973.98 W) – (0.408 kW + 1391.3 W + 5.67 kW)

= 6.55 kW

4.2.2 Calculation for 4000 l/h Cooling Water Flowrate Losses

Q_{fuel} = 1.1L x 45.5 MJ ÷ 3600

= 13.9 kW

$Q_{superheater}$ = 2.1 x (60 ÷ 10)

= 0.35 kW

$(mh)_{air}$ = 3.68 x 1.005 x 40.6

= 150.2 W

$(mh)_{feedwater}$ = 71.6639 x 136.62 ÷ 10

= 979.07 W

$$W_{turbine} = \frac{2\pi\,(2.9)(1.7)}{60}\,(kW)$$

= 0.516 kW

$(mh)_{ex\ st.}$ = (0.975 + 3.68)x 1.15 x 270.3

= 1447.0 W

m_f = 1.1/1000 x 870

= 0.975

m_a = $\frac{0.103 \text{ Pa} \times 0.175 \text{ m2} \times 1.8 \text{ (kg/s)}}{0.287 \text{ kJ/(kgK)}(30.7)}$

= 3.68 (kg/s)

$(mh)_{condensate}$ = 71.6639 x 306.1 ÷ 3600

= 6.09 kW

$Q_{loss} = (Q_{fuel} + Q_{superheater} + (mh)_{air} + (mh)_{feedwater}) - (W_{turbine} + (mh)_{exhaust\ stack} + (mh)_{condensate})$

Q_{loss} = (13.9 kW + 0.35 kW + 150.2 W + 979.07 W) – (0.516 kW + 1447.0 W + 6.09 kW)

= 7.33 kW

4.2.3 Calculation for 5000 l/h Cooling Water Flowrate Losses

Q_{fuel} = 1L x 45.5 MJ ÷ 3600

= 12.64 kW

$Q_{superheater}$ = 2.52 x (60 ÷ 10)

= 0.42 kW

$(mh)_{air}$ = 3.68 x 1.005 x 30.9

= 114.3 W

$(mh)_{feedwater}$ = 68.6510 x 129.93 ÷ 10

= 891.95 W

$W_{turbine}$ = $\frac{2\pi (2.7)(1.8)}{60}$ (kW)

$= \quad 0.509$ kW

$(mh)_{ex\ st.} = (0.87 + 3.68) \times 1.15 \times 252.7$

$= 1322.3$ W

$m_f = 1/1000 \times 870$

$= 0.87$

$m_a = \dfrac{0.103\ Pa \times 0.175\ m2 \times 1.8\ (kg/s)}{0.287\ kJ/(kgK)(30.7)}$

$= 3.68\ (kg/s)$

$(mh)_{condensate} = 68.6510 \times 294.76 \div 3600$

$= 5.62$ kW

$Q_{loss} = (Q_{fuel} + Q_{superheater} + (mh)_{air} + (mh)_{feedwater}) - (W_{turbine} + (mh)_{exhaust\ stack} + (mh)_{condensate})$

$Q_{loss} = (12.64\ kW + 0.42\ kW + 114.3\ W + 891.95\ W) - (0.509\ kW + 1322.3\ W + 5.62\ kW)$

$= 6.61$ kW

4.2.4 Calculation for 6000 l/h Cooling Water Flowrate Losses

$Q_{fuel} = 0.9L \times 45.5\ MJ \div 3600$

$= 11.38$ kW

$Q_{superheater} = 1.8 \times (60 \div 10)$

$= 0.3$ kW

$(mh)_{air} = 3.68 \times 1.005 \times 40.5$

$= 149.8$ W

$(mh)_{feedwater} = 63.5953 \times 150.83 \div 10$

$= 959.19\ W$

$W_{turbine} = \dfrac{2\pi(2.9)(1.4)}{60}(kW)$

$= 0.425\ kW$

$(mh)_{ex\ st.} = (0.783 + 3.68) x\ 1.15 \times 227.1$

$= 1165.6\ W$

$m_f = 0.9/1000 \times 870$

$= 0.783$

$m_a = \dfrac{0.103\ Pa}{0.287\ kJ/(kgK)(30.7)} \times 0.175\ m2 \times 1.8\ (kg/s)$

$= 3.68\ (kg/s)$

$(mh)_{condensate} = 63.5953 \times 288.94 \div 3600$

$= 5.10\ kW$

$Q_{loss} = (Q_{fuel} + Q_{superheater} + (mh)_{air} + (mh)_{feedwater}) - (W_{turbine} + (mh)_{exhaust\ stack} + (mh)_{condensate})$

$Q_{loss} = (11.38\ kW + 0.3\ kW + 149.8\ k + 959.19\ k) - (0.425\ kW + 1165.6\ k + 5.10\ kW)$

$= 6.10\ Kw$

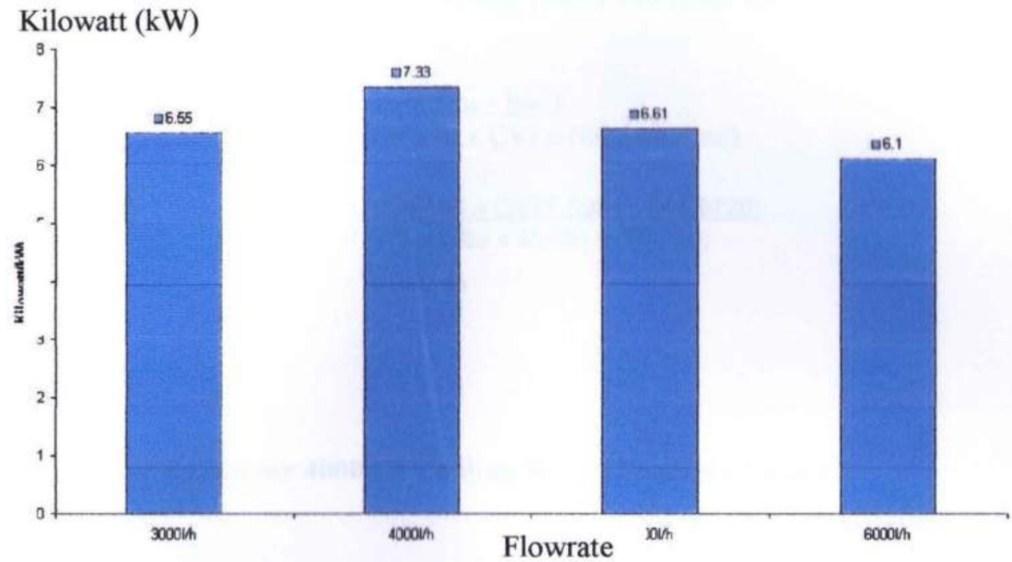

Figure 4.1: Losses of each cooling water flow

4.3 Cooling water flowrate analysis

Boiler efficiency calculation.

$$\text{Boiler efficiency} = \frac{\text{energy to produce steam}}{\text{energy supplied in fuel oil}}$$

$$= \frac{ms \times (hs - hfw)}{mf \times \rho f \times CVf \times (60 / \text{runtime})} \qquad (4.8)$$

Energy to produce steam = ms x (hs – hfw)

ms = steam mass flowrate

hs = enthalpy of boiler saturated vapors

hfw = enthalpy of feedwater

Energy supplied in fuel oil = mf x ρf x CVf x (60 / runtime)

mf = boiler fuel pulses, liter

ρf = density of fuel, kg/ltr = 0.85

CVf = gross calorific value of fuel, 45.49 MJ/kg

4.3.1 Calculation for 3000 l/h Cooling Water Flowrate Losses

Boiler efficiency $= \dfrac{m_s \times (h_s - h_{fw})}{m_f \times \rho_f \times CV_f \times (60 / runtime)}$

$= \dfrac{65.8543 \times (2571.5964 - 147.9720)}{1.0 \times 0.85 \times 45490 \times (60 / 10)}$

$= 69.07\ \%$

4.3.2 Calculation for 4000 l/h Cooling Water Flowrate Losses

Boiler efficiency $= \dfrac{m_s \times (h_s - h_{fw})}{m_f \times \rho_f \times CV_f \times (60 / runtime)}$

$= \dfrac{71.6639 \times (2569.5389 - 136.2680)}{1.1 \times 0.85 \times 45490 \times (60 / 10)}$

$= 72.62\ \%$

4.3.3 Calculation for 5000 l/h Cooling Water Flowrate Losses

Boiler efficiency $= \dfrac{m_s \times (h_s - h_{fw})}{m_f \times \rho_f \times CV_f \times (60 / runtime)}$

$= \dfrac{68.6510 \times (2567.8473 - 129.5800)}{1.0 \times 0.85 \times 45490 \times (60 / 10)}$

$= 75.40\ \%$

4.3.4 Calculation for 6000 l/h Cooling Water Flowrate Losses

Boiler efficiency $= \dfrac{m_s \times (h_s - h_{fw})}{m_f \times \rho_f \times CV_f \times (60 / runtime)}$

$= \dfrac{63.5953 \times (2570.3136 - 150.4800)}{0.9 \times 0.85 \times 45490 \times (60 / 10)}$

$= 78.99\ \%$

Table 3.1 Efficiency for each flowrate

Flowrate (l/h)	Efficiency (%)
3000	69.07
4000	72.62
5000	75.40
6000	78.99

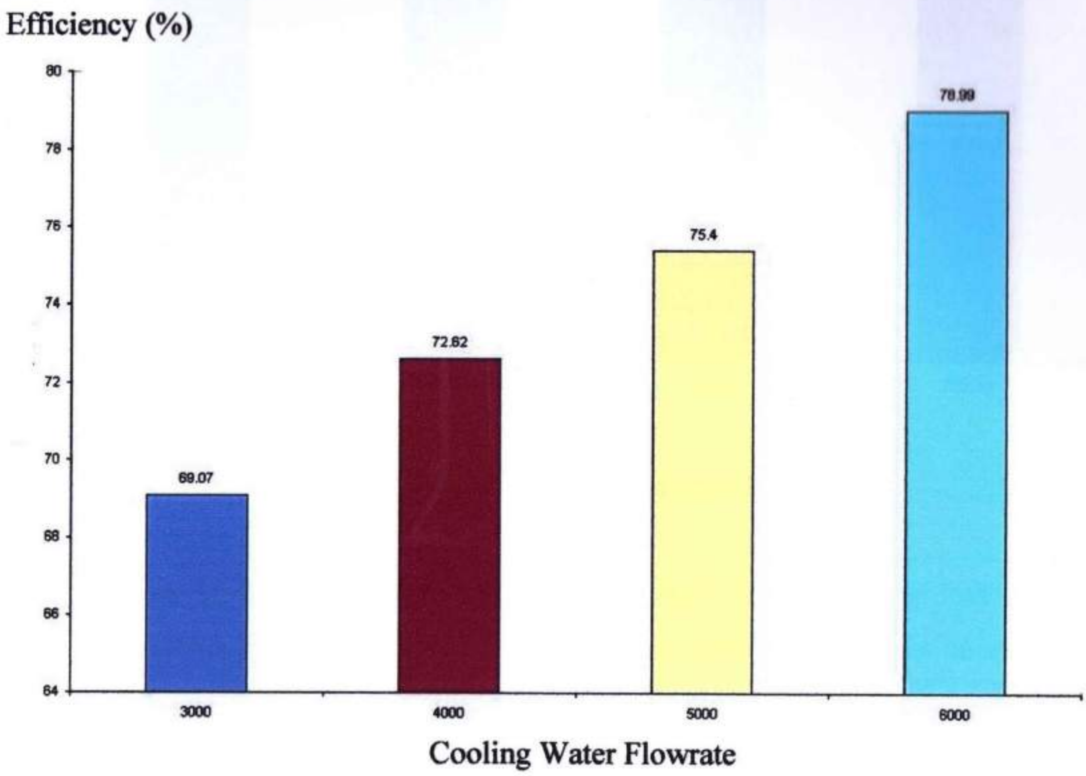

Figure 4.2: Boiler efficiency according to different cooling water flowrate

4.4 Discussion on Losses

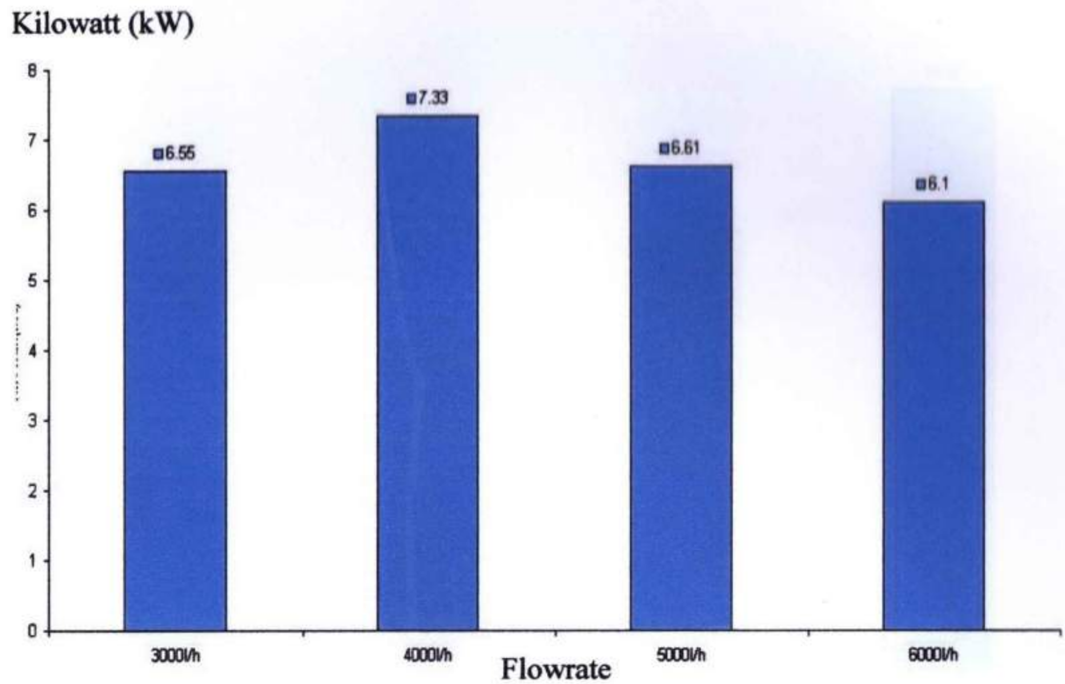

Figure 4.1: Losses of each cooling water flow

These is the graph that had been plot after calculating the losses from 3000l/h, 4000l/h, 5000l/h and 6000l/h cooling water flowrate. The maximum losses are when the water flowrate 4000 l/h at 7.33 kW and it decrease proportionally until the water flowrate 6000l/h at 6.1 kW. Even the losses at 3000l/h water flowrate is lower than losses at water flowrate 4000l/h and 5000l/h but the losses at 6000l/h still lower than 3000l/h. These prove that the higher the cooling water flowrate will give minimum losses than others.

This is because the higher cooling water flowrate in the condenser, the time for steam to condensate is much quickly and the heat will not loss to others parts. Furthermore, when the steam is condensate quickly so there is no problem for feed pump to support water in boiler and convert it into steam again.

4.5 Discussion on Boiler Efficiency

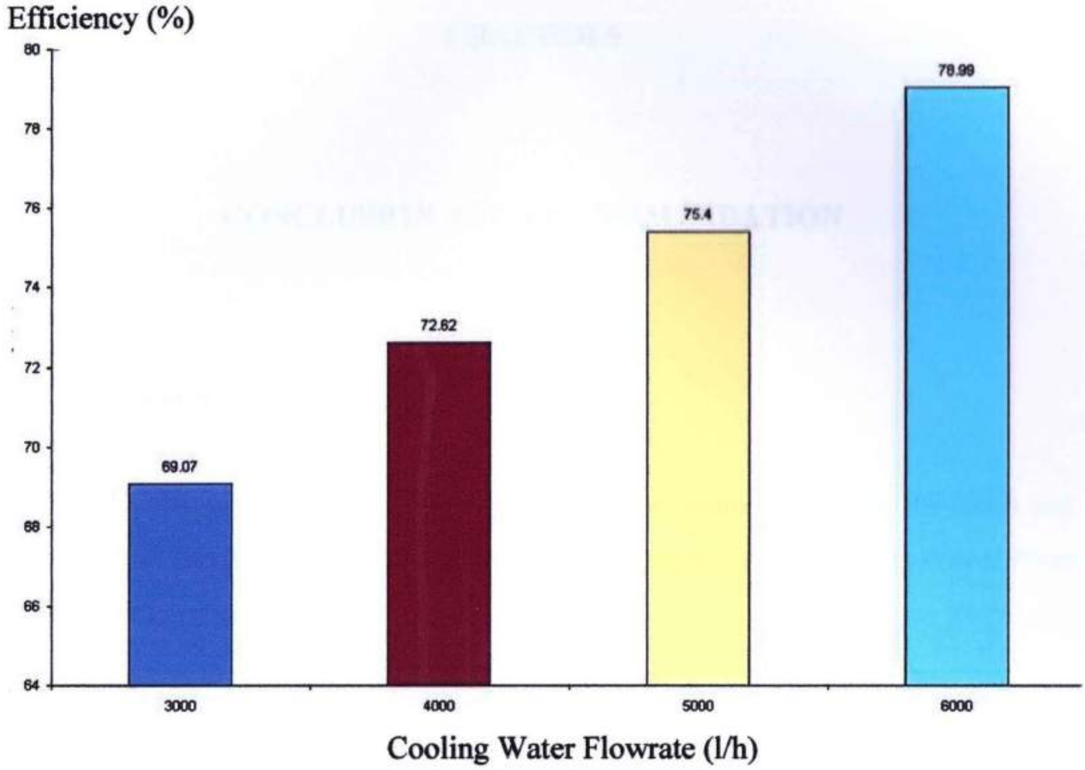

Figure 4.2: Boiler efficiency according to different cooling water flowrate

These is the graph that had been plot after calculating the efficiency for 3000l/h, 4000l/h, 5000l/h and 6000l/h cooling water flowrate.

From the graph the most cooling water flowrate that give optimum efficiency to boiler is 6000 l/h that is 78.99 % and the lowest is 3000 l/h that is 69.07 %. The graph increase proportionally that prove the higher the cooling water flowrate use the higher boiler efficiency can get. That mean the energy been supplied from oil combustion is 78.99% used to generate power at the turbine.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter will conclude and give recommendation following the result and discussion for the optimum cooling water flowrate usage in the Cussons Power Plant at Mechanical Laboratory.

5.2 Conclusion

First of all, the main objective of this project is to analysis the effect to boiler efficiency and calculates losses of component by using energy balance analysis of different cooling water flowrate. Then finally find the optimum flowrate for the Cussons Power Plant in Mechanical Laboratory.

From the discussion get that the highest cooling water flowrate 6000l/h will give the better result that is lowest energy losses and highest efficiency from 3000l/h, 4000l/h, and 5000l/h. That means the energy did not loss very much and fully used by boiler to convert the water into steam again.

Even though the different of the efficiency is only 4-5% but it effect for long term usage of oil for the boiler. That means the boiler used the oil effectively. For larger industrial that use bigger power plant than power plant in UMP, the different 4-5% efficiency will save cost for oil usage.

Finally for the conclusion the optimum cooling water flowrate for Cussons Power Plant in Mechanical Laboratory is 6000l/h.

5.3 Recommendation

After all the process in completing the project, there were several recommendation can be make in future. That is:-

1. For experiment, it can be done more properly by understanding all the parts function and related the data of each part effectively.

2. The parameters that use to be set must same for each data and know where are the parts that control the parameters, because there are many controllers at the boiler.

3. For analysis, there are many data can be related to find the optimum cooling water flowrate of the boiler. Example condensate time and fuel consumption.

4. The analysis of boiler efficiency can be expanded by changing the parameter of the of reduced steam temperature (T4), reduced steam pressure (P5) and steam flow (ms).

5. The analysis also can be done at boiler cooling tower.

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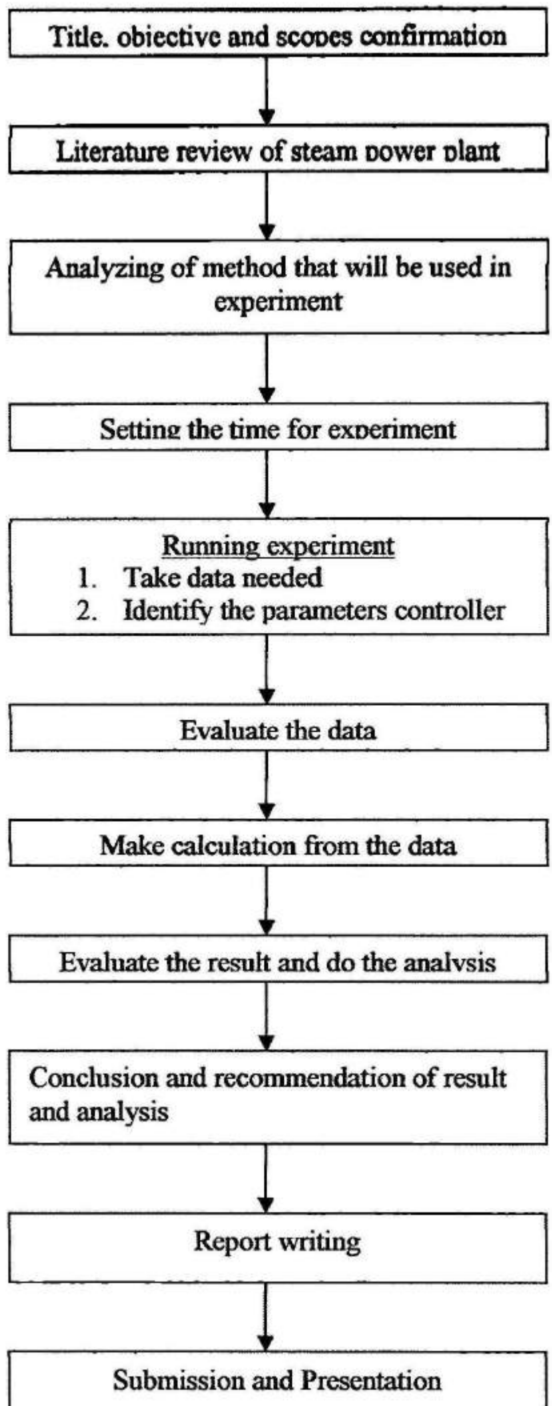
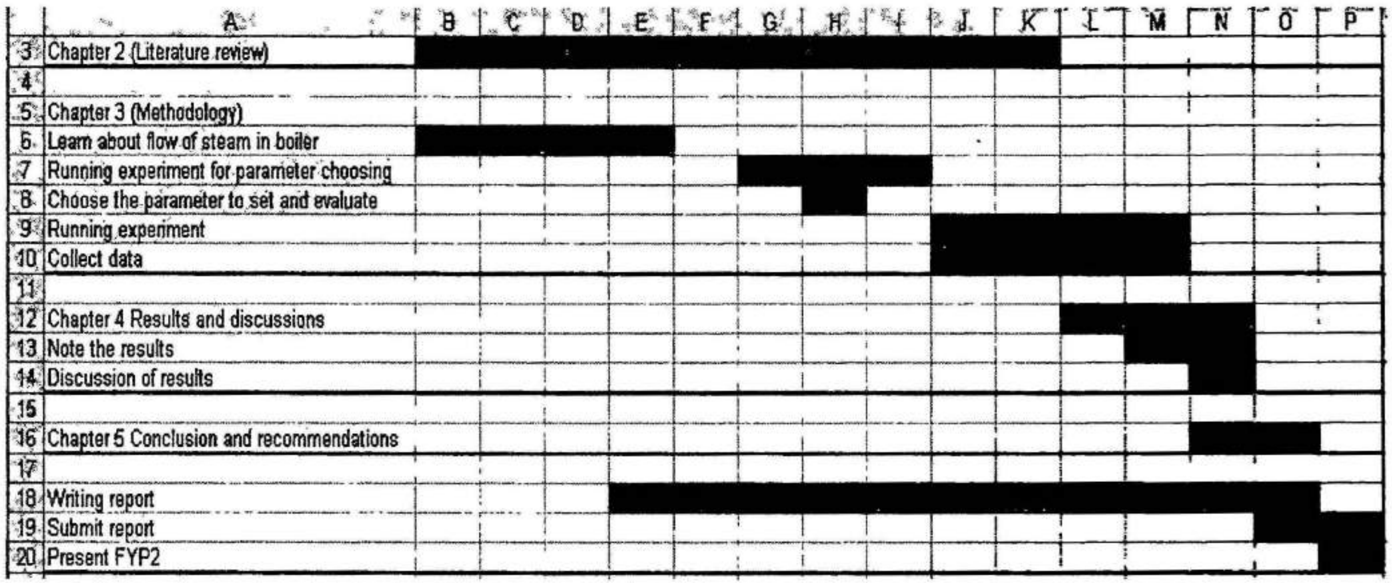
APPENDIX A-1: PROJECT FLOW CHART



APPENDIX A-2: GANTT CHART



APPENDIX A-3: LOG DATA FOR 3000l/h

Type	-100.0 to 100.0	-250.0 to 250.0	-250.0 to 250.0	-120.0 to 80.0	-120.0 to 80.0	-1000.0 to 1000.0	-250.0 to 250.0	-100.0 to 100.0	-100.0 to 100.0	-250.0 to 250.0	-100.0 to 100.0	-100.0 to 100.0	-100.0 to 100.0	-250.0 to 250.0
Units	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C
Time, s	Feedwater In - T1	Superheater Steam - T4	Boiler Steam - T3	Cool Tower In	Cool Tower Out	Boiler Flue - T11	Steam Orifice - T5	Condensate - T8	Cool Water In - T9	Turbine Out - T7	Cool Water Out - T10	Ambient - T12	Fuel Oil - T2	Turbine In -T6
0	35.0	214.6	175.1	33.0	28.9	265.0	211.4	75.1	36.9	150.9	50.9	40.9	37.5	202.5
30	35.1	207.6	177.1	32.9	28.4	261.3	206.9	74.7	36.5	151.1	50.5	41.1	37.5	201.2
60	35.1	205.0	176.0	32.8	29.0	225.5	202.9	74.1	36.0	151.2	49.7	40.9	37.7	199.7
90	35.2	204.9	174.3	32.8	31.5	217.8	200.7	73.3	35.9	151.2	49.6	40.8	37.7	198.0
120	35.2	204.9	175.5	32.7	34.6	252.8	199.0	73.3	36.8	151.1	50.2	41.0	37.6	196.4
150	35.3	204.7	176.9	32.7	36.7	247.1	197.1	73.7	37.4	150.8	51.1	40.3	37.7	194.6
180	35.3	204.9	175.5	32.6	31.5	216.7	196.1	74.2	38.3	150.6	51.6	39.8	37.9	193.1
210	35.1	205.0	173.0	32.5	30.0	231.4	195.8	74.3	38.5	150.5	52.1	40.6	37.7	191.9
240	35.1	204.9	172.8	32.5	29.2	257.9	195.6	74.2	37.7	150.1	51.4	40.8	37.7	190.9
270	35.2	204.9	173.0	32.4	28.6	269.5	195.2	73.9	37.0	149.7	51.0	40.9	37.6	190.1
300	35.2	205.0	174.6	32.4	28.2	275.6	195.0	74.2	36.5	149.5	50.5	41.1	37.6	189.5
330	35.3	205.0	177.0	32.3	29.0	275.1	194.4	74.0	36.1	149.2	50.3	41.1	37.7	188.8
360	35.3	205.1	176.3	32.3	32.0	235.2	193.9	73.8	35.9	148.9	49.8	40.3	38.0	188.0
390	35.4	205.2	174.7	32.2	34.9	212.0	193.8	73.4	36.7	148.7	50.0	40.3	38.0	187.6
420	35.4	204.9	175.0	32.2	37.2	248.2	193.7	73.8	37.4	148.5	51.3	40.6	37.8	187.2
450	35.4	204.5	176.9	32.1	32.8	260.5	193.2	74.2	38.4	148.1	52.0	40.6	37.8	186.8
480	35.2	204.5	174.8	32.1	30.6	224.5	193.0	74.7	39.3	147.9	52.7	40.2	38.0	186.3
510	35.3	204.7	172.9	32.1	29.7	248.1	193.4	74.5	38.1	147.7	51.9	40.5	37.8	186.1
540	35.3	204.6	173.0	32.0	28.9	265.6	193.7	74.2	37.5	147.4	51.7	40.9	37.8	186.0
570	35.3	204.7	174.3	31.9	28.4	274.0	193.9	74.3	36.9	147.2	51.0	41.0	37.8	186.0
600	35.4	204.6	176.7	31.9	28.2	280.2	193.9	74.4	36.3	146.9	50.2	41.1	37.8	185.8

-10.0 to 10.0	-6000.0 to 6000.0	-100.0 to 100.0	-100.0 to 100.0	-10.0 to 10.0	-10.0 to 10.0	-12.0 to 4.00	-8.00 to 6.00	-350.0 to 350.0	-2.00 to 2.00	-4000.0 to 4000.0	-1000.0 to 1000.0	Totalize	Totalize	Totalize
Bar	l/H	%	%	Bar	Bar	Nm	Bar	mbar	Bar	RPM	s	Cool Tower Makeup Water	Fuel Flow	kWH
Boiler Steam Press - P8	Coolant Flow	Tower In RH	Tower Out RH	Steam Press - P5	Turbine In Press - P6	Torque	Turbine Out Press - P7	Steam Flow	Atmospheric - P12	Speed	Condensate time	Cool Tower Makeup Water	Fuel Flow	kWH
7.1	3209.6	89.4	45.6	5.1	0.0	1.3	-1.0	159.7	0.0	3.0	1.1	0.0	1.0	0.0
7.5	3248.2	89.1	46.0	5.1	0.0	1.3	-1.0	156.6	0.0	3.0	1.1	0.0	4.0	0.0
7.2	3236.8	93.9	47.5	4.9	0.0	1.3	-1.0	149.0	0.0	2.9	1.1	0.0	4.0	2.0
6.9	3284.1	94.0	48.0	4.9	0.0	1.2	-1.0	149.1	0.0	3.0	1.1	0.0	5.0	3.0
7.2	3267.6	94.2	47.5	5.1	0.0	1.4	-1.0	154.5	0.0	3.0	1.1	0.0	9.0	4.0
7.4	3268.9	94.0	47.6	5.0	0.0	1.3	-1.0	152.8	0.0	2.9	1.1	0.0	12.0	6.0
7.1	3268.9	94.2	46.8	4.9	0.0	1.3	-1.0	148.5	0.0	3.1	1.1	0.0	12.0	7.0
6.7	3228.1	92.9	47.0	4.9	0.0	1.2	-1.0	147.1	0.0	3.1	1.1	0.0	14.0	9.0
6.6	3288.7	90.3	47.3	5.0	0.0	1.3	-1.0	150.9	0.0	3.1	1.1	0.0	18.0	9.0
6.7	3129.4	89.5	47.6	5.0	0.0	1.3	-1.0	152.8	0.0	3.2	1.1	0.0	22.0	10.0
7.0	3239.7	89.7	47.6	5.1	0.0	1.3	-1.0	157.3	0.0	3.0	1.1	0.0	27.0	10.0
7.5	3207.9	94.0	48.9	5.1	0.0	1.3	-1.0	156.7	0.0	3.0	1.1	0.0	30.0	11.0
7.3	3230.1	94.1	48.8	4.9	0.0	1.3	-1.0	149.7	0.0	3.0	1.1	0.0	30.0	13.0
7.0	3279.8	94.2	48.2	4.9	0.0	1.3	-1.0	149.2	0.0	3.0	1.1	0.0	30.0	14.0
7.1	3313.8	93.9	49.5	5.1	0.0	1.4	-1.0	157.4	0.0	3.0	1.1	0.0	34.0	15.0
7.4	3279.3	94.6	48.1	5.1	0.0	1.3	-1.0	155.7	0.0	3.0	1.1	0.0	37.0	17.0
7.0	3374.1	93.6	48.2	4.9	0.0	1.2	-1.0	147.8	0.0	3.4	1.1	0.0	37.0	18.0
6.6	3180.8	91.8	48.1	4.9	0.0	1.3	-1.0	150.1	0.0	3.4	1.1	0.0	40.0	20.0
6.7	3138.7	89.5	48.3	5.0	0.0	1.3	-1.0	152.9	0.0	3.4	1.1	0.0	44.0	22.0
6.9	3202.7	89.5	48.7	5.1	0.0	1.3	-1.0	158.6	0.0	3.3	1.1	0.0	48.0	23.0
7.4	3203.4	92.4	49.1	5.1	0.0	1.3	-1.0	158.1	0.0	3.2	1.1	0.0	51.0	25.0

APPENDIX A-4: LOG DATA FOR 4000l/h

Type	-100.0 to 100.0	-250.0 to 250.0	-250.0 to 250.0	-120.0 to 80.0	-120.0 to 80.0	-1000.0 to 1000.0	-250.0 to 250.0	-100.0 to 100.0	-100.0 to 100.0	-250.0 to 250.0	-100.0 to 100.0	-100.0 to 100.0	-100.0 to 100.0	-250.0 to 250.0
Units	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C
Time, s	Feedwater In - T1	Superheater Steam - T4	Boiler Steam - T3	Cool Tower In	Cool Tower Out	Boiler Flue - T11	Steam Orifice - T5	Condensate - T8	Cool Water In - T9	Turbine Out - T7	Cool Water Out - T10	Ambient - T12	Fuel Oil - T2	Turbine In -T6
0	32.1	203.7	175.4	34.3	30.1	281.6	186.9	72.4	34.3	135.3	46.6	40.4	38.7	178.7
30	32.2	202.4	175.1	34.4	32.9	244.6	188.8	72.8	34.8	135.1	47.2	40.3	39.0	179.4
60	32.2	202.4	173.3	34.4	35.5	224.2	190.2	72.8	36.0	135.4	47.9	39.9	39.0	180.0
90	32.3	202.6	174.0	34.4	31.6	258.5	191.4	72.7	37.8	135.7	49.0	40.0	38.9	180.7
120	32.2	202.4	175.3	34.4	30.7	272.4	192.1	73.7	37.1	135.7	49.7	40.3	38.9	181.5
150	32.3	202.5	175.3	34.3	30.3	279.1	192.7	73.9	36.5	135.9	49.1	41.1	39.0	182.2
180	32.3	202.5	175.5	34.3	29.9	282.7	193.1	73.7	36.0	136.2	48.4	40.6	39.1	182.8
210	32.4	202.4	174.9	34.2	29.5	261.7	193.3	73.5	35.5	136.5	48.0	40.2	39.2	183.2
240	32.4	202.6	172.2	34.0	29.3	252.5	193.4	72.8	35.1	137.0	46.8	40.3	39.2	183.4
270	32.5	202.5	173.3	33.9	29.1	271.6	193.7	72.1	34.7	137.5	46.5	40.7	39.2	183.8
300	32.5	202.5	175.3	33.8	29.3	279.7	193.8	72.3	34.4	137.7	46.8	40.8	39.2	184.1
330	32.5	202.4	175.4	33.9	31.0	249.4	193.8	72.9	34.5	137.7	47.0	40.2	39.5	184.4
360	32.6	202.4	173.7	33.9	34.3	222.8	193.9	72.7	35.3	138.1	47.3	39.9	39.5	184.5
390	32.7	202.5	173.8	34.0	34.9	254.6	194.0	72.5	36.6	138.6	48.1	39.8	39.3	184.6
420	32.7	202.4	175.4	33.9	31.5	271.4	194.0	73.3	38.5	138.7	50.2	40.4	39.4	184.8
450	32.8	202.5	175.0	33.9	30.7	239.1	194.0	74.2	37.2	138.8	49.9	39.8	39.7	184.9
480	32.7	202.8	172.1	33.9	30.2	237.8	194.1	73.5	36.6	139.2	48.7	40.6	39.5	184.9
510	32.8	203.0	171.7	33.9	29.7	263.6	194.2	72.6	36.1	139.6	47.6	40.6	39.5	184.9
540	32.9	202.9	171.9	33.9	29.4	274.7	194.2	72.2	35.5	139.9	47.1	40.6	39.6	184.9
570	32.9	202.8	172.3	33.8	29.1	280.0	194.2	71.9	35.1	140.2	46.7	40.7	39.6	184.9
600	33.0	202.9	173.3	33.8	28.9	283.2	194.3	71.9	34.8	140.3	46.5	40.9	39.6	185.0

-10.0 to 10.0	-6000.0 to 6000.0	-100.0 to 100.0	-100.0 to 100.0	-10.0 to 10.0	-10.0 to 10.0	-12.0 to 4.00	-8.00 to 6.00	-350.0 to 350.0	-2.00 to 2.00	-4000.0 to 4000.0	-1000.0 to 1000.0	Totalize	Totalize	Totalize
Bar	l/H	%	%	Bar	Bar	Nm	Bar	mbar	Bar	RPM	s	Cool Tower Makeup Water	Fuel Flow	KWH
Boiler Steam Press - P3	Coolant Flow	Tower In RH	Tower Out RH	Steam Press - P5	Turbine In Press - P6	Torque	Turbine Out Press - P7	Steam Flow	Atmospheric - P12	Speed	Condensate time	Cool Tower Makeup Water	Fuel Flow	KWH
7.4	4074.0	93.5	47.4	5.9	0.0	1.8	-1.0	166.5	0.0	2.6	1.0	0.0	1.0	1.0
7.3	4093.6	93.9	47.6	5.8	0.0	1.8	-1.0	160.0	0.0	2.6	1.0	0.0	1.0	2.0
6.9	4109.9	94.8	47.7	5.5	0.0	1.6	-1.0	148.9	0.0	2.6	1.0	0.0	2.0	4.0
7.1	4061.6	94.3	47.2	5.7	0.0	1.7	-1.0	158.0	0.0	2.9	1.0	0.0	5.0	6.0
7.3	4181.3	90.7	47.2	5.9	0.0	1.8	-1.0	164.7	0.0	3.1	1.0	0.0	9.0	7.0
7.3	4114.9	88.2	47.4	5.9	0.0	1.8	-1.0	165.4	0.0	3.1	1.1	0.0	12.0	9.0
7.4	4158.1	88.8	47.5	5.9	0.0	1.8	-1.0	166.5	0.0	3.1	1.1	0.0	16.0	11.0
7.2	4195.7	88.8	47.5	5.8	0.0	1.8	-1.0	158.5	0.0	3.1	1.1	0.0	18.0	13.0
6.7	4075.2	89.4	48.3	5.4	0.0	1.6	-1.0	144.9	0.0	3.1	1.0	0.0	19.0	15.0
6.9	4115.3	89.6	48.8	5.6	0.0	1.6	-1.0	153.8	0.0	2.9	1.0	0.0	24.0	16.0
7.3	4088.9	93.1	49.2	5.9	0.0	1.8	-1.0	167.5	0.0	3.0	1.0	0.0	28.0	18.0
7.3	4106.3	93.7	49.1	5.9	0.0	1.8	-1.0	164.2	0.0	2.9	1.0	0.0	28.0	20.0
7.0	4106.7	94.0	48.4	5.6	0.0	1.7	-1.0	152.5	0.0	2.9	1.0	0.0	28.0	22.0
7.0	4071.9	95.2	48.3	5.7	0.0	1.7	-1.0	157.4	0.0	2.9	1.0	0.0	32.0	23.0
7.3	4116.8	94.3	48.1	5.9	0.0	1.8	-1.0	168.4	0.0	3.0	1.0	0.0	35.0	25.0
7.2	4073.0	91.4	48.4	5.8	0.0	1.8	-1.0	160.9	0.0	2.8	1.0	0.0	36.0	27.0
6.6	4135.0	88.8	48.7	5.4	0.0	1.6	-1.0	142.8	0.0	2.8	1.0	0.0	38.0	29.0
6.6	4064.2	88.6	48.7	5.3	0.0	1.5	-1.0	141.9	0.0	2.8	1.0	0.0	41.0	31.0
6.6	4026.9	89.1	48.1	5.3	0.0	1.5	-1.0	144.0	0.0	2.8	1.0	0.0	45.0	32.0
6.7	4096.6	89.6	48.6	5.4	0.0	1.7	-1.0	146.5	0.0	2.8	1.0	0.0	48.0	34.0
6.9	4054.7	90.2	48.4	5.6	0.0	1.5	-1.0	155.6	0.0	2.7	1.0	0.0	53.0	35.0

APPENDIX A-5: LOG DATA FOR 5000l/h

Type	-100.0 to 100.0	-250.0 to 250.0	-250.0 to 250.0	-120.0 to 80.0	-120.0 to 80.0	-1000.0 to 1000.0	-250.0 to 250.0	-100.0 to 100.0	-100.0 to 100.0	-250.0 to 250.0	-100.0 to 100.0	-100.0 to 100.0	-100.0 to 100.0	-250.0 to 250.0
Units	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C
Time, s	Feedwater In - T1	Superheater Steam - T4	Boiler Steam - T3	Cool Tower In	Cool Tower Out	Boiler Flue - T11	Steam Orifice - T5	Condensate - T8	Cool Water In - T9	Turbine Out - T7	Cool Water Out - T10	Ambient - T12	Fuel Oil - T2	Turbine In - T6
0	30.6	200.8	173.2	34.9	30.0	272.7	181.0	69.5	33.8	100.9	43.2	38.5	35.9	162.8
30	30.6	201.0	173.3	34.9	30.1	277.2	184.5	69.4	33.7	101.1	42.9	38.6	36.0	164.7
60	30.6	201.4	174.3	35.0	30.9	280.0	185.9	69.7	34.4	102.7	43.4	38.4	36.1	165.2
90	30.7	201.5	174.9	35.1	32.3	252.2	187.0	70.1	35.7	108.5	45.0	38.4	36.2	168.8
120	30.8	201.7	173.3	35.1	30.7	222.6	187.9	70.7	36.8	110.4	46.4	38.2	36.2	171.4
150	30.8	201.4	172.9	35.2	30.6	249.1	188.3	70.7	36.1	111.9	45.3	39.0	36.1	172.6
180	30.7	201.3	172.7	35.3	30.3	266.1	188.9	70.1	35.6	113.1	44.6	39.2	36.2	166.3
210	30.8	201.3	173.9	35.2	30.1	273.9	189.5	70.0	35.2	114.5	44.6	39.5	36.4	173.4
240	30.8	201.3	175.3	35.1	29.8	262.6	190.0	70.1	34.8	115.5	44.5	39.0	36.4	170.5
270	30.9	201.0	173.9	35.1	29.7	228.5	190.4	70.1	35.4	117.0	44.0	38.7	36.5	176.5
300	30.8	201.4	171.4	35.1	29.5	241.5	190.8	69.5	34.4	118.7	43.2	39.1	36.5	177.1
330	30.9	201.5	171.1	35.2	29.4	262.8	191.2	68.6	34.1	120.1	42.8	39.3	36.6	177.7
360	31.0	201.4	171.3	35.0	29.3	272.2	191.8	69.1	34.0	121.3	42.9	39.4	36.7	178.1
390	31.0	201.4	173.4	35.0	29.7	277.1	191.5	69.0	34.0	122.0	43.1	38.8	36.8	178.6
420	31.1	201.6	175.3	35.1	30.9	279.9	191.7	70.1	34.9	122.5	44.3	39.2	36.9	179.3
450	31.2	201.6	174.6	35.1	31.4	239.6	191.8	70.9	36.2	123.2	45.5	38.7	37.0	179.7
480	31.2	201.6	172.8	35.1	30.4	224.3	192.0	70.9	36.8	124.3	46.2	38.5	36.9	180.0
510	31.3	201.6	173.6	35.1	30.2	256.7	192.2	70.8	36.2	125.3	45.6	39.0	36.9	180.4
540	31.1	201.5	173.5	35.1	30.0	270.2	192.3	70.6	35.7	126.0	45.0	38.8	37.0	180.7
570	31.2	201.6	173.6	35.1	29.8	276.7	192.4	70.3	35.3	126.8	44.7	39.4	37.1	180.9
600	31.2	201.7	174.5	35.1	29.7	280.7	192.5	70.5	35.0	127.4	44.5	39.3	37.2	181.2

-10.0 to 10.0	-6000.0 to 6000.0	-100.0 to 100.0	-100.0 to 100.0	-10.0 to 10.0	-10.0 to 10.0	-12.0 to 4.00	-8.00 to 6.00	-350.0 to 350.0	-2.00 to 2.00	-4000.0 to 4000.0	-1000.0 to 1000.0	Totalize	Totalize	Totalize
Bar	l/H	%	%	Bar	Bar	Nm	Bar	mbar	Bar	RPM	s	Cool Tower Makeup Water	Fuel Flow	kWH
Boiler Steam Press - P3	Coolant Flow	Tower In RH	Tower Out RH	Steam Press - P5	Turbine In Press - P6	Torque	Turbine Out Press - P7	Steam Flow	Atmospheric - P12	Speed	Condensate time	Cool Tower Makeup Water	Fuel Flow	kWH
7.1	5176.9	84.8	45.1	5.5	0.0	1.7	-1.0	154.7	0.0	3.0	1.0	0.0	2.0	1.0
7.1	5180.7	91.3	45.0	5.5	0.0	1.7	-1.0	156.5	0.0	3.0	1.0	0.0	6.0	3.0
7.3	5154.2	93.4	45.6	5.7	0.0	1.8	-1.0	165.6	0.0	2.9	1.0	0.0	10.0	5.0
7.4	5184.1	93.5	44.5	5.8	0.0	1.8	-1.0	164.0	0.0	2.8	1.0	0.0	11.0	8.0
7.0	5179.1	86.0	44.7	5.5	0.0	1.8	-1.0	152.1	0.0	2.8	1.0	0.0	12.0	10.0
7.0	5170.5	85.5	44.3	5.5	0.0	1.7	-1.0	152.6	0.0	3.0	1.0	0.0	16.0	12.0
6.9	5164.2	85.5	43.8	5.4	0.0	1.7	-1.0	150.9	0.0	3.0	1.0	0.0	20.0	14.0
7.2	5159.3	85.9	43.8	5.6	0.0	1.9	-1.0	161.5	0.0	2.8	1.0	0.0	24.0	16.0
7.4	5139.2	87.0	44.3	5.9	0.0	1.8	-1.0	167.1	0.0	2.8	1.0	0.0	28.0	18.0
7.1	5205.8	87.4	44.4	5.6	0.0	1.8	-1.0	155.0	0.0	3.0	1.0	0.0	28.0	20.0
6.7	5237.3	87.7	44.4	5.2	0.0	1.6	-1.0	131.0	0.0	2.6	1.0	0.0	30.0	22.0
6.6	5115.8	87.7	44.6	5.2	0.0	1.6	-1.0	139.8	0.0	2.7	1.0	0.0	34.0	24.0
6.7	5161.6	89.0	44.5	5.2	0.0	1.6	-1.0	141.6	0.0	2.5	1.0	0.0	36.0	26.0
7.1	5179.8	93.2	45.2	5.6	0.0	1.8	-1.0	157.6	0.0	2.5	1.0	0.0	39.0	28.0
7.5	5173.9	93.5	45.4	5.9	0.0	1.9	-1.0	169.6	0.0	2.5	1.0	0.0	41.0	30.0
7.3	5155.4	93.8	44.3	5.8	0.0	1.9	-1.0	159.2	0.0	2.5	1.0	0.0	43.0	32.0
6.9	5183.6	88.9	44.5	5.5	0.0	1.8	-1.0	148.9	0.0	2.5	1.0	0.0	44.0	34.0
7.1	5173.0	87.2	44.7	5.6	0.0	1.7	-1.0	155.3	0.0	2.7	1.0	0.0	47.0	36.0
7.1	5174.7	87.5	45.3	5.6	0.0	1.8	-1.0	154.1	0.0	2.7	1.0	0.0	48.0	38.0
7.1	5151.7	87.5	45.1	5.6	0.0	1.7	-1.0	154.3	0.0	2.7	1.0	0.0	49.0	40.0
7.3	5159.0	87.9	44.9	5.8	0.0	1.8	-1.0	163.7	0.0	2.6	1.0	0.0	49.0	42.0

APPENDIX A-6: LOG DATA FOR 6000l/h

Type	-100.0 to 100.0	-250.0 to 250.0	-250.0 to 250.0	-120.0 to 80.0	-120.0 to 80.0	-1000.0 to 1000.0	-250.0 to 250.0	-100.0 to 100.0	-100.0 to 100.0	-250.0 to 250.0	-100.0 to 100.0	-100.0 to 100.0	-100.0 to 100.0	-250.0 to 250.0
Units	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C	Deg C
Time, s	Feedwater In - T1	Superheater Steam - T4	Boiler Steam - T3	Cool Tower In	Cool Tower Out	Boiler Flue - T11	Steam Orifice - T5	Condensate - T8	Cool Water In - T9	Turbine Out - T7	Cool Water Out - T10	Ambient - T12	Fuel Oil - T2	Turbine In - T6
0	35.6	204.3	176.6	31.7	29.8	264.7	192.6	70.3	38.6	145.9	46.3	40.9	38.0	185.1
30	35.6	204.1	173.9	31.6	29.2	233.9	192.8	69.8	37.8	145.8	45.3	40.8	38.0	185.2
60	35.6	204.2	173.2	31.6	28.7	261.9	193.2	69.2	37.2	145.8	44.8	40.6	38.0	185.3
90	35.7	204.4	175.3	31.6	28.4	273.9	193.3	69.2	36.7	145.7	44.5	40.2	38.0	185.2
120	35.7	204.3	177.1	31.7	28.5	260.5	192.8	68.9	36.3	145.5	43.9	40.3	38.1	185.1
150	35.7	204.4	175.9	31.7	29.4	226.4	192.6	68.7	36.7	145.5	43.9	40.0	38.4	185.2
180	35.8	204.6	174.4	31.7	30.9	218.6	193.0	68.6	38.0	145.5	44.8	40.6	38.3	185.1
210	35.8	204.9	175.5	31.6	31.2	253.6	193.1	69.1	39.1	145.4	46.4	40.6	38.2	185.0
240	35.9	205.1	177.0	31.6	29.5	248.4	192.9	69.8	38.7	145.3	46.3	40.7	38.4	185.0
270	35.9	205.3	175.6	31.5	29.0	217.7	192.9	69.5	37.9	145.3	45.4	40.3	38.6	184.9
300	35.8	205.5	174.2	31.4	28.6	230.0	193.2	69.1	37.2	145.3	44.8	40.6	38.3	184.9
330	35.8	205.5	173.9	31.4	28.4	257.8	193.5	68.7	36.8	145.2	44.3	41.0	38.3	185.0
360	35.9	205.6	174.2	31.4	28.6	270.5	193.7	68.3	36.4	143.2	44.1	41.2	38.3	185.2
390	36.1	205.6	174.6	31.3	29.6	276.9	193.8	68.6	36.8	144.7	44.1	41.2	38.3	185.3
420	36.2	205.6	176.6	31.4	30.7	280.6	193.6	69.3	38.0	144.7	45.3	41.4	38.3	185.4
450	36.2	205.5	176.7	31.4	29.9	242.3	193.1	69.7	39.4	144.6	46.6	40.8	38.6	185.4
480	36.2	205.4	175.1	31.4	29.2	216.0	193.1	69.6	38.3	144.7	46.0	40.4	38.8	185.4
510	36.3	205.3	174.7	31.4	28.9	242.0	193.3	69.5	37.7	144.8	45.2	40.8	38.5	185.3
540	36.3	205.2	176.5	31.3	28.6	264.2	193.2	69.3	37.1	144.7	44.8	41.1	38.5	185.2
570	36.3	205.0	176.3	31.3	28.3	230.5	192.9	69.1	36.7	144.6	44.2	40.4	38.8	185.1
600	36.4	204.7	174.5	31.2	28.8	209.6	193.0	68.6	36.3	144.7	43.8	40.5	38.7	185.1

-10.0 to 10.0	-6000.0 to 6000.0	-100.0 to 100.0	-100.0 to 100.0	-10.0 to 10.0	-10.0 to 10.0	-12.0 to 4.00	-8.00 to 6.00	-350.0 to 350.0	-2.00 to 2.00	-4000.0 to 4000.0	-1000.0 to 1000.0	Totalize	Totalize	Totalize
Bar	l/H	%	%	Bar	Bar	Nm	Bar	mbar	Bar	RPM	s	Cool Tower Makeup Water	Fuel Flow	kWH
Boiler Steam Press - P3	Coolant Flow	Tower In RH	Tower Out RH	Steam Press - P5	Turbine In Press - P6	Torque	Turbine Out Press - P7	Steam Flow	Atmospheric - P12	Speed	Condensate time	Cool Tower Makeup Water	Fuel Flow	kWH
7.3	5990.0	93.2	48.9	5.0	0.0	1.3	-1.0	152.4	0.0	3.4	1.1	0.0	0.0	1.0
6.8	5980.1	90.6	49.4	4.9	0.0	1.3	-1.0	148.4	0.0	3.3	1.1	0.0	1.0	3.0
6.7	6068.7	89.5	49.5	4.9	0.0	1.3	-1.0	152.7	0.0	3.3	1.1	0.0	6.0	4.0
7.1	5982.1	89.8	49.3	5.1	0.0	1.4	-1.0	158.4	0.0	3.2	1.1	0.0	10.0	5.0
7.5	6013.2	93.3	49.3	5.1	0.0	1.5	-1.0	156.0	0.0	3.2	1.1	0.0	12.0	7.0
7.2	6027.3	94.2	49.5	4.9	0.0	1.3	-1.0	150.8	0.0	2.9	1.1	0.0	12.0	8.0
6.9	5986.8	94.1	51.1	4.9	0.0	1.4	-1.0	151.0	0.0	2.9	1.1	0.0	13.0	10.0
7.2	5981.0	94.4	49.4	5.1	0.0	1.4	-1.0	157.3	0.0	2.9	1.1	0.0	17.0	11.0
7.4	6049.6	92.9	49.3	5.0	0.0	1.4	-1.0	155.5	0.0	2.9	1.1	0.0	19.0	13.0
7.1	5968.6	89.2	49.4	4.9	0.0	1.3	-1.0	150.8	0.0	2.9	1.1	0.0	19.0	14.0
6.9	6017.3	88.6	49.6	4.9	0.0	1.3	-1.0	151.0	0.0	3.1	1.1	0.0	21.0	16.0
6.8	6075.2	89.3	50.0	5.0	0.0	1.4	-1.0	153.3	0.0	3.1	1.1	0.0	24.0	17.0
6.9	6169.8	93.6	50.5	5.0	0.0	1.2	-1.0	154.7	0.0	3.1	1.1	0.0	28.0	18.0
7.0	5950.4	94.2	51.0	5.0	0.0	1.4	-1.0	155.8	0.0	3.1	1.1	0.0	32.0	20.0
7.4	5984.5	94.2	52.4	5.1	0.0	1.5	-1.0	158.4	0.0	2.9	1.1	0.0	36.0	21.0
7.3	6031.3	94.2	50.5	5.0	0.0	1.5	-1.0	152.5	0.0	2.9	1.1	0.0	36.0	23.0
7.0	6013.2	90.6	50.2	4.9	0.0	1.4	-1.0	151.0	0.0	2.9	1.1	0.0	36.0	24.0
7.0	6020.9	88.8	50.4	5.0	0.0	1.5	-1.0	155.4	0.0	2.9	1.1	0.0	39.0	25.0
7.4	5979.0	88.7	50.0	5.1	0.0	1.5	-1.0	157.7	0.0	2.9	1.1	0.0	43.0	27.0
7.3	5999.9	88.9	50.1	4.9	0.0	1.5	-1.0	151.5	0.0	2.8	1.1	0.0	43.0	28.0
6.9	6013.7	93.9	50.7	4.9	0.0	1.4	-1.0	150.5	0.0	2.9	1.1	0.0	43.0	30.0

APPENDIX A-7: CALCULATED VALUE FOR 3000L/H

Calculated Data			
ORIFICE 1 Steam temperature			467.9500
	Tc		0.2771
ORIFICE 1 Steam pressure	Psat		0.5100
ORIFICE 1 Steam specific volume	vg	cu.m/kg	0.3866
ORIFICE 1 Steam Density		kg/cu.m	2.5868
ORIFICE 1 Steam mass flow rate		kg/hr	65.8543
TURBINE Steam inlet temperature	T	K	462.3500
TURBINE Steam inlet pressure	P	atmos	-0.0104
	k1		0.3783
	k2		-13.6492
	k3		-11.7592
	k4		0.0000
	k5		3.7422
	k6		-51.0775
	k7		-49.1875
	k8		-173.6878
	k9		20302.8471
	k10		-268.8288
	k11		30577.9489
TURBINE Exhaust temperature	T	K	421.9500
TURBINE Exhaust pressure	P	atmos	146.8507
	k1		0.4542
	k2		-17.8126
	k3		-15.9226
	k4		-1.9286
	k5		4.0918
	k6		-72.8847
	k7		-70.9947
	k8		-208.8007
	k9		34419.5419
	k10		-302.4719
	k11		49078.3384
TURBINE Steam line inlet pressure		bar.a	-0.0106
TURBINE Steam nozzle inlet pressure		bar.a	40.8741
TURBINE Steam consumption		kg/min	1.0000
TURBINE Steam line inlet enthalpy	hg	kJ/kg	2858.8660
TURBINE Exhaust enthalpy	hg	kJ/kg	-106815.1678
TURBINE Isentropic exhaust enthalpy	hg	kJ/kg	1.0000
TURBINE Brake power		kW	0.0004
TURBINE Specific steam consumption		kg/kW	146912.2552
TURBINE Steam line energy supplied		kJ/min	2858.8660
TURBINE Exhaust energy supplied		kJ/min	-106815.1678
TURBINE Energy drop through turbine		kJ/min	109674.0338
TURBINE Brake power energy		kJ/min	0.0245
TURBINE Friction/losses energy		kJ/min	109674.0093
TURBINE Cooling water energy		kJ/min	0.0000
TURBINE Condensate Energy		kJ/min	0.0000
TURBINE Isentropic energy drop		kJ/min	2857.8660

TURBINE Rankine energy		kJ/min	2858.8660
TURBINE Mechanical conversion efficiency		%	0.0000
TURBINE Isentropic efficiency		%	3837.6199
TURBINE Rankine efficiency		%	3836.2775
TURBINE Thermal efficiency		%	0.0009
BOILER Steam Temperature			449.4500
	Tc		0.3057
BOILER Steam Pressure		bar.a	7.3000
BOILER Saturated liquid enthalpy	hf	kJ/kg	746.2896
BOILER Vapour enthalpy	hg	kJ/kg	2774.4083
BOILER Latent heat	hfg	kJ/kg	2028.1187
BOILER Enthalpy in wet steam	hs	kJ/kg	2571.5964
BOILER Enthalpy in feedwater	hfwtr	kJ/kg	147.9720
BOILER Energy to produce steam		kJ/hr	159606.1958
BOILER Energy supplied in fuel oil		kJ/hr	231071.0040
BOILER Efficiency using fuel oil		%	69.0724
BOILER Equivalent evaporation from & at 100C		kg/hr	70.7161
SUPERHEATER Inlet temperature		K	467.9500
	Tc		0.2771
SUPERHEATER Inlet pressure	P	atmos	7.2044
	K1		0.3542
	K2		-12.4923
	K3		-10.6023
	K4		-0.0024
	K5		3.6310
	K6		-45.3592
	K7		-43.4692
	K8		-161.3963
	K9		16837.3482
	K10		-257.4312
	K11		25985.2024
SUPERHEATER Outlet temperature		K	477.8500
SUPERHEATER Saturated liquid enthalpy	hf	kJ/kg	746.2896
SUPERHEATER Inlet enthalpy		kJ/kg	2789.3630
SUPERHEATER Inlet latent heat	hfg	kJ/kg	2043.0735
SUPERHEATER Inlet energy in wet steam	hs	kJ/kg	2585.0557
SUPERHEATER Outlet enthalpy	hsup	kJ/kg	2853.5409
SUPERHEATER Energy gained by steam		kJ/hr	17680.9193
SUPERHEATER Energy supplied by Electricity		kJ/hr	1.5000
SUPERHEATER Efficiency using Electricity		%	1178727.9544
COOLING TOWER Sat vap press air in wb	Paiwb	Pa	3303.9408
COOLING TOWER Sat vap press air in db	Paidb	Pa	4833.7196
COOLING TOWER Sat vap press air out wb	Paowb	Pa	1827.1821
COOLING TOWER Sat vap press air out db	Paodb	Pa	4619.7644
COOLING TOWER Air inlet saturation		%RH	92.7000
COOLING TOWER Air inlet specific enthalpy	ha1	kJ/kg	-1559.9382
COOLING TOWER air inlet moisture content		kg/kg	-0.6219
COOLING TOWER Air inlet specific volume		cu.m/kg	-26.5363
COOLING TOWER Air outlet saturation		%RH	48.1000

COOLING TOWER Air outlet specific enthalpy	ha2	kJ/kg	-1559.4676
COOLING TOWER Air outlet moisure content		kg/kg	-0.6218
COOLING TOWER Air outlet specific volume		cu.m/kg	14.0446
COOLING TOWER Air mass flow	ma	kg/min	31597523.4628
COOLING TOWER Water in enthalpy	hf1	kJ/min	43849.8469
COOLING TOWER Water out enthalpy	hf3	kJ/min	170.2463
COOLING TOWER Make-up water enthalpy	hf2	kJ/min	200.5123
COOLING TOWER Make-up water flow rate	mfm	kg/min	1.2930
PLANT Nett work output		kJ/min	0.0245
PLANT Total heat input		kJ/min	3851.2084
PLANT Thermal efficiency		%	0.0006
FEEDWATER Temp	Tc		0.5233
FEEDWATER Specific volume		cu.m/kg	0.0010
TURBINE Steam line energy supplied		kW	47.6478
TURBINE Exhaust energy supplied		kW	-1780.2528
TURBINE Energy drop through turbine		kW	1827.9006
TURBINE Brake power energy		kW	0.0004
TURBINE Friction/losses energy		kW	1827.9002
TURBINE Cooling water energy		kW	0.0000
TURBINE Condensate Energy		kW	0.0000
TURBINE Isentropic energy drop		kW	47.6311
TURBINE Rankine energy		kW	47.6478
COOLING TOWER Water in enthalpy	hf1	kW	730.8308
COOLING TOWER Water out enthalpy	hf3	kW	2.8374
COOLING TOWER Make-up water enthalpy	hf2	kW	3.3419
SUPERHEATER Energy gained by steam		kW	4.9114
SUPERHEATER Energy supplied by fuel oil		kW	0.0004
BOILER Energy to produce steam		kW	44.3351
BOILER Energy supplied in fuel oil		kW	64.1864

APPENDIX A-8: CALCULATED VALUE FOR 4000L/H

Calculated Data			
ORIFICE 1 Steam temperature			466.8500
	Tc		0.2788
ORIFICE 1 Steam pressure	Psat		0.5800
ORIFICE 1 Steam specific volume	vg	cu.m/kg	0.3396
ORIFICE 1 Steam Density		kg/cu.m	2.9444
ORIFICE 1 Steam mass flow rate		kg/hr	71.6639
TURBINE Steam inlet temperature	T	K	457.2500
TURBINE Steam inlet pressure	P	atmos	-0.0109
	k1		0.3868
	k2		-14.0737
	k3		-12.1837
	k4		0.0000
	k5		3.7813
	k6		-53.2163
	k7		-51.3263
	k8		-177.8641
	k9		21627.8217
	k10		-272.7480
	k11		32327.1393
TURBINE Exhaust temperature	T	K	411.3500
TURBINE Exhaust pressure	P	atmos	136.3896
	k1		0.4779
	k2		-19.2969
	k3		-17.4069
	k4		-1.9136
	k5		4.2009
	k6		-81.0652
	k7		-79.1752
	k8		-218.8689
	k9		40009.3167
	k10		-312.3935
	k11		56342.3677
TURBINE Steam line inlet pressure		bar.a	-0.0111
TURBINE Steam nozzle inlet pressure		bar.a	40.6731
TURBINE Steam consumption		kg/min	1.0000
TURBINE Steam line inlet enthalpy	hg	kJ/kg	2849.0225
TURBINE Exhaust enthalpy	hg	kJ/kg	-133530.6479
TURBINE Isentropic exhaust enthalpy	hg	kJ/kg	1.0000
TURBINE Brake power		kW	0.0005
TURBINE Specific steam consumption		kg/kW	116218.6197
TURBINE Steam line energy supplied		kJ/min	2849.0225
TURBINE Exhaust energy supplied		kJ/min	-133530.6479
TURBINE Energy drop through turbine		kJ/min	136379.6704
TURBINE Brake power energy		kJ/min	0.0310
TURBINE Friction/losses energy		kJ/min	136379.6395
TURBINE Cooling water energy		kJ/min	0.0000
TURBINE Condensate Energy		kJ/min	0.0000
TURBINE Isentropic energy drop		kJ/min	2848.0225

TURBINE Rankine energy		kJ/min	2849.0225
TURBINE Mechanical conversion efficiency		%	0.0000
TURBINE Isentropic efficiency		%	4788.5742
TURBINE Rankine efficiency		%	4786.8934
TURBINE Thermal efficiency		%	0.0011
BOILER Steam Temperature			447.8500
	Tc		0.3081
BOILER Steam Pressure		bar.a	7.2000
BOILER Saturated liquid enthalpy	hf	kJ/kg	739.2271
BOILER Vapour enthalpy	hg	kJ/kg	2772.9068
BOILER Latent heat	hfg	kJ/kg	2033.6798
BOILER Enthalpy in wet steam	hs	kJ/kg	2569.5389
BOILER Enthalpy in feedwater	hfwtr	kJ/kg	136.2680
BOILER Energy to produce steam		kJ/hr	174377.6737
BOILER Energy supplied in fuel oil		kJ/hr	240132.6120
BOILER Efficiency using fuel oil		%	72.6172
BOILER Equivalent evaporation from & at 100C		kg/hr	77.2608
SUPERHEATER Inlet temperature		K	466.8500
	Tc		0.2788
SUPERHEATER Inlet pressure	P	atmos	7.1057
	K1		0.3573
	K2		-12.6383
	K3		-10.7483
	K4		-0.0024
	K5		3.6454
	K6		-46.0717
	K7		-44.1817
	K8		-163.0276
	K9		17262.6799
	K10		-258.9319
	K11		26550.4179
SUPERHEATER Outlet temperature		K	475.7500
SUPERHEATER Saturated liquid enthalpy	hf	kJ/kg	739.2271
SUPERHEATER Inlet enthalpy		kJ/kg	2788.6047
SUPERHEATER Inlet latent heat	hfg	kJ/kg	2049.3777
SUPERHEATER Inlet energy in wet steam	hs	kJ/kg	2583.6670
SUPERHEATER Outlet enthalpy	hsup	kJ/kg	2849.3293
SUPERHEATER Energy gained by steam		kJ/hr	19038.3998
SUPERHEATER Energy supplied by Electricity		kJ/hr	2.1000
SUPERHEATER Efficiency using Electricity		%	906590.4689
COOLING TOWER Sat vap press air in wb	Paiwb	Pa	3477.8505
COOLING TOWER Sat vap press air in db	Paidb	Pa	5317.1117
COOLING TOWER Sat vap press air out wb	Paowb	Pa	1734.6786
COOLING TOWER Sat vap press air out db	Paodb	Pa	4192.2441
COOLING TOWER Air inlet saturation		%RH	90.7000
COOLING TOWER Air inlet specific enthalpy	ha1	kJ/kg	-1560.1822
COOLING TOWER air inlet moisture content		kg/kg	-0.6219
COOLING TOWER Air inlet specific volume		cu.m/kg	-25.3496
COOLING TOWER Air outlet saturation		%RH	48.3000

COOLING TOWER Air outlet specific enthalpy	ha2	kJ/kg	-1559.2090
COOLING TOWER Air outlet moisure content		kg/kg	-0.6218
COOLING TOWER Air outlet specific volume		cu.m/kg	14.0635
COOLING TOWER Air mass flow	ma	kg/min	24843161.2737
COOLING TOWER Water in enthalpy	hf1	kJ/min	58026.1748
COOLING TOWER Water out enthalpy	hf3	kJ/min	146.6026
COOLING TOWER Make-up water enthalpy	hf2	kJ/min	175.6280
COOLING TOWER Make-up water flow rate	mfm	kg/min	1.1769
PLANT Nett work output		kJ/min	0.0310
PLANT Total heat input		kJ/min	4002.2452
PLANT Thermal efficiency		%	0.0008
FEEDWATER Temp	Tc		0.5277
FEEDWATER Specific volume		cu.m/kg	0.0010
TURBINE Steam line energy supplied		kW	47.4837
TURBINE Exhaust energy supplied		kW	-2225.5108
TURBINE Energy drop through turbine		kW	2272.9945
TURBINE Brake power energy		kW	0.0005
TURBINE Friction/losses energy		kW	2272.9940
TURBINE Cooling water energy		kW	0.0000
TURBINE Condensate Energy		kW	0.0000
TURBINE Isentropic energy drop		kW	47.4670
TURBINE Rankine energy		kW	47.4837
COOLING TOWER Water in enthalpy	hf1	kW	967.1029
COOLING TOWER Water out enthalpy	hf3	kW	2.4434
COOLING TOWER Make-up water enthalpy	hf2	kW	2.9271
SUPERHEATER Energy gained by steam		kW	5.2884
SUPERHEATER Energy supplied by fuel oil		kW	0.0006
BOILER Energy to produce steam		kW	48.4382
BOILER Energy supplied in fuel oil		kW	66.7035

APPENDIX A-9: CALCULATED VALUE FOR 5000L/H

Calculated Data			
ORIFICE 1 Steam temperature			464.0500
	Tc		0.2831
ORIFICE 1 Steam pressure	Psat		0.5600
ORIFICE 1 Steam specific volume	vg	cu.m/kg	0.3509
ORIFICE 1 Steam Density		kg/cu.m	2.8496
ORIFICE 1 Steam mass flow rate		kg/hr	68.6510
TURBINE Steam inlet temperature	T	K	450.8500
TURBINE Steam inlet pressure	P	atmos	-0.0106
	k1		0.3979
	k2		-14.6416
	k3		-12.7516
	k4		0.0000
	k5		3.8322
	k6		-56.1095
	k7		-54.2195
	k8		-183.2030
	k9		23443.0842
	k10		-277.7916
	k11		34718.3729
TURBINE Exhaust temperature	T	K	393.4500
TURBINE Exhaust pressure	P	atmos	118.7241
	k1		0.5224
	k2		-22.3504
	k3		-20.4604
	k4		-1.8630
	k5		4.4058
	k6		-98.4706
	k7		-96.5806
	k8		-236.8192
	k9		52320.5461
	k10		-330.3614
	k11		72261.3674
TURBINE Steam line inlet pressure		bar.a	-0.0107
TURBINE Steam nozzle inlet pressure		bar.a	39.3704
TURBINE Steam consumption		kg/min	1.0000
TURBINE Steam line inlet enthalpy	hg	kJ/kg	2836.6844
TURBINE Exhaust enthalpy	hg	kJ/kg	-194126.8171
TURBINE Isentropic exhaust enthalpy	hg	kJ/kg	1.0000
TURBINE Brake power		kW	0.0005
TURBINE Specific steam consumption		kg/kW	118009.2694
TURBINE Steam line energy supplied		kJ/min	2836.6844
TURBINE Exhaust energy supplied		kJ/min	-194126.8171
TURBINE Energy drop through turbine		kJ/min	196963.5015
TURBINE Brake power energy		kJ/min	0.0305
TURBINE Friction/losses energy		kJ/min	196963.4710
TURBINE Cooling water energy		kJ/min	0.0000
TURBINE Condensate Energy		kJ/min	0.0000
TURBINE Isentropic energy drop		kJ/min	2835.6844

TURBINE Rankine energy		kJ/min	2836.6844
TURBINE Mechanical conversion efficiency		%	0.0000
TURBINE Isentropic efficiency		%	6945.8894
TURBINE Rankine efficiency		%	6943.4408
TURBINE Thermal efficiency		%	0.0011
BOILER Steam Temperature			446.5500
	Tc		0.3101
BOILER Steam Pressure		bar.a	7.0000
BOILER Saturated liquid enthalpy	hf	kJ/kg	733.4965
BOILER Vapour enthalpy	hg	kJ/kg	2771.6641
BOILER Latent heat	hfg	kJ/kg	2038.1675
BOILER Enthalpy in wet steam	hs	kJ/kg	2567.8473
BOILER Enthalpy in feedwater	hfwtr	kJ/kg	129.5800
BOILER Energy to produce steam		kJ/hr	167389.5968
BOILER Energy supplied in fuel oil		kJ/hr	222009.3960
BOILER Efficiency using fuel oil		%	75.3975
BOILER Equivalent evaporation from & at 100C		kg/hr	74.1646
SUPERHEATER Inlet temperature		K	464.0500
	Tc		0.2831
SUPERHEATER Inlet pressure	P	atmos	6.9083
	K1		0.3590
	K2		-12.7160
	K3		-10.8260
	K4		-0.0023
	K5		3.6531
	K6		-46.4522
	K7		-44.5622
	K8		-163.8863
	K9		17490.6002
	K10		-259.7233
	K11		26853.1076
SUPERHEATER Outlet temperature		K	474.6500
SUPERHEATER Saturated liquid enthalpy	hf	kJ/kg	733.4965
SUPERHEATER Inlet enthalpy		kJ/kg	2786.5967
SUPERHEATER Inlet latent heat	hfg	kJ/kg	2053.1001
SUPERHEATER Inlet energy in wet steam	hs	kJ/kg	2581.2867
SUPERHEATER Outlet enthalpy	hsup	kJ/kg	2847.9335
SUPERHEATER Energy gained by steam		kJ/hr	18305.5857
SUPERHEATER Energy supplied by Electricity		kJ/hr	2.5200
SUPERHEATER Efficiency using Electricity		%	726412.1304
COOLING TOWER Sat vap press air in wb	Paiwb	Pa	3563.0731
COOLING TOWER Sat vap press air in db	Paidb	Pa	5651.7592
COOLING TOWER Sat vap press air out wb	Paowb	Pa	1647.9722
COOLING TOWER Sat vap press air out db	Paodb	Pa	4314.2592
COOLING TOWER Air inlet saturation		%RH	88.7000
COOLING TOWER Air inlet specific enthalpy	ha1	kJ/kg	-1560.3423
COOLING TOWER air inlet moisture content		kg/kg	-0.6219
COOLING TOWER Air inlet specific volume		cu.m/kg	-24.8320
COOLING TOWER Air outlet saturation		%RH	44.5000

COOLING TOWER Air outlet specific enthalpy	ha2	kJ/kg	-1559.2713
COOLING TOWER Air outlet moisure content		kg/kg	-0.6218
COOLING TOWER Air outlet specific volume		cu.m/kg	14.5415
COOLING TOWER Air mass flow	ma	kg/min	37483246.0093
COOLING TOWER Water in enthalpy	hf1	kJ/min	76007.2599
COOLING TOWER Water out enthalpy	hf3	kJ/min	137.2208
COOLING TOWER Make-up water enthalpy	hf2	kJ/min	160.3174
COOLING TOWER Make-up water flow rate	mfm	kg/min	1.0834
PLANT Nett work output		kJ/min	0.0305
PLANT Total heat input		kJ/min	3700.1986
PLANT Thermal efficiency		%	0.0008
FEEDWATER Temp	Tc		0.5301
FEEDWATER Specific volume		cu.m/kg	0.0010
TURBINE Steam line energy supplied		kW	47.2781
TURBINE Exhaust energy supplied		kW	-3235.4470
TURBINE Energy drop through turbine		kW	3282.7250
TURBINE Brake power energy		kW	0.0005
TURBINE Friction/losses energy		kW	3282.7245
TURBINE Cooling water energy		kW	0.0000
TURBINE Condensate Energy		kW	0.0000
TURBINE Isentropic energy drop		kW	47.2614
TURBINE Rankine energy		kW	47.2781
COOLING TOWER Water in enthalpy	hf1	kW	1266.7877
COOLING TOWER Water out enthalpy	hf3	kW	2.2870
COOLING TOWER Make-up water enthalpy	hf2	kW	2.6720
SUPERHEATER Energy gained by steam		kW	5.0849
SUPERHEATER Energy supplied by fuel oil		kW	0.0007
BOILER Energy to produce steam		kW	46.4971
BOILER Energy supplied in fuel oil		kW	61.6693

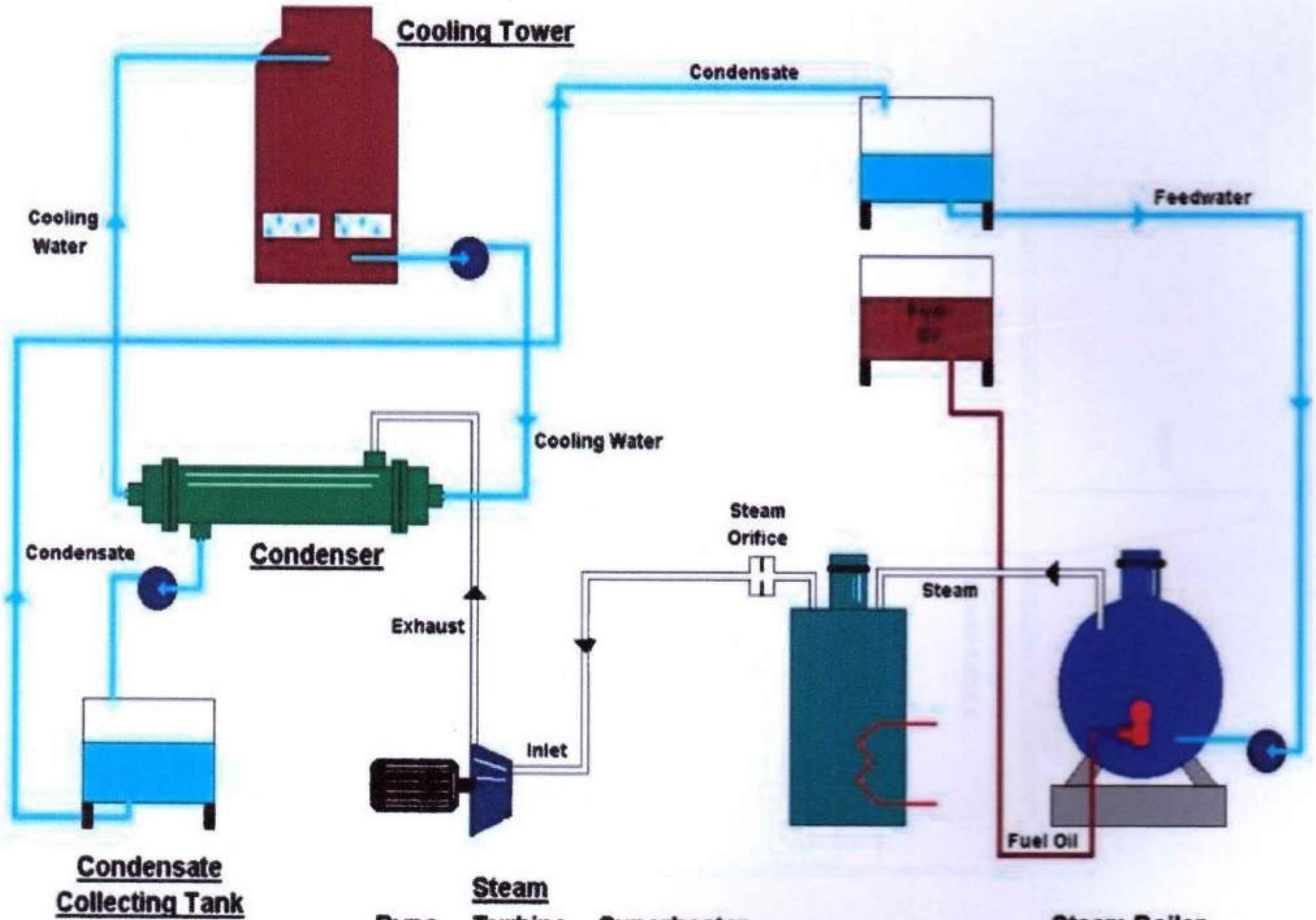
APPENDIX A-10: CALCULATED VALUE FOR 6000L/H

Calculated Data			
ORIFICE 1 Steam temperature			466.1500
	Tc		0.2799
ORIFICE 1 Steam pressure	Psat		0.4900
ORIFICE 1 Steam specific volume	vg	cu.m/kg	0.4018
ORIFICE 1 Steam Density		kg/cu.m	2.4890
ORIFICE 1 Steam mass flow rate		kg/hr	63.5953
TURBINE Steam inlet temperature	T	K	458.2500
TURBINE Steam inlet pressure	P	atmos	-0.0104
	k1		0.3851
	k2		-13.9886
	k3		-12.0986
	k4		0.0000
	k5		3.7735
	k6		-52.7858
	k7		-50.8958
	k8		-177.0399
	k9		21359.9171
	k10		-271.9726
	k11		31973.7310
TURBINE Exhaust temperature	T	K	418.1500
TURBINE Exhaust pressure	P	atmos	143.1005
	k1		0.4625
	k2		-18.3210
	k3		-16.4310
	k4		-1.9243
	k5		4.1299
	k6		-75.6647
	k7		-73.7747
	k8		-212.3649
	k9		36303.4641
	k10		-305.9709
	k11		51529.5632
TURBINE Steam line inlet pressure		bar.a	-0.0106
TURBINE Steam nozzle inlet pressure		bar.a	40.5690
TURBINE Steam consumption		kg/min	1.0000
TURBINE Steam line inlet enthalpy	hg	kJ/kg	2850.9493
TURBINE Exhaust enthalpy	hg	kJ/kg	-115717.4525
TURBINE Isentropic exhaust enthalpy	hg	kJ/kg	1.0000
TURBINE Brake power		kW	0.0004
TURBINE Specific steam consumption		kg/kW	141122.6096
TURBINE Steam line energy supplied		kJ/min	2850.9493
TURBINE Exhaust energy supplied		kJ/min	-115717.4525
TURBINE Energy drop through turbine		kJ/min	118568.4018
TURBINE Brake power energy		kJ/min	0.0255
TURBINE Friction/losses energy		kJ/min	118568.3763
TURBINE Cooling water energy		kJ/min	0.0000
TURBINE Condensate Energy		kJ/min	0.0000
TURBINE Isentropic energy drop		kJ/min	2849.9493

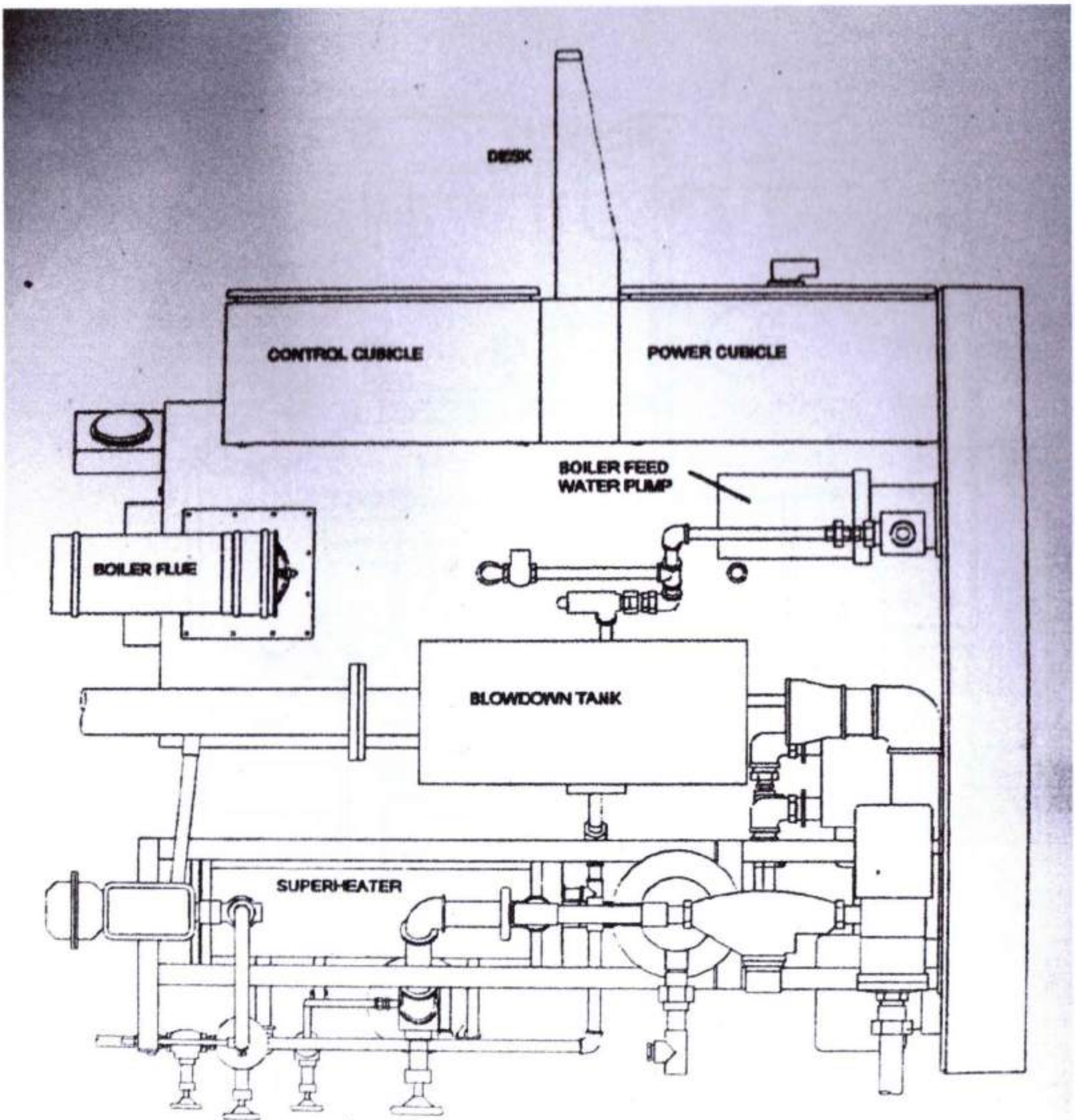
TURBINE Rankine energy		kJ/min	2850.9493
TURBINE Mechanical conversion efficiency		%	0.0000
TURBINE Isentropic efficiency		%	4160.3688
TURBINE Rankine efficiency		%	4158.9095
TURBINE Thermal efficiency		%	0.0009
BOILER Steam Temperature			448.4500
	Tc		0.3072
BOILER Steam Pressure		bar.a	7.1000
BOILER Saturated liquid enthalpy	hf	kJ/kg	741.8743
BOILER Vapour enthalpy	hg	kJ/kg	2773.4735
BOILER Latent heat	hfg	kJ/kg	2031.5993
BOILER Enthalpy in wet steam	hs	kJ/kg	2570.3136
BOILER Enthalpy in feedwater	hfwtr	kJ/kg	150.4800
BOILER Energy to produce steam		kJ/hr	153889.9324
BOILER Energy supplied in fuel oil		kJ/hr	194824.5720
BOILER Efficiency using fuel oil		%	78.9890
BOILER Equivalent evaporation from & at 100C		kg/hr	68.1834
SUPERHEATER Inlet temperature		K	466.1500
	Tc		0.2799
SUPERHEATER Inlet pressure	P	atmos	7.0070
	K1		0.3537
	K2		-12.4716
	K3		-10.5816
	K4		-0.0023
	K5		3.6289
	K6		-45.2588
	K7		-43.3688
	K8		-161.1641
	K9		16777.6140
	K10		-257.2179
	K11		25905.7851
SUPERHEATER Outlet temperature		K	478.1500
SUPERHEATER Saturated liquid enthalpy	hf	kJ/kg	741.8743
SUPERHEATER Inlet enthalpy		kJ/kg	2788.1131
SUPERHEATER Inlet latent heat	hfg	kJ/kg	2046.2389
SUPERHEATER Inlet energy in wet steam	hs	kJ/kg	2583.4893
SUPERHEATER Outlet enthalpy	hsup	kJ/kg	2855.2799
SUPERHEATER Energy gained by steam		kJ/hr	17284.5968
SUPERHEATER Energy supplied by Electricity		kJ/hr	1.8000
SUPERHEATER Efficiency using Electricity		%	960255.3754
COOLING TOWER Sat vap press air in wb	Paiwb	Pa	3180.1441
COOLING TOWER Sat vap press air in db	Paidb	Pa	4593.6073
COOLING TOWER Sat vap press air out wb	Paowb	Pa	1751.4416
COOLING TOWER Sat vap press air out db	Paodb	Pa	4049.7956
COOLING TOWER Air inlet saturation		%RH	92.7000
COOLING TOWER Air inlet specific enthalpy	ha1	kJ/kg	-1559.8059
COOLING TOWER air inlet moisture content		kg/kg	-0.6219
COOLING TOWER Air inlet specific volume		cu.m/kg	-27.4880
COOLING TOWER Air outlet saturation		%RH	50.1000

COOLING TOWER Air outlet specific enthalpy	ha2	kJ/kg	-1559.1324
COOLING TOWER Air outlet moisure content		kg/kg	-0.6218
COOLING TOWER Air outlet specific volume		cu.m/kg	15.2292
COOLING TOWER Air mass flow	ma	kg/min	72940626.1294
COOLING TOWER Water in enthalpy	hf1	kJ/min	79045.2045
COOLING TOWER Water out enthalpy	hf3	kJ/min	145.4296
COOLING TOWER Make-up water enthalpy	hf2	kJ/min	186.2895
COOLING TOWER Make-up water flow rate	mfm	kg/min	1.1915
PLANT Nett work output		kJ/min	0.0255
PLANT Total heat input		kJ/min	3247.1062
PLANT Thermal efficiency		%	0.0008
FEEDWATER Temp	Tc		0.5224
FEEDWATER Specific volume		cu.m/kg	0.0010
TURBINE Steam line energy supplied		kW	47.5158
TURBINE Exhaust energy supplied		kW	-1928.6242
TURBINE Energy drop through turbine		kW	1976.1400
TURBINE Brake power energy		kW	0.0004
TURBINE Friction/losses energy		kW	1976.1396
TURBINE Cooling water energy		kW	0.0000
TURBINE Condensate Energy		kW	0.0000
TURBINE Isentropic energy drop		kW	47.4992
TURBINE Rankine energy		kW	47.5158
COOLING TOWER Water in enthalpy	hf1	kW	1317.4201
COOLING TOWER Water out enthalpy	hf3	kW	2.4238
COOLING TOWER Make-up water enthalpy	hf2	kW	3.1045
SUPERHEATER Energy gained by steam		kW	4.8013
SUPERHEATER Energy supplied by fuel oil		kW	0.0005
BOILER Energy to produce steam		kW	42.7472
BOILER Energy supplied in fuel oil		kW	54.1179

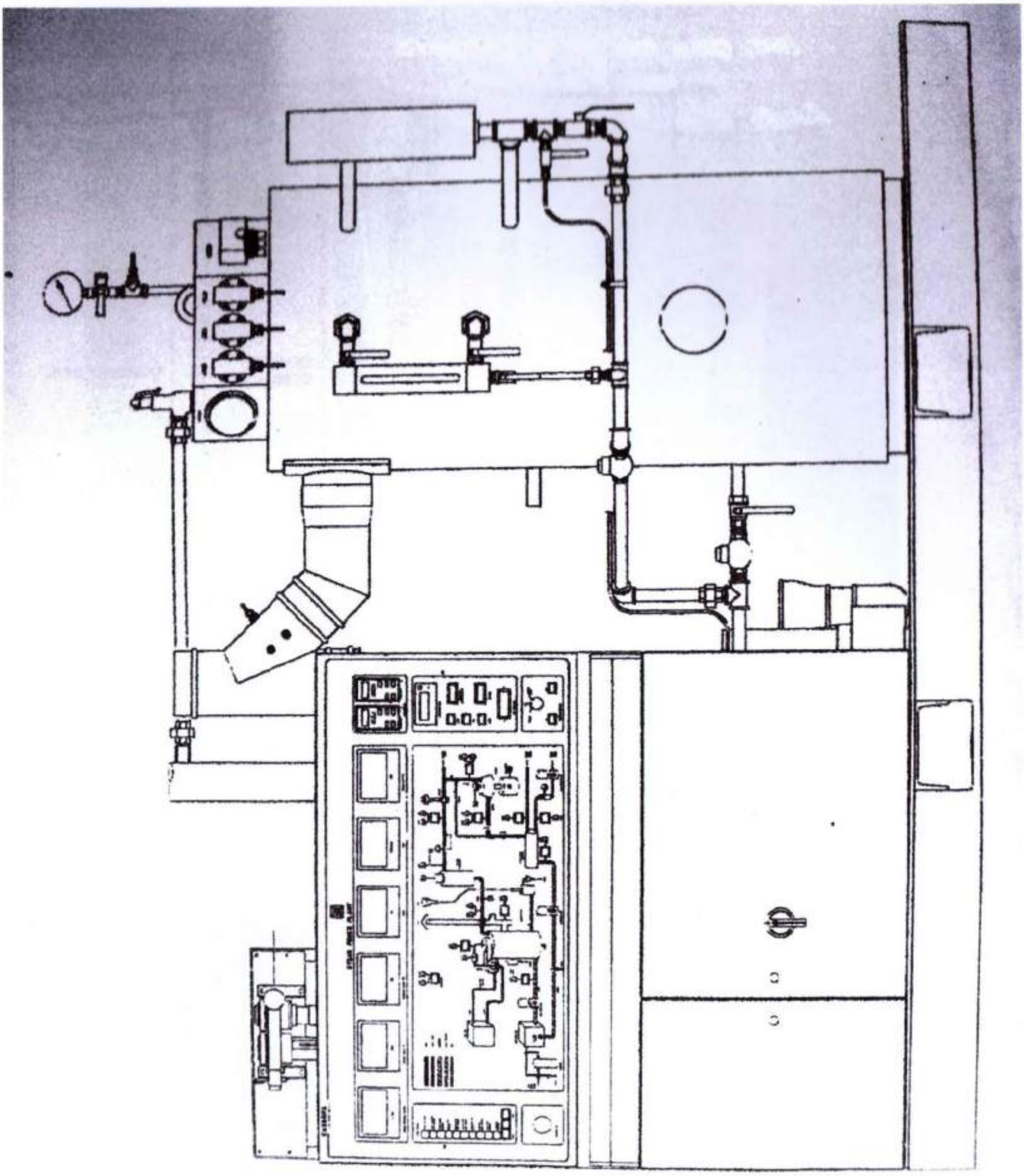
APPENDIX B-1: PLANT COMPONENT AND CYCLE



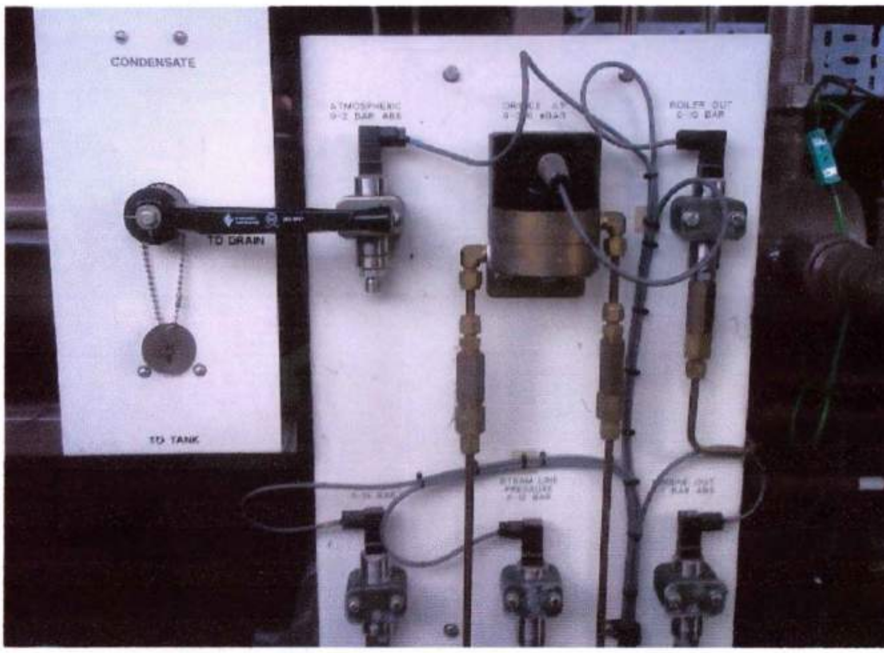
APPENDIX B-2: BOILER TOP VIEW



APPENDIX B-3: BOILER FRONT VIEW



APPENDIX B-4: VALVES AND STEAM TURBINE



APPENDIX B-5: BOILER AND CONTROL PANEL