CERTIFICATION OF APPROVAL

A Study on the Effect of Steam Leakage to the Heat Rate of Steam Power Plant

by

Choi Yee Xiong

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

(SHAHARIN ANWAR SULAIMAN)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

CHOI YEE XIONG

ABSTRACT

Leakages in steam lines or components in a steam power plant might not cost a big amount of money during the days when fuel price was low but nowadays, the extra cost due to steam leakage is very significant. Moreover, steam leakage is mostly found on old steam power plant, the additional cost due to steam leakage will cause big loses and the particular steam power plant might have to be shut down. This final year project focuses on the awareness on implications of steam leakage in a steam power plant. The main objective of this project is to identify the impact of steam leakage to the heat rate of the steam power plant. A 5-KW steam power plant in UTP was used to study the effects of steam leakage. Major components of the steam power plant cycle such as the boiler, condenser and turbine were looked into in this project. Steam leakage experiments were conducted using the 5-KW steam power plant. The results showed that steam leaking in the steam power plant would increase the fuel consumption, by as high as 35%.

ACKNOWLEDGEMENT

Firstly, I would like to thank my Final Year Project (FYP) supervisor, Dr. Shaharin Anwar Sulaiman for all the guidance and assistance he had provided me in completing my project. Dr. Shaharin's professionalism in the energy's industry and his ever willingness to lent his helping hand were a great inspiration to me. He had always be there to guide me in whatever difficulties that I had experienced throughout this one year of project period. I truly appreciate his exceptional dedication.

I would also like to thank those who had contributed in making this FYP a success. I would like to thank my co-supervisor Ms. Chin Yee Sing for giving valuable advices and providing useful pointers and constructive comments on this FYP topic.

Special thanks to UTP steam power plant's technician Mr. Fahmi for helping me in arranging the lab session for doing the steam leakage experiment and providing all the tools and equipments needed.

I would also like to express my utmost gratitude to Mr. Hon from Tractors Malaysia Sdn Bhd for sharing his experience and provide guidance on the way to solve problems on this FYP. Special thanks to his colleagues that had been helping me by emailing useful comment and research materials.

Last but not least, I would like to thank my family's unconditional support. This FYP is completed successfully, thanks to everyone that was mentioned above. Thank you once again.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Leakages in steam lines or components in a steam power plant might not cost a big amount of money during the days when fuel price was low but nowadays, the extra cost due to steam leakage is very significant. Moreover, steam leakage is mostly found on old steam power plant, the additional cost due to steam leakage will cause big loses and the particular steam power plant might have to be shut down. This final year project focuses on the awareness on implications of steam leakage in a steam power plant. The main objective of this project is to identify the impact of steam leakage to the heat rate of the steam power plant. A 5-KW steam power plant in UTP was used to study the effects of steam leakage. Major components of the steam power plant cycle such as the boiler, condenser and turbine were looked into in this project. Steam leakage experiments were conducted using the 5-KW steam power plant. The results showed that steam leaking in the steam power plant would increase the fuel consumption, by as high as 35%.

CHAPTER 1

INTRODUCTION

1.1 Project Background

Fuel is a critical resource in today's industrial world, it is essential as the primary source of power for the production of electricity. Nowadays, the price of hydrocarbon has increased to an enormous level due to the decline in the availability of fossil fuel reserve. The price of crude oil increases from USD 18 /barrel in 1998 to USD 117 /barrel in 2008. This data shows that fuel price has increase by over 6 times for the recent 10 years and the price still increases at an average rate of 30% every year (NYMEX, 2008).

High fuel price means that the cost of producing electricity is getting higher and the profitability of the steam power plant is decreasing. It will be very critical to look into the efficiency of the steam power plant nowadays due to the high fuel price nowadays. Most of the steam power plants are designed for 30 to 40 year life and ageing plants are susceptible to efficiency losses. Thus, the operation cost for a steam power plant will also increase abruptly in coming years and therefore cost control is extremely important for companies to remain in the market.

The steam-electric power plants, which produce about 86% of all electric generation (Worrell, 2005). With the availability of electricity providing most of the industrialized world a very high degree of comfort, the source of this electricity and the means for its production are often neglected. In United States, approximately 90% of the electricity is produced from power plants that use steam as an energy source, with the remaining 10% of the electricity produced from hydroelectric power plants (Everett, 2005).The steam power plants of today are a combination of complex engineered systems that work to produce steam in the most efficient manner that is economically feasible. The goal is to produce electricity at the lowest cost possible. The heat required to produce electricity nowadays is a significant operating cost that affects the ultimate cost of the end product.

One percent of heat rate improvement for a 500MW plant will save approximately USD 500,000 annually in a condition of Capacitor Factor = 85% and Boiler Efficiency = 88% (GIK, 2007). A well maintained, ideal plant can only produce a maximum efficiency of 48% (Everett, 2005), but most of the plants do not manage to maintain such an optimum performance. Beside the limitation of the efficiency, a lot of study and work can be done on maintaining the plant to produce optimum efficiency such as limiting the rate of steam leakage.

An improvement on the heat rate of steam power plant needs a huge cost because modification of system is needed. However it will be feasible to implement it nowadays due to the increasing fuel price. About 80% of power plants are facing the steam leakage problem. These losses are mostly controllable cost, with 20% eliminatable by checking and closing valves on a regular basis and another 80% by routine maintenance (Goldberg, 2005).

Not only must the modern steam power plant generate electricity in an efficient manner to produce power with the lowest operational cost; it must also perform an environmentally acceptable manner. Environmental protection is a major consideration in all modern steam generating systems, where low-cost steam and electricity must be produced with a minimum impact on the environment. Air pollution control that limits the emissions of sulfur dioxide (SO_2) and other acid gases, particulates, and nitrogen oxides (NO_X) are important issues for all combustion processes (GIK, 2007).

Each power plant has many interacting systems, and in a steam power plant these include fuel and ash handling, handling of combustion air and the products of combustion, feed water and condensate, steam, environmental control systems, and the control systems that are necessary for a safe, reliable, and efficiently run power plant.

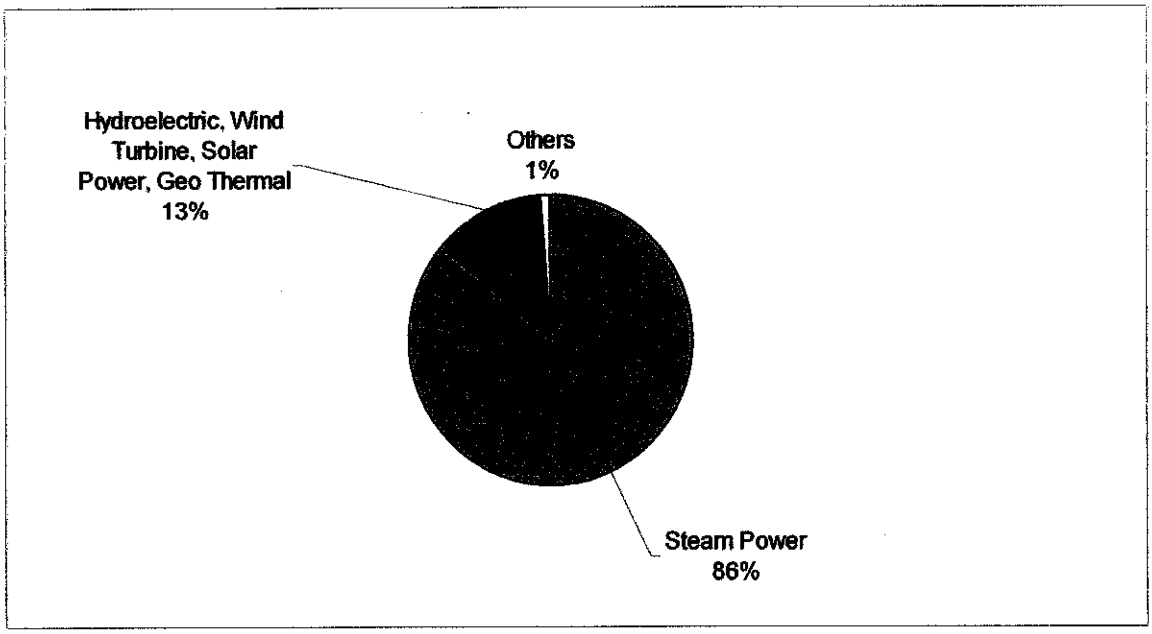


Figure 1.1: Percentage of source of electricity produced use in world. Reproduced from (Worrell, 2005).

1.2 Problem Statement

1.2.1 Power plants are in the risk of financial risk

Fuel price plays the most important role in the cost of operating a steam power plant. 70% of the operational cost in steam power plant is contributed by the fuel cost, others cost such as maintenance, labour and administration only consist 30% of the total operational cost. The cost to produce a single unit of KW electricity is mostly affected by the fuel price. Therefore, most of the aging power plants that having problem with low efficiency will not be able to face the impact of increasing fuel price. Moreover, these plants will not be as competitive as other's new power plant and in the end will be eliminated.

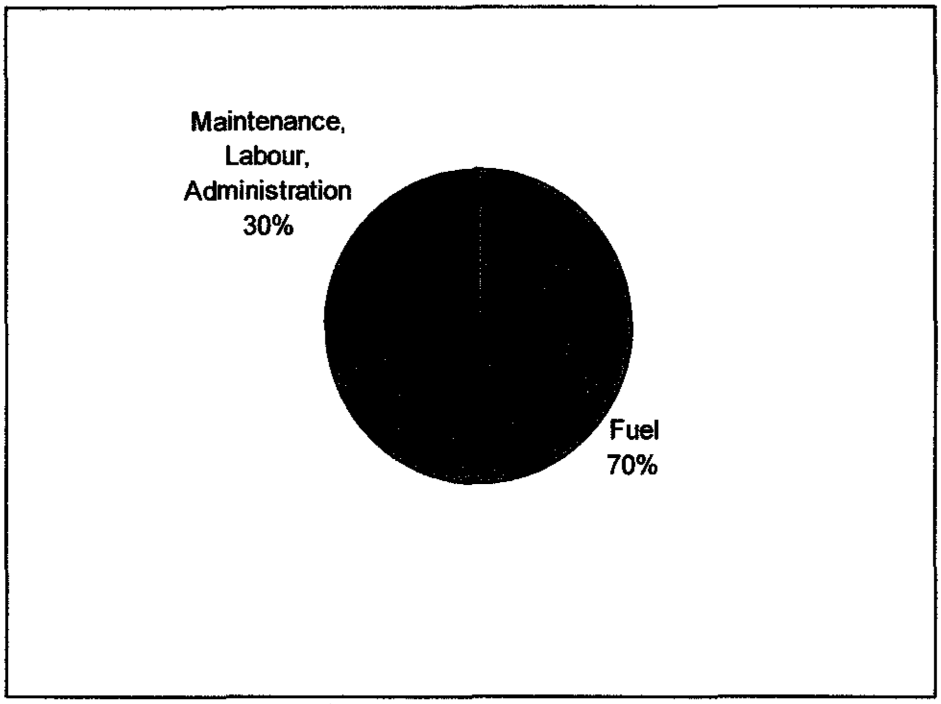


Figure 1.2: Percentage of source of electricity produced use in world.
Reproduced from (Worrell, 2005).

1.2.2 Poor performance due to steam leakage

Recoverable lost

Steam leakage becomes a common problem in steam power plant due to several factors such as high temperature and high differential pressure in the steam pipeline. This occur when cycling of valves are being open and closed. These are consider recoverable lost and can be eliminated by can be eliminated by checking and closing valves on a regular basis and by routine maintenance.

Irrecoverable lost

This is a limitation of the plant by the law of thermodynamics and the design of the major components in the system. The efficiency of steam power plant nowadays has reach a bottleneck of 48% (S.Mott, 2005). Besides the limitation of thermodynamics, a certain amount of steam will be leaked during the dry run session at all the start up drains to make sure that the steam power plant can be operating well.

1.3 Objective

1.3.1 Study the effect due to steam leakage

Steam leakage might cause higher fuel consumption, weaker power output and damage the steam pipeline. Focus will be on the effect on the heat rate of the steam power plant due to the steam leakage.

1.4 Scope of Study

Effect of steam leakage in steam power plant will be justified by having experimental on steam leakage using the 5-KW steam power plant in UTP. Among the parameters of interest are analysis on the fuel consumption and the amount of steam being leaked. Comparison will be made between steam power plant running with steam leakage and without steam leakage. This analysis will determined the effect of steam leakage to the heat rate of the power plant. The results gained from the experimental analysis and the research could be applied for future evaluation on a large scale industry steam power plant.

1.4.1 Heat Rate

Heat rate is the common measure of system efficiency and the general definition is energy input divided by power output. The fuel using in the experimental steam power plant is diesel, which has a calorific value content of 42.12 MJ/Liter. The maximum power output in this particular steam power plant is 5-KW. Having known the power output and the amount of fuel consumed, the heat rate can be calculated by inserting parameters required into the heat rate equations which will be shown in the project. Heat rate is very important as every single percent of heat rate improvement save enormous amount of cost. During the steam leakage experiment, the amount of fuel consumption was observed and analyzed to obtain the relation of steam leakage to the heat rate performance.

1.4.2 Economic Evaluation

To eliminate steam leakage, higher maintenance cost is required. During the time where fuel price is still cheap, steam leakage is neglected as a big problem because it the cost of fixing the leakage might be higher than the cost cause by steam leakage. Therefore an economic analysis will be studied to judge the feasibility of solving steam leakage problem.

CHAPTER 2

LITERATURE REVIEW

2.1 Steam-electric power plant

In a steam-electric power plant, the prime mover is steam driven. Water is heated and turned into steam that spins a steam turbine. After it passes through the turbine, the steam is condensed in a condenser. Steam-electric plants are very similar to one another, only the heat source is different (Babcock & Wilcox Co, 2005). After passing through the turbine, the steam is condensed in a condenser for recirculation.

2.2 Fuels

Steam power plant must first obtain heat, which must come from an energy source that varies significantly, often based on the plant's location in the world. This source of heat could be of fossil fuel (coal, oil, or natural gas), nuclear fuel (e.g. uranium) and other forms of energy such as sewage sludge, geothermal energy and depending on whether the fuel is of solid or a gas (Everett, 2005).

2.3 The Steam-Plant Cycle

The simplest steam cycleof 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 (Everett, 2005).

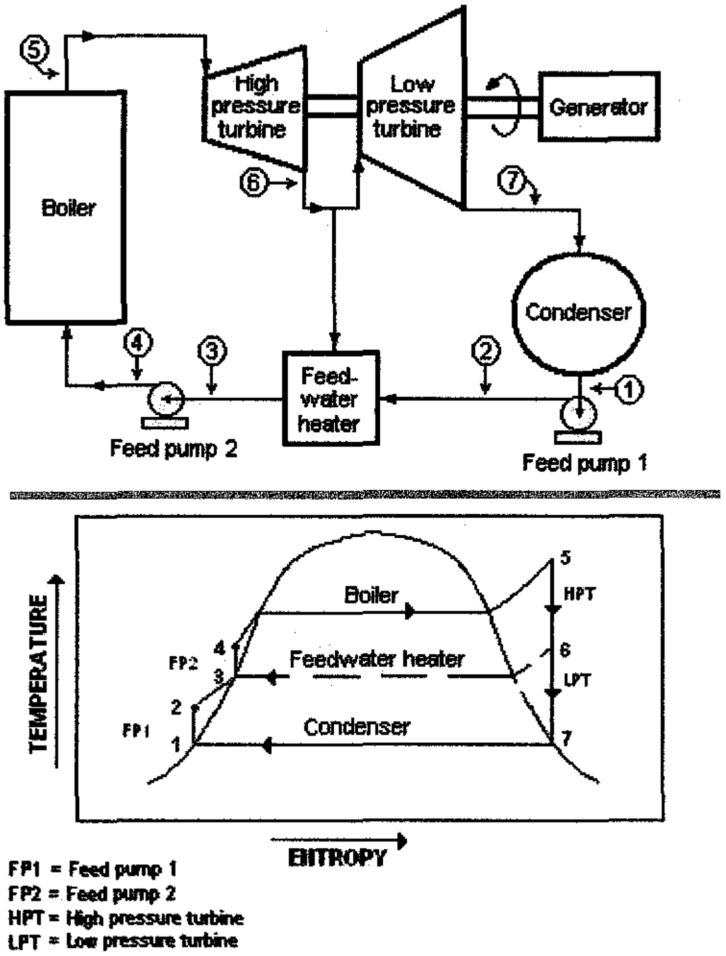


Figure 2.1: A Rankine cycle with a two-stage steam turbine and a single feedwater heater.

Shown in Figure 2.1 is a thermodynamic cycle. Like other thermodynamic cycles, the maximum efficiency of the Rankine cycle is given by calculating the maximum efficiency of the Carnot cycle. Rankine cycles describe the operation of steam heat engines commonly found in power generation plants. In such vapour power plants, power is generated by alternately vaporizing and condensing a working fluid (in many cases water, although refrigerants such as ammonia may also be used). The working fluid in a Rankine cycle follows a closed loop and is re-used constantly. Water vapour seen billowing from power plants is evaporating cooling water, not working fluid. (Note that steam is invisible until it comes in contact with cool, saturated air, at which point it condenses and forms the white billowy clouds, seen leaving cooling towers).

2.4 Leakage Detection System

Efficient and reliable operation is the main requirement of the modern power plant. The most probable reason for failure in the power plant boiler is steam leakage (Afgan, 1998). It is usually detected when urgent action is needed to prevent accidents in the plant. Advance detection of steam leakage is of primary interest to secure maintenance planning and prevent the adverse effect of steam line rupture. The development of the tube failure detection system is a demanding issue for the large power plant boilers. One of the systems is based on selected diagnostic variables obtained by radiation heat flux measurements (Afgan, 1998).

2.5 Calorific Value of the Fuel

The calorific value of a solid of liquid fuel may be obtained approximately from a chemical analysis of a sample. The sample fuel analysis will give the values of the constituents in a dry sample. The constituents considered are usually carbon, hydrogen, sulphur, nitrogen, oxygen and residual ash. Of these elements only carbon, hydrogen and sulphur contribute significantly to the calorific value. Diesel, the main fuel used in UTP 5-KW steam power plant, has a calorific value of 42.12 MJ/Liter (Raheman and Phadatare, 2004).

CHAPTER 3

METHODOLOGY

This project was implemented in several stages as described in the following sections.

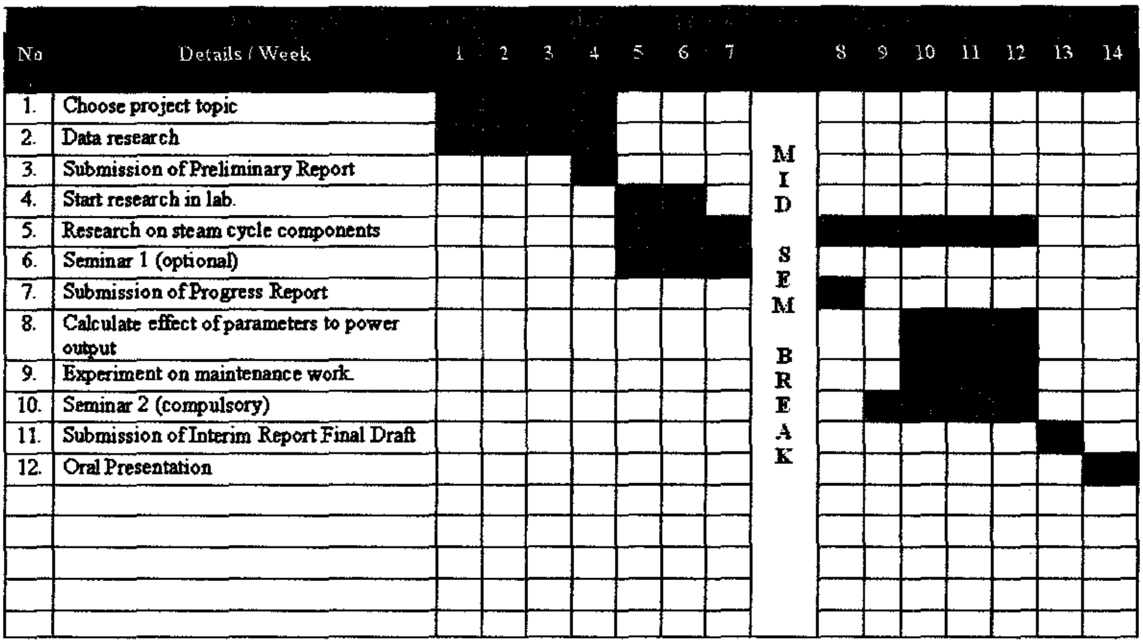
3.1 Information Gathering

In order to understand the background work related to the present projects, respective books, journals and thesis develops by external and internal parties were referred to. The information selected was relevant to the main objective of this project.

3.2 Consulting experts from relevant industry

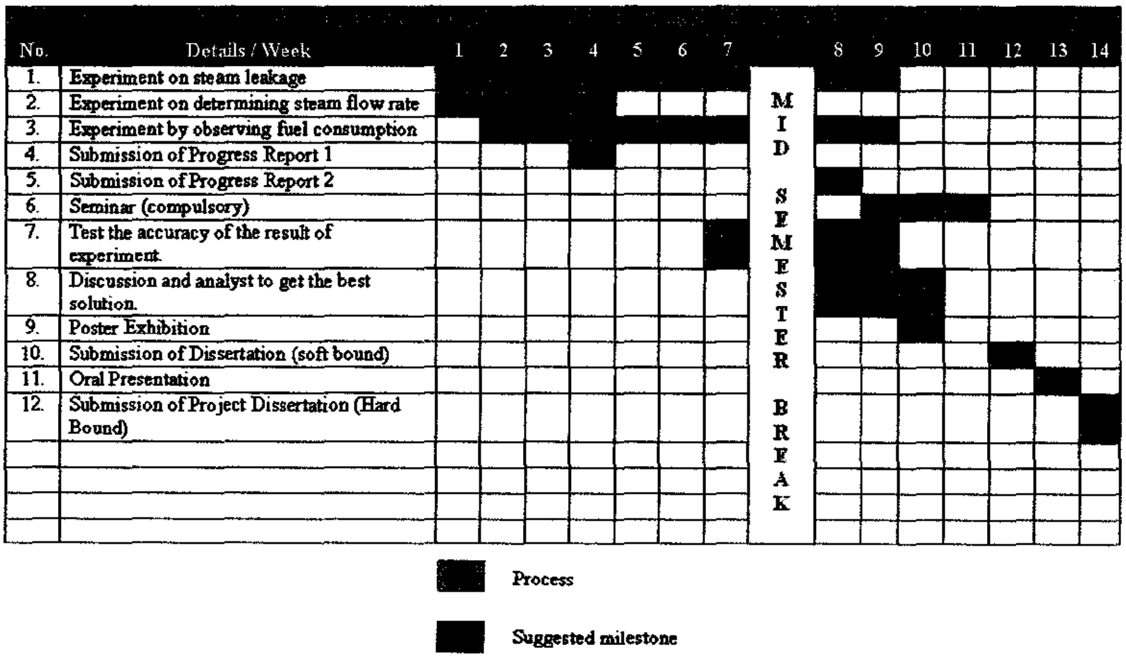
Experts such as engineers from steam power plant were consulted. Their advices and comment were noted in assisting the implementation of the project. During this project period, a visit to Tractors Malaysia Sdn Bhd was made and one of its project engineer gave helpful advice to this project. Besides that, plant engineer from Malakoff Corp. Berhad. has gave some advice regarding the heat rate and efficiency of the steam power plant.

Figure 3.1 shows the project Gantt chart for semester 1, which is the first half period of this 1-year project. Topic choosing and data research took the first 4 weeks. Research at the lab was started at week 5. Experiment on leakage started on week 10 and the work for semester 1 end at week 14 which is after the oral presentation. Figure 3.2 shows the Gantt chart for semester 2, most of the time was spent on steam leakage experiment. After getting the results, experiment is being evaluated to test the accuracy of the result. This project will end at week 14 with the submission of hard bound dissertation.



No	Details / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1.	Choose project topic	■	■	■	■				MID SEM BREAK							
2.	Data research	■	■	■	■											
3.	Submission of Preliminary Report				■											
4.	Start research in lab.					■	■									
5.	Research on steam cycle components					■	■	■		■	■	■	■	■		
6.	Seminar 1 (optional)					■	■	■								
7.	Submission of Progress Report									■						
8.	Calculate effect of parameters to power output											■	■	■		
9.	Experiment on maintenance work.											■	■	■		
10.	Seminar 2 (compulsory)										■	■	■	■		
11.	Submission of Interim Report Final Draft														■	
12.	Oral Presentation															■

Figure 3.1: Gantt chart for Semester 1.



No.	Details / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1.	Experiment on steam leakage	■	■	■	■	■	■	■	MID SEMESTER BREAK	■	■					
2.	Experiment on determining steam flow rate	■	■	■	■											
3.	Experiment by observing fuel consumption		■	■	■	■	■	■		■	■					
4.	Submission of Progress Report 1				■											
5.	Submission of Progress Report 2									■						
6.	Seminar (compulsory)										■	■	■			
7.	Test the accuracy of the result of experiment							■		■	■					
8.	Discussion and analyst to get the best solution.									■	■	■				
9.	Poster Exhibition											■				
10.	Submission of Dissertation (soft bound)													■		
11.	Oral Presentation														■	
12.	Submission of Project Dissertation (Hard Bound)															■

■ Process

■ Suggested milestone

Figure 3.2: Gantt chart for Semester

Figure 3.3 shows the workflow for the steam leakage experiment. Firstly, the steam power plant was started and operated for 30 minutes. This process, also known as dry run, allowed the steam to flow throughout the steam pipelines. By having the dry run, the system would be warmed up to working temperature and this ensured that the steam in the pipeline was clean. After the dry run, the steam power plant was operated without steam leakage for 120 minutes. Data such as power output and diesel consumption was taken for every minute. The power output was measured from the dynamometer bundled at the turbine unit. The diesel consumption was determined from the diesel flow meter at the boiler, and by observing the fuel level beside the fuel tank.

The steam power plant was then operated with steam leaking. The leaked point is shown in Figure 3.4 and Figure 3.5. The steam was leaked for 15 minutes before the data was recorded to allow steady working conditions. The experiment with leakage was performed for 120 minutes. The experiments were repeated for steams leakage at 1%, 3% and 6% of the total flow rate.

3.3 Steam leakage experiment work flow

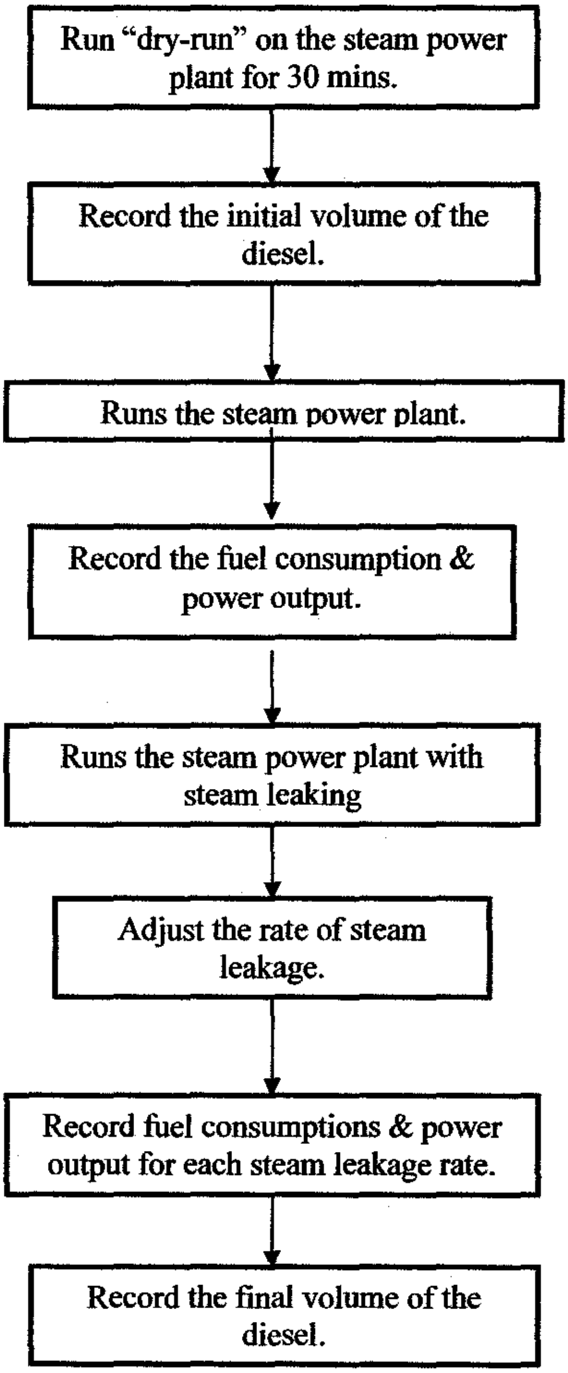
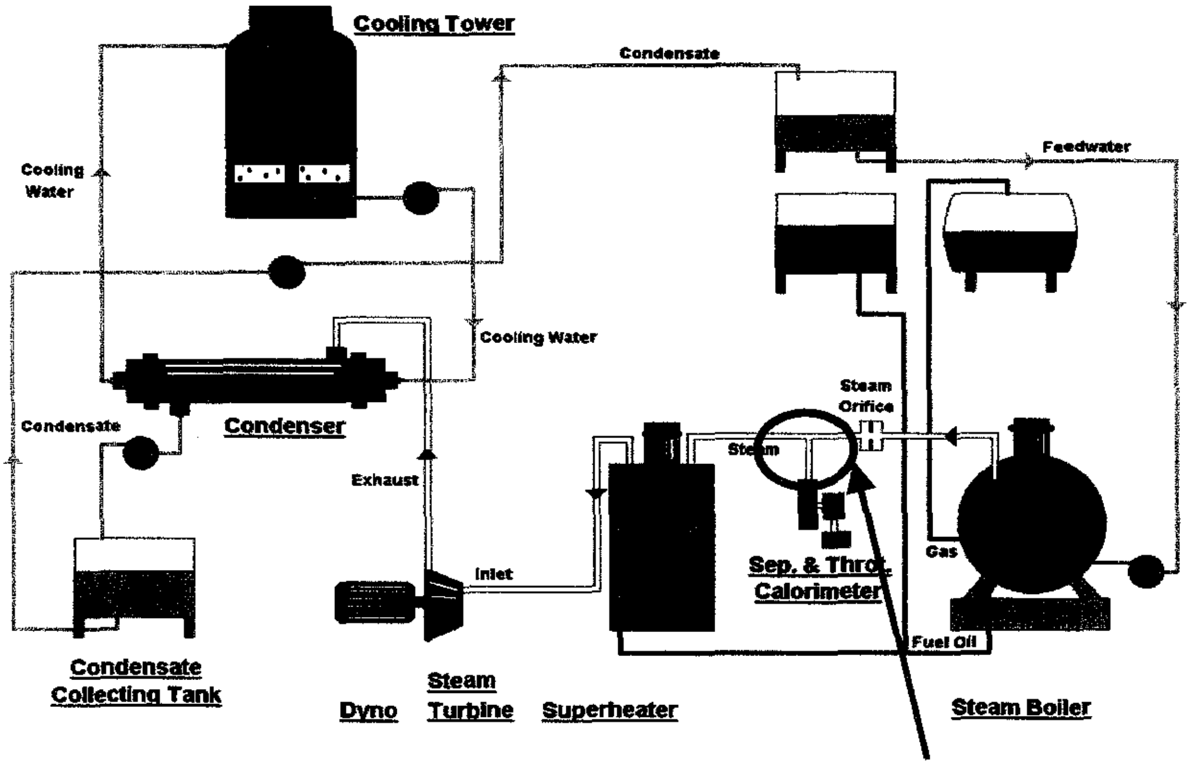


Figure 3.3: Experiment workflow

3.4 Steam Leakage Experiment



Steam leakage part

Figure 3.4: Diagram for UTP 5-KW steam power plant.

Figure 3.4 shows the diagram for UTP 5-KW steam power plant. There are many types of pipelines in the system such as steam pipelines, feed water pipelines and steam reheat pipelines. The red circled part shown in Figure 3.4 denotes the location where steam was leaked. In this project, the steam pipeline that link from boiler to the superheater was chosen for the leakage experiment it had the highest steam pressure. A mini condenser that was installed within the pipeline enabled the steam to be leaked by condensation. The flow rate of the steam was determined by weight difference of the collected condensed steam over a period of 120 minutes.

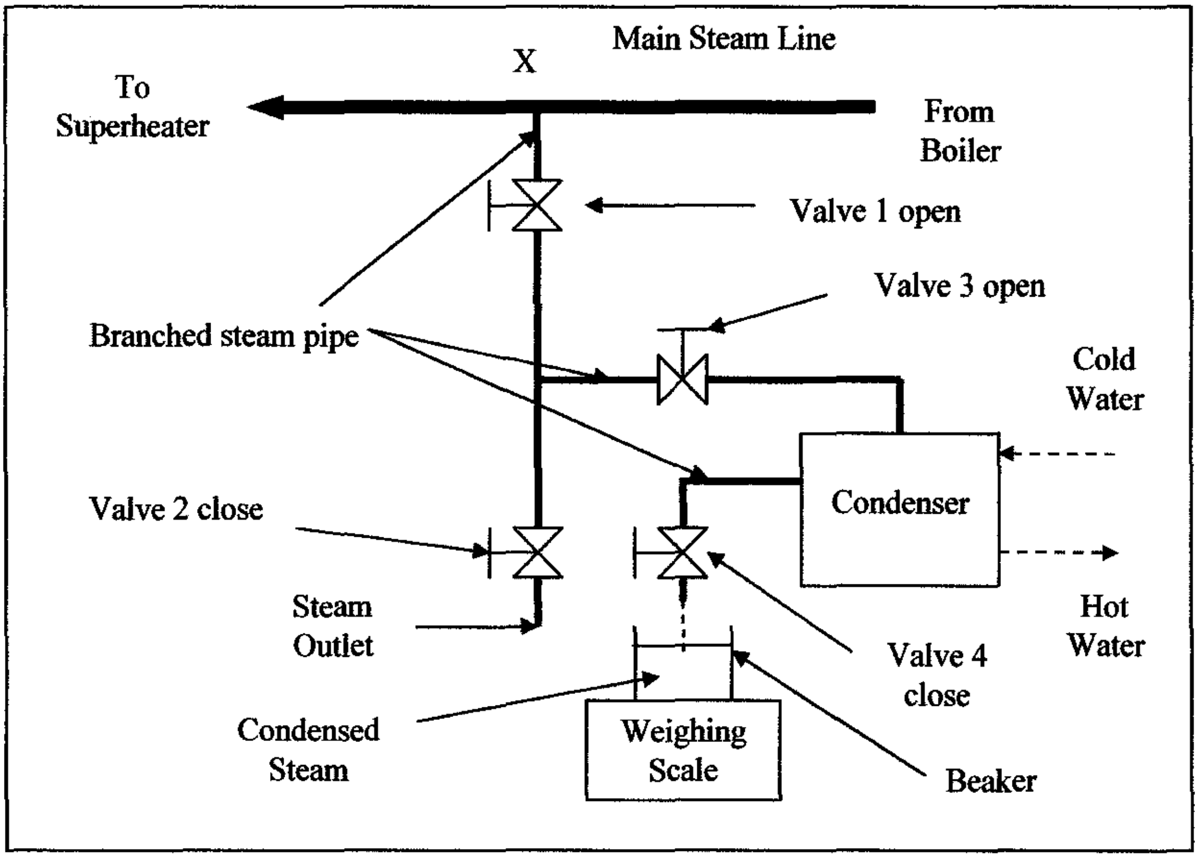


Figure 3.5: Schematic of the condensed steam collection system

Figure 3.5 shows the schematic of the condensed steam collection system. In Figure 3.5, the thick line at the top represents the main steam line that delivers the steam from the boiler to the superheater. A tee branched the main steam pipe at point X to allow the steam to be leaked. The condenser unit connecting the branched steam pipe is not originally part of the steam power plant system. The condenser was installed for experiment purposes.

At the start of the experiment, the condenser was switched on. The cold water started to flow through the condenser. The purpose of having this condenser was to remove heat from the steam and condense it. Valve 1 was then open fully to allow the steam to flow into the branched steam pipe. Valve 2 and Valve 3 were remained close. The function for Valve 2 was to leak out the steam directly without being condensed. In this experiment, Valve 2 was not opened because the steam was at a very high temperature (215°C) and would be very hard to be trapped and measured. Valve 3 and Valve 4 were then opened, allowing steam flow into the condenser. The condensed water flowed out into the beaker from the pipe line through Valve 4. The function of valve 4 was to control the steam flow rate. The effect of varying the flow rate of steam leakage on the fuel consumption was studied. The beaker with volume measurement scale on it was placed on a weighing scale to measure the mass of condensed water collected at every minute. A picture showing equipments involving the steam leakage will be shown in Figure 3.6.

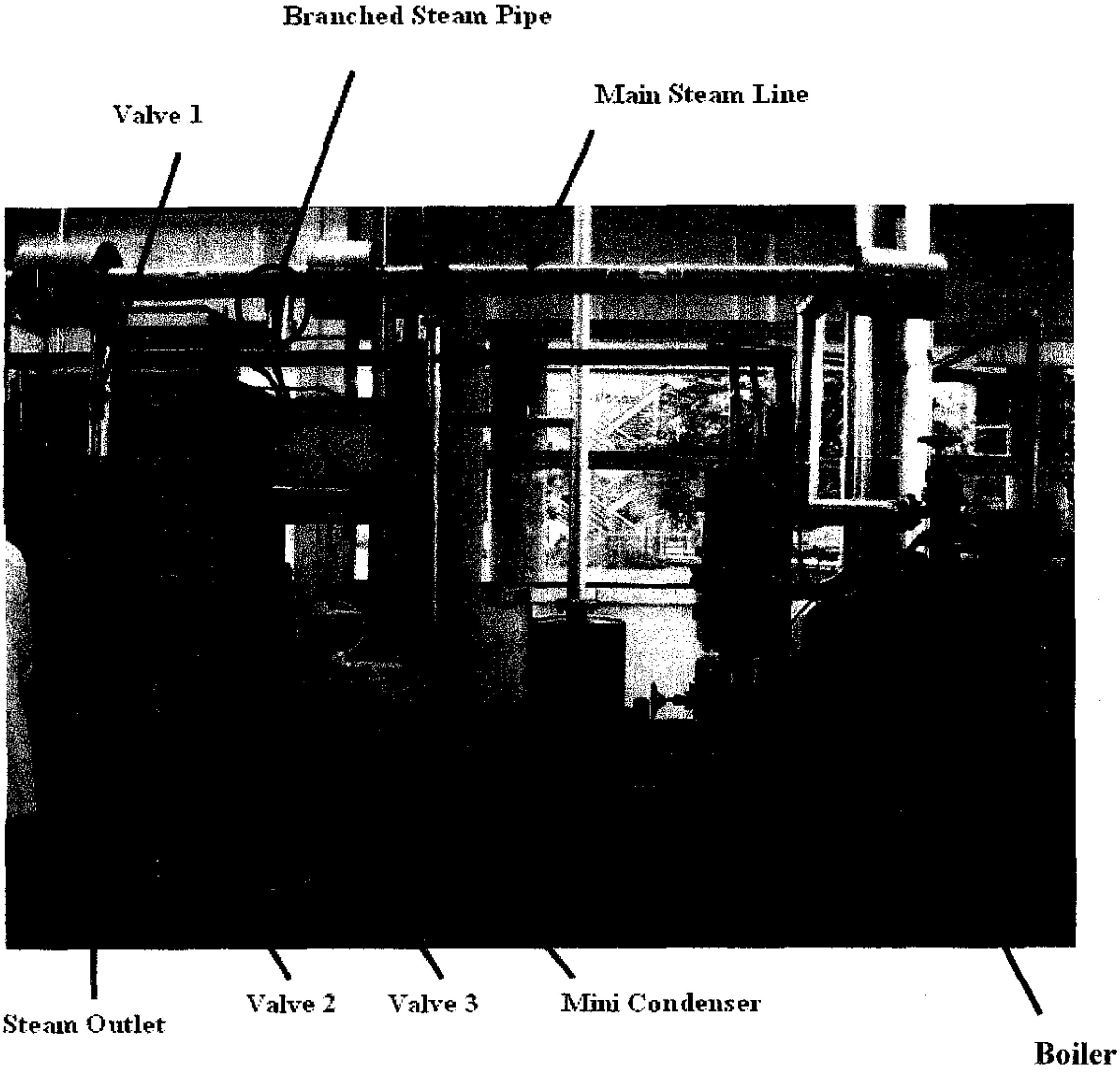


Figure 3.6: Picture of the equipment involved in the steam leakage experiment

The top red circled on the picture in Figure 3.6 shows the branched steam pipe that is connected to the main steam line. The flow rate of the steam in the main steam pipeline is 4350ml/min according to the specification of the system. In this experiment, the rate of steam leaking was varied from 40ml/min to 300ml/min as indicated in Table 3.1.

Table 3.1 Percentage and volume of steam leakage of the total flow rate.

1%	43ml/min
3%	130ml/min
6%	270ml/min

The power output of the steam power plant was measured from the dynamometer at the turbine.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Steam Leakage Rate

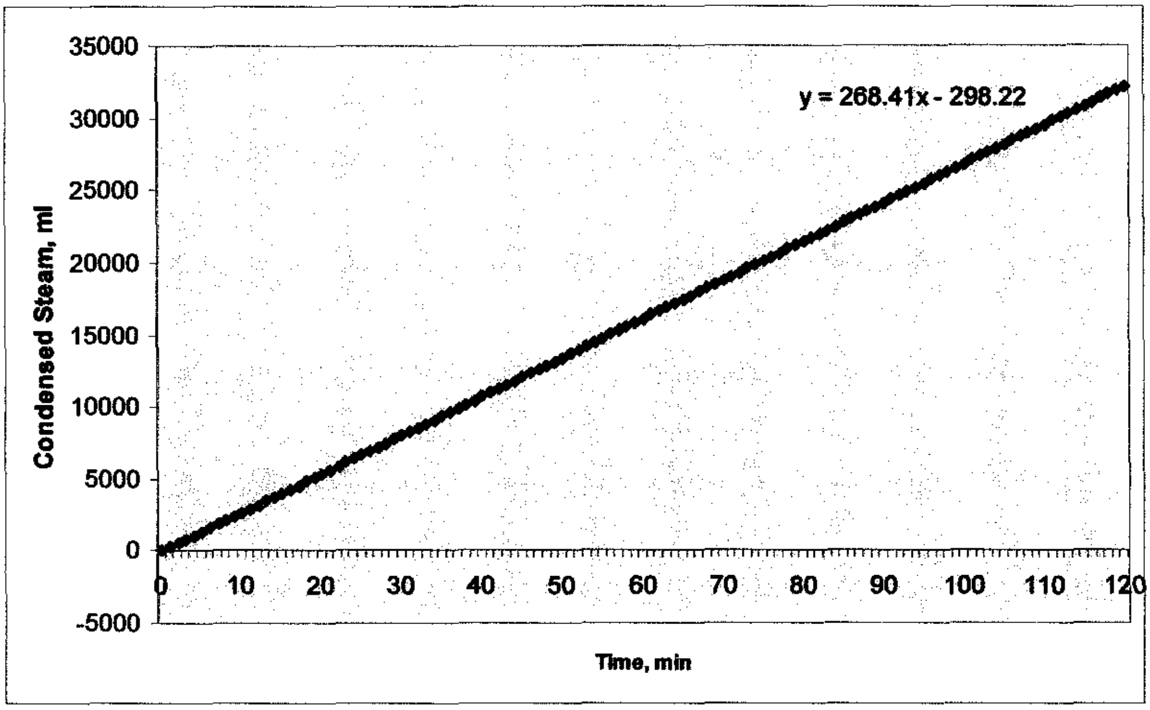


Figure 4.1: Condensed water versus time for 6% leakage.

Shown in Figure 4.1 is the variation of condensed steam leakage versus time for 120 minutes. The amount of steam leaked dropped at the first 13 minutes because of the sudden drop in pressure within the pipeline. The boiler detected the drop in pressure and started to increase the combustion rate to maintain the pressure in the pipeline. Therefore the rate of steam leaking is quite consistent after the 13th minutes. The average rate of steam leaking is 268.41ml/min shown from the slope of the graph.

4.2 Power Output

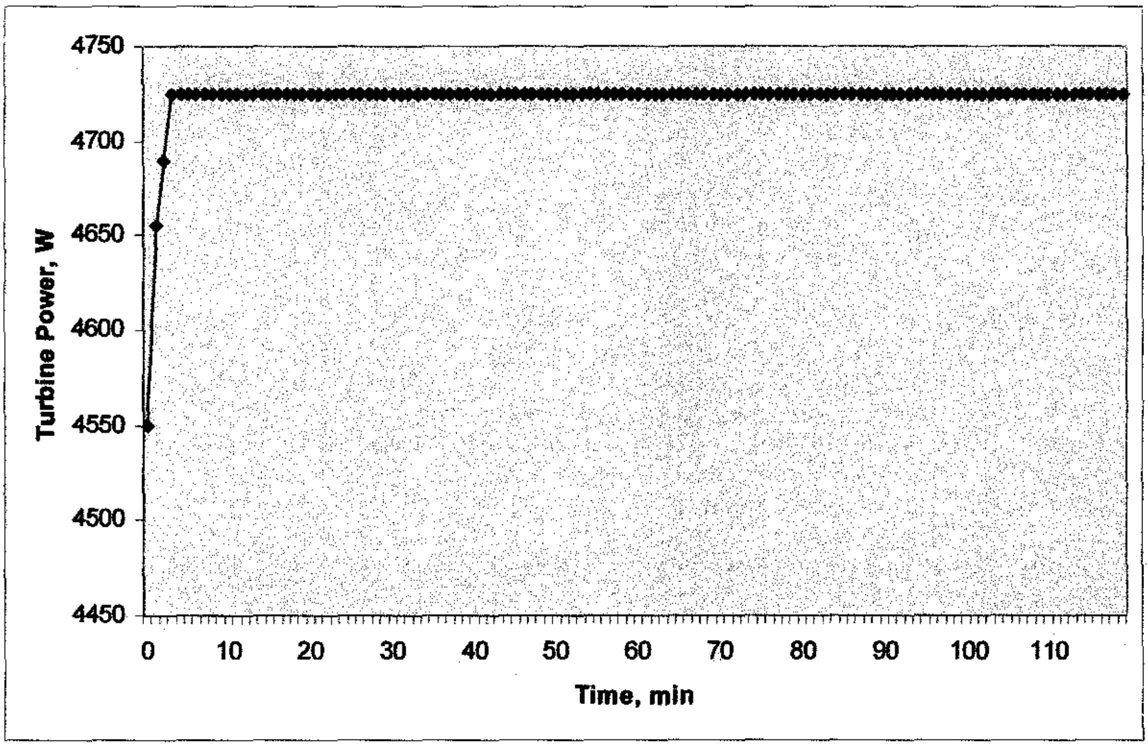


Figure 4.2: Power Output at Turbine without leakage versus time.

Figure 4.2 shows the variation of power output at the turbine versus time for experiment without steam leakage. The power value was calculated by multiplying the value of voltage with that current. The power output climbed from 4550 W at the first minute to 4725 W within 5 minutes. This was due to the torque adjustment. Torque need to be adjusted to tune the power output. The power output maintained a constant value at 4725 W starting from the 5th minute till the 120th minute. The average power output was 4723 W.

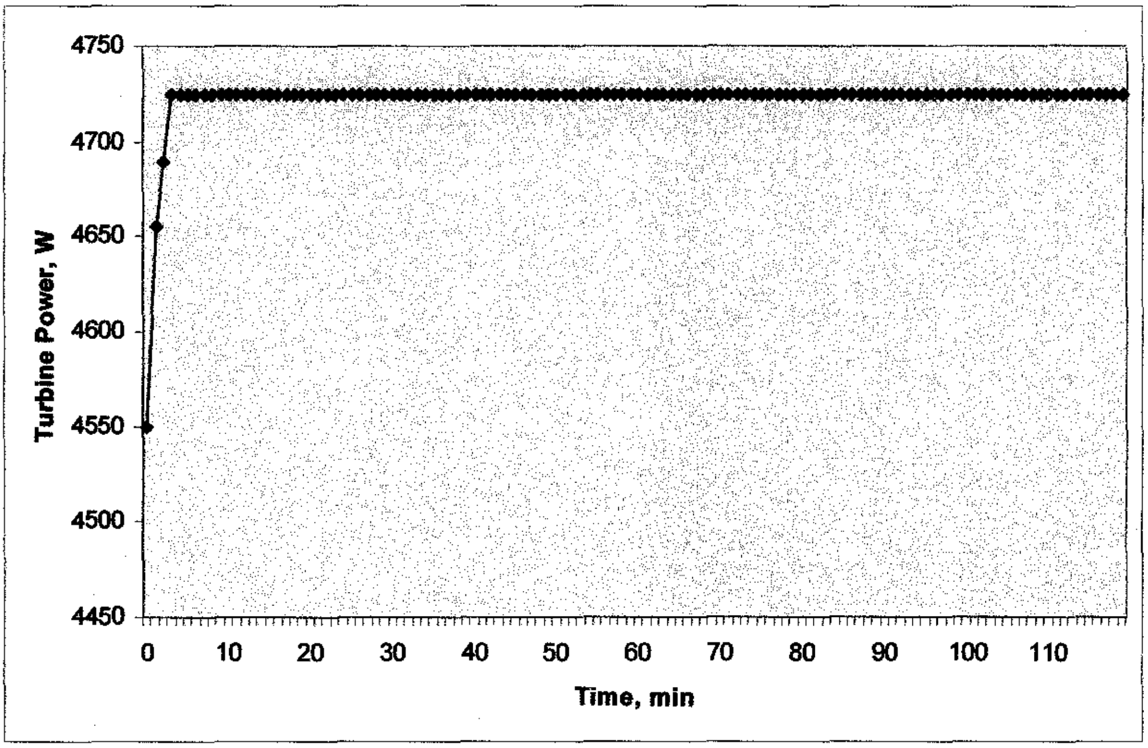


Figure 4.3: Power Output at Turbine with leakage versus time.

Figure 4.3 shows the variation of power output at the turbine versus time for experiment with steam leakage every minute for 120 minutes. The power value was calculated by multiplying the value of voltage with that current. The power output climbed from 4386 W at the first minute to 4725 W within 5 minutes. As in Figure 4.2, this was due to the torque adjustment to tune the power output. The power output maintain constant at 4725 W starting from the 5th minute till the 120th minute. The average power output was 4719 W. The constant power output of 4725 W was exactly the same with that for experiment without steam leakage. The reason for the constant in the power output is because the boiler ran at a higher rate of combustion to "refill" back the steam that leaked out during the experiment.

4.3 Fuel Consumption

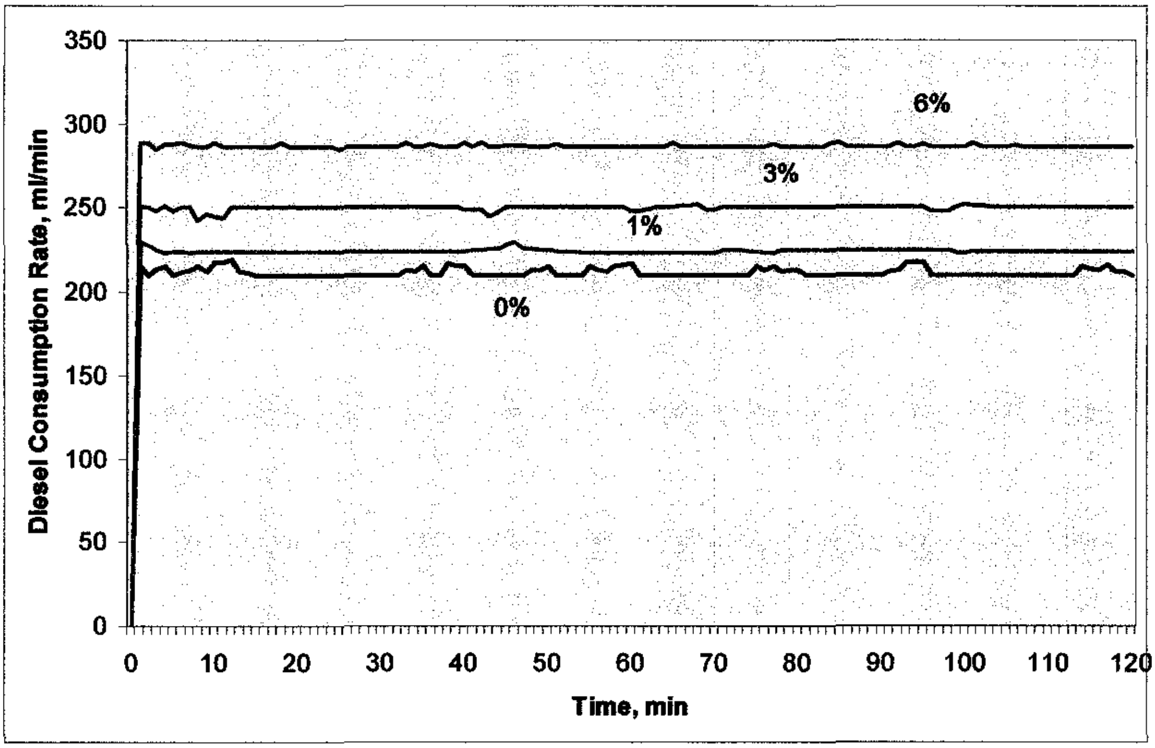


Figure 4.4: Diesel consumption versus time for various rates of leakages.

Shown in Figure 4.4 is the diesel consumption rate versus time for various rates of leakages. The steam flow rate in the main steam pipelines is 4350ml/min. The graph shows that a higher percentage of steam leakage rate will cause a higher fuel consumption rate. The average consumption rate for each leakage rate shows that 1% of steam leakage will increase the diesel consumption rate by 5%, 3% of steam leakage causes 17% higher in diesel consumption and 6% of steam leakage causes 35% increase in diesel consumption.

4.4 Fuel Consumption Graph Analysis

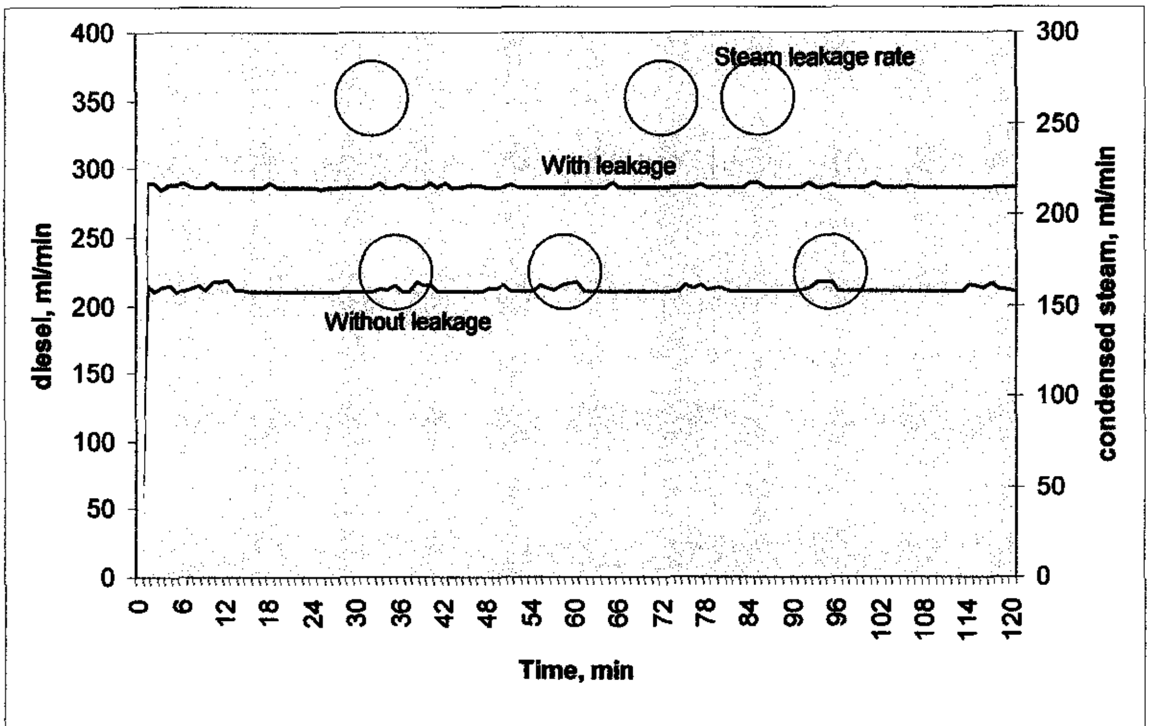


Figure 4.5: Typical variation of diesel consumption with time for the steam power plant operating with 6% leakage and without steam leakage for 120 minutes.

Shown in Figure 4.4 is the typical variation of diesel consumption rate with time for the steam power plant operating with 6% leakage and without steam leakage for 120 minutes. The blue colour thin line shows the diesel consumption rate with 6% of steam leakage, pink colour line shows the diesel consumption rate without leakage and the yellow thick line shows the steam leakage rate. The red colour circled parts show the fluctuations in the diesel consumption rate and steam leakage rate. Both of these are due to the operation of the boiler. The decrease in steam leakage rate means that the amount of steam in the main steam line was not sufficient and therefore causing low pressure which was below 8 bars. When the boiler detected low pressure, it increased the combustion rate to increase the amount of steam thus increasing the pressure in the main steam line. Therefore the amount of steam leakage rate increased back to the average leakage rate and at the same time due to the increased in combustion rate, the boiler consumed more diesel than the normal operating time, thus causing the diesel consumption rate increased as shown in the red circles. The boiler decreased the combustion rate to normal operating combustion rate after the pressure in the main steam line reached a pressure of 9 bars. The fluctuations of curve is that steam leakage rate dropped and return to the normal rate of leakage within 2 minutes, while for diesel consumption rate, it increased and dropped to the normal rate of consumption within 2 minutes as well. The value of power output is not plotted in the graph because it remains constant all the time either steam leakage happens or without steam leakage.

Steam Leakage (%)	Diesel consumption for 5KW power plant running for 2 hours	Extra diesel consumed due to steam leakage	% increase in diesel consumption
0	25.3	0	0
1	26.8	0.9	5.8
3	29.8	3.9	17.6
6	34.3	8.4	35.3

Table 4.1: Extra cost due to different percentage of steam leakage on a 5-KW steam power plant.

Table 4.1 shows the extra diesel consumption caused by the steam leakage. Diesel consumption at various % of steam leakage is compared to diesel consumption with no steam leakage. The total extra diesels consumed are shown and the % increases are calculated.

4.5 Heat Rate Calculation

The effect of steam leakage at various % to the heat rate of the system is shown by calculating using the heat rate equation.

Heat Rate Calculation

$$\text{Heat Rate (kJ/kWh)} = \frac{\text{Energy Input (kJ/hr)}}{\text{Power Output (kW)}}$$

$$\text{Net Heat Rate (kJ/kWh)} = \frac{\text{Fuel Flow (kg/hr)} \times \text{Fuel Heating Value (kJ/kg)}}{\text{Power Output (kW)}}$$

Power Output for UTP steam power plant = 4.725 kW

Calorific value of Diesel (Low Heating Value) = 42.12 MJ/liter = 42120 kJ/l

Density of Diesel at 25°C = 850 g/liter

Percentage of steam leaking

The steam flow rate in the pipeline is 4.35kg/min = 4350ml/min

Heat Rate for Steam Power Plant running without steam leakage

Total Diesel Consumed = 25.392 liters

Diesel Consumed = 12.696 liters/hr

Power Output = 4.725 kW

$$= \frac{12.696 liter/hr \times 42120 kJ/liter}{4.725 kW} = 113175.77 \text{ (kJ/kWh)}$$

Heat Rate for Steam Power Plant running with 1% steam leakage

Total Diesel Consumed = 26.880 liters

Diesel Consumed = 13.440 liters/hr

Power Output = 4.725 kW

$$= \frac{13.440 liter/hr \times 42120 kJ/liter}{4.725 kW} = 119808 \text{ (kJ/kWh)}$$

Heat Rate for Steam Power Plant running with 3% steam leakage

Total Diesel Consumed = 29.880 liters

Diesel Consumed = 14.940 liters/hr

Power Output = 4.725 kW

$$= \frac{14.940 liter/hr \times 42120 kJ/liter}{4.725 kW} = 133179.43 \text{ (kJ/kWh)}$$

Heat Rate for Steam Power Plant running with 6%steam leakage

Total Diesel Consumed = 34.374 liters

Diesel Consumed = 17.187 liters/hr

Power Output = 4.725 kW

$$= \frac{17.187 liter/hr \times 42120 kJ/liter}{4.725 kW} = 153209.83 \text{ (kJ/kWh)}$$

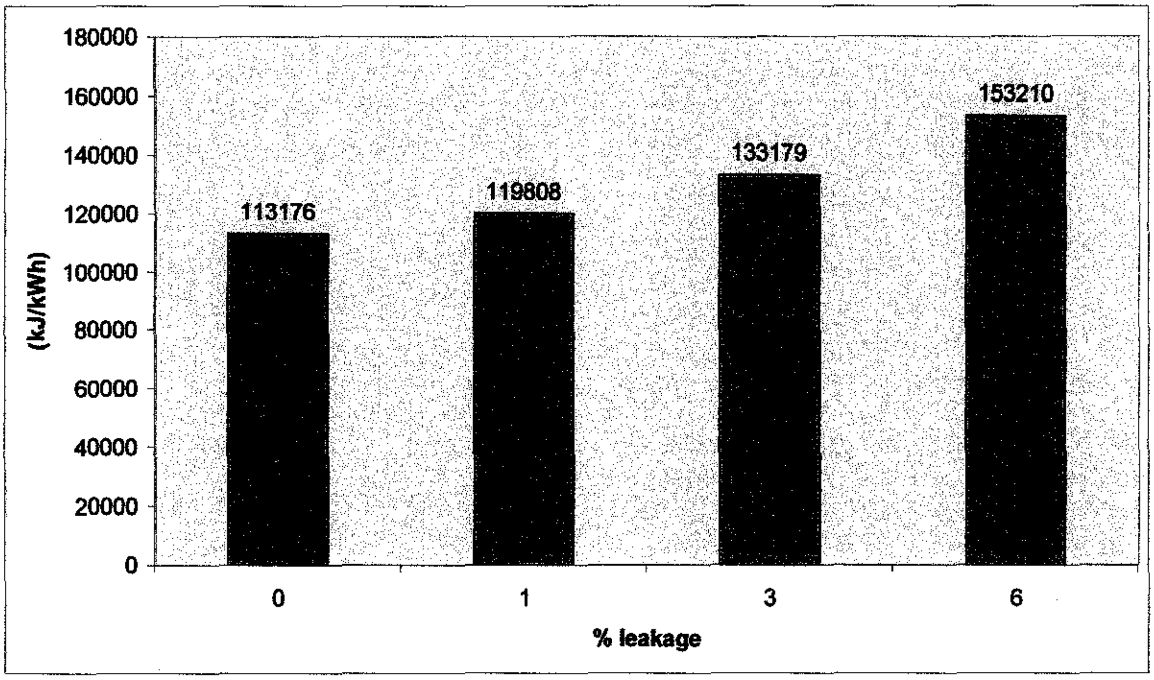


Figure 4.6: Heat rate comparison for steam power plant running with various rates of steam leakage.

Figure 4.6 shows the heat rate comparison for steam power plant running with various rate of steam leakage. Heat rate is in the unit of kJ/kWh, this means certain amount of energy in kJ is needed to produce a 1 kW of power in 1 hour. From the graph above, it is shown that the effect of steam leakage to the heat rate of steam power plant is significant. The higher value of heat rate means that more energy is needed to produce a single unit of power. The result in Figure 4.6 shows that the higher is steam leakage rate, the higher heat rate is needed, and thus will cost more in terms of fuel.

4.6 Energy Calculation

Table 4.2: Weight of steam leakage and volume of extra diesel required for different percentage of steam leakage rate.

Steam Leakage (%)	Extra Diesel Required (liter/min)
6	0.074
3	0.037
1	0.012

Table 4.2 shows the mass flow rate of leaked steam and the rate of consumption of diesel for different experiment condition. This data was collected from experiments and is important for the energy calculation. In this calculation, it was assumed that the extra energy required to heat up the amount of make-up water was equal to the steam loss. That particular amount of water is heated up from room temperature 25 °C to 215 °C. Table 4.3 shows the amount of energy needed to heat up each different volume of water and Table 4.4 shows the actual extra energy used due to the steam loss.

Table 4.3: Calculation for energy required to heat up the water from 25 °C to 215 °C for different mass of water.

mass of water (kg)	Cp for 0-100 °C (J/g)	T(100-25)	latent heat for vaporization (J/g)	Cp for 100-200 °C (J/g)	T (215-100)	Energy (KJ)
0.268	4.187	75	2260	1.996	115	751.355
0.137	4.187	75	2260	1.996	115	384.088
0.044	4.187	75	2260	1.996	115	123.357

Table 4.3 shows that the energy required to heat up different mass of water from 25 °C to 215 °C. By using the equation of latent heat $Q= mCp\Delta T$ (4.1), where m is mass of water, cp is the specific heat and ΔT is the temperature difference. The energy required was calculated. For 6% of steam leakage, 0.268kg of condensed steam was leaked from the system every minute, for 3% of steam leakage, 0.137kg/min of steam was leaked and for 1% of steam leakage, 0.044kg/min of steam will be leaked. The energy required to heat

these amount of water from 25°C to 215°C is shown above. To heat up 0.268 kg of water 25°C to 215°C, 751.355 KJ of energy is required, to heat up 0.137 kg of water requires 384.088 KJ and 0.044 kg of water needs 123.357 KJ of energy to heat it up.

Table 4.4: Extra energy used due to steam leakage

Steam Leakage (%)	Diesel (liter)	Calorific value (KJ/liter)	Boiler Efficiency	Energy (KJ)
6	0.074	42120	0.88	2757.6
3	0.037	42120	0.88	1371.4
1	0.012	42120	0.88	459.61

Energy used = amount of diesel consumed x calorific value of diesel x boiler efficiency. (4.2). For 6% of steam leakage, 0.0744 liter of extra diesel is needed every minute, for 3% of steam leakage, 0.037 liter of extra diesel required and for 1% of steam leakage, it consumed 0.0124 liter of extra diesel. The energy released after considering the boiler efficiency is shown in the Table 4.4.

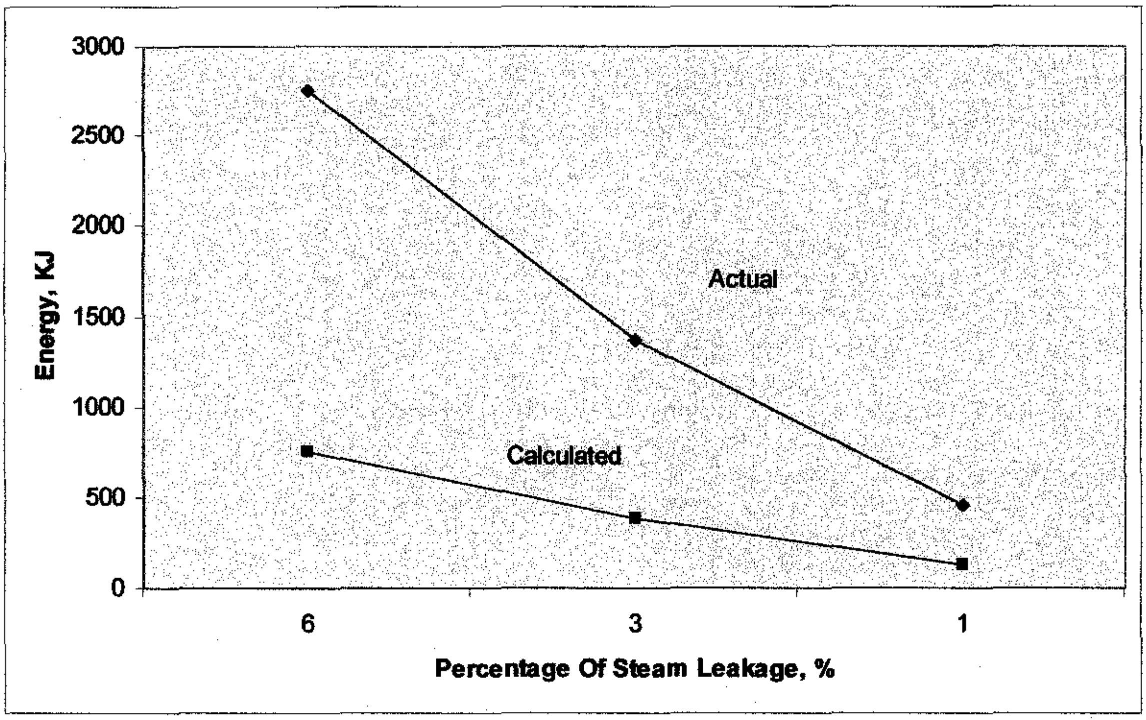


Figure 4.7: Comparison between the actual energy used with calculated energy used to heat up water from 25-215 °C.

Figure 4.7 shows that the actual energy required was about 4 times higher than the calculated one. This indicates that the energy that lost from the fuel before transformed into heat in steam is high. Besides heat, the lost in the kinetic energy of the steam also contributes significant energy lost. In addition, the friction force between the steam and the steam pipeline was probably another reason of the energy lost. Besides providing heat to the water, the boiler had to maintain the high pressure in the steam pipe line which is 8 – 9 bars. These pressures would provide enough kinetic energy to make sure the steam could flow through the whole steam power plant system. At the same time, while the steam flowing in the steam pipeline, it created friction between the steam and the steam pipeline.

CONCLUSION

The present research has proven that the steam leakage in steam power plant would cost more fuel for the steam power plant operation. An additional fuel by 35% is a very big amount for a steam power plant. In FYP I, the steam leakage experiment was done as well, but the power output of the experiment is maintained constant. No power drop was detected. This was because when the boiler system found that the steam was reduced in the system, it ran with a higher rate of combustion to maintain the amount of steam in the system. As a result, the boiler consumed more diesels. Therefore, fuel consumption was used as the main criteria to observe the energy lost instead of using power output. Clearly that steam leakage would cause extra cost to operate a steam power plant. As mentioned earlier, 70% of the operational cost would be contributed by fuel cost, therefore even 1% of steam leakage that would cause 5.86% of extra cost would be a big amount for the steam power plant. This project proves that steam leakage is a very crucial problem that should be look into for every steam power plant in the industry.

As a recommendation for future work, the cost needed to fix the steam power plant from steam leakage problem has to be investigated to justify the investment in maintaining 0 % steam leakage. This project is hoped to provide awareness to the steam power plant industry where the scale of power output is in a larger scale.

Reference

Afgan N., 1998, *Steam Leakage Detection System On Nuclear Power Plant.*

Babcock & Wilcox Co. 2005, *Steam: Its Generation and Use, 41st edition. ISBN 0-9634570-0-4.*

Elliott C., Kao Chen, Robert.S (coauthors) Robert T.K.(Editor in Chief) (1936) 1997, *Kents' Mechanical Engineers' Handbook, Eleventh edition (Two volumes)*

Everett B. W. 2005, *Steam Power Plant Operation 8th Edition*

GIK Institute Of Science And Technology 2007, *Heat Rate Of Steam Power Plant*

Golberg 2005, *Steam Leak at Hope Creek Nuclear Power Plant*

Ishigai S. 1999, *Steam Power Engineering, Thermal and Hydraulic Design Principles Standard Handbook of Powerplant Engineering, 2nd edition*Thomas

J.Moran 1998, *Fundamentals of engineering thermodynamics*, New York, John Wiley& Sons

Kenneth W. 2006, *Fundamentals of Steam Power*

Raheman H. and Phadatare A.G.2004, *Energy savings in steam system.*

S.Mott 2005, *Wiley Engineering Handbook Series,* Wiley John & Sons

Worrell 2005, *Ernst Energy savings in steam system*

APPENDICES

Time, min	Condensed Steam, ml	Time, min	Condensed Steam, ml
61	270	91	270
62	270	92	270
63	270	93	270
64	270	94	270
65	265	95	270
66	270	96	270
67	270	97	270
68	265	98	270
69	270	99	270
70	270	100	270
71	255	101	270
72	270	102	270
73	270	103	270
74	255	104	270
75	270	105	270
76	270	106	270
77	270	107	270
78	270	108	270
79	265	109	270
80	270	110	270
81	270	111	270
82	270	112	270
83	250	113	270
84	270	114	270
85	270	115	270
86	250	116	270
87	270	117	270
88	270	118	270
89	270	119	270
90	270	120	270
		Average	**268**

The average rate of steam leaking is 268ml/min throughout the 2 hours experiment.

Table 2: Power Output at Turbine without steam leakage.

Time, min	Voltage, V	Current, I	Power, W
1	130	35	4550
2	133	35	4655
3	134	35	4690
4	136	35	4760
5	135	35	4725
6	135	35	4725
7	135	35	4725
8	135	35	4725
9	135	35	4725
10	135	35	4725
11	135	35	4725
12	135	35	4725
13	135	35	4725
14	135	35	4725
15	135	35	4725
16	135	35	4725
17	135	35	4725
18	135	35	4725
19	135	35	4725
20	135	35	4725
21	135	35	4725
22	135	35	4725
23	135	35	4725
24	135	35	4725
25	135	35	4725
26	135	35	4725
27	135	35	4725
28	135	35	4725
29	135	35	4725
30	135	35	4725

Time, min	Voltage, V	Current, I	Power, W
31	135	35	4725
32	135	35	4725
33	135	35	4725
34	135	35	4725
35	135	35	4725
36	135	35	4725
37	135	35	4725
38	135	35	4725
39	135	35	4725
40	135	35	4725
41	135	35	4725
42	135	35	4725
43	135	35	4725
44	135	35	4725
45	135	35	4725
46	135	35	4725
47	135	35	4725
48	135	35	4725
49	135	35	4725
50	135	35	4725
51	135	35	4725
52	135	35	4725
53	135	35	4725
54	135	35	4725
55	135	35	4725
56	135	35	4725
57	135	35	4725
58	135	35	4725
59	135	35	4725
60	135	35	4725

Time, min	Voltage, V	Current, I	Power, W
61	135	35	4725
62	135	35	4725
63	135	35	4725
64	135	35	4725
65	135	35	4725
66	135	35	4725
67	135	35	4725
68	135	35	4725
69	135	35	4725
70	135	35	4725
71	135	35	4725
72	135	35	4725
73	135	35	4725
74	135	35	4725
75	135	35	4725
76	135	35	4725
77	135	35	4725
78	135	35	4725
79	135	35	4725
80	135	35	4725
81	135	35	4725
82	135	35	4725
83	135	35	4725
84	135	35	4725
85	135	35	4725
86	135	35	4725
87	135	35	4725
88	135	35	4725
89	135	35	4725
90	135	35	4725

Time, min	Voltage, V	Current, I	Power, W
91	135	35	4725
92	135	35	4725
93	135	35	4725
94	135	35	4725
95	135	35	4725
96	135	35	4725
97	135	35	4725
98	135	35	4725
99	135	35	4725
100	135	35	4725
101	135	35	4725
102	135	35	4725
103	135	35	4725
104	135	35	4725
105	135	35	4725
106	135	35	4725
107	135	35	4725
108	135	35	4725
109	135	35	4725
110	135	35	4725
111	135	35	4725
112	135	35	4725
113	135	35	4725
114	135	35	4725
115	135	35	4725
116	135	35	4725
117	135	35	4725
118	135	35	4725
119	135	35	4725
120	135	35	4725
Average	**135**	**35**	**4723**

The average value for Voltage, V is 135, Ampere, I is 35, Power is 4723W throughout the 2 hours running without steam leakage.

Table 3: Power Output at Turbine with 6% steam leakage.

Time, min	Voltage, V	Current, I	Power, W
1	129	34	4386
2	132	34	4488
3	133	35	4655
4	134	35	4690
5	135	35	4725
6	135	35	4725
7	135	35	4725
8	135	35	4725
9	135	35	4725
10	135	35	4725
11	135	35	4725
12	135	35	4725
13	135	35	4725
14	135	35	4725
15	135	35	4725
16	135	35	4725
17	135	35	4725
18	135	35	4725
19	135	35	4725
20	135	35	4725
21	135	35	4725
22	135	35	4725
23	135	35	4725
24	135	35	4725
25	135	35	4725
26	135	35	4725
27	135	35	4725
28	135	35	4725
29	135	35	4725
30	135	35	4725

Time, min	Voltage, V	Current, I	Power, W
31	135	35	4725
32	135	35	4725
33	135	35	4725
34	135	35	4725
35	135	35	4725
36	135	35	4725
37	135	35	4725
38	135	35	4725
39	135	35	4725
40	135	35	4725
41	135	35	4725
42	135	35	4725
43	135	35	4725
44	135	35	4725
45	135	35	4725
46	135	35	4725
47	135	35	4725
48	135	35	4725
49	135	35	4725
50	135	35	4725
51	135	35	4725
52	135	35	4725
53	135	35	4725
54	135	35	4725
55	135	35	4725
56	135	35	4725
57	135	35	4725
58	135	35	4725
59	135	35	4725
60	135	35	4725

Time, min	Voltage, V	Current, I	Power, W
61	135	35	4725
62	135	35	4725
63	135	35	4725
64	135	35	4725
65	135	35	4725
66	135	35	4725
67	135	35	4725
68	135	35	4725
69	135	35	4725
70	135	35	4725
71	135	35	4725
72	135	35	4725
73	135	35	4725
74	135	35	4725
75	135	35	4725
76	135	35	4725
77	135	35	4725
78	135	35	4725
79	135	35	4725
80	135	35	4725
81	135	35	4725
82	135	35	4725
83	135	35	4725
84	135	35	4725
85	135	35	4725
86	135	35	4725
87	135	35	4725
88	135	35	4725
89	135	35	4725
90	135	35	4725

Time, min	Voltage, V	Current, I	Power, W
91	135	35	4725
92	135	35	4725
93	135	35	4725
94	135	35	4725
95	135	35	4725
96	135	35	4725
97	135	35	4725
98	135	35	4725
99	135	35	4725
100	135	35	4725
101	135	35	4725
102	135	35	4725
103	135	35	4725
104	135	35	4725
105	135	35	4725
106	135	35	4725
107	135	35	4725
108	135	35	4725
109	135	35	4725
110	135	35	4725
111	135	35	4725
112	135	35	4725
113	135	35	4725
114	135	35	4725
115	135	35	4725
116	135	35	4725
117	135	35	4725
118	135	35	4725
119	135	35	4725
120	135	35	4725
Average	**135**	**35**	**4719**

The average value for Voltage, V is 135, Ampere, I is 35, Power is 4719W throughout the 2 hours running with steam leakage.

Table 4: Diesel Consumption when Steam Boiler runs without leakage.

Time, min	Diesel, ml	Time, min	Diesel, ml
1	215	31	210
2	210	32	210
3	214	33	213
4	215	34	212
5	210	35	215
6	212	36	210
7	213	37	210
8	215	38	217
9	212	39	215
10	218	40	215
11	218	41	210
12	219	42	210
13	212	43	210
14	211	44	210
15	210	45	210
16	210	46	210
17	210	47	210
18	210	48	213
19	210	49	213
20	210	50	215
21	210	51	210
22	210	52	210
23	210	53	210
24	210	54	210
25	210	55	215
26	210	56	213
27	210	57	212
28	210	58	215
29	210	59	216
30	210	60	217

Time, min	Diesel, ml	Time, min	Diesel, ml
61	210	91	212
62	210	92	213
63	210	93	218
64	210	94	218
65	210	95	218
66	210	96	210
67	210	97	210
68	210	98	210
69	210	99	210
70	210	100	210
71	210	101	210
72	210	102	210
73	210	103	210
74	210	104	210
75	215	105	210
76	213	106	210
77	215	107	210
78	212	108	210
79	213	109	210
80	213	110	210
81	210	111	210
82	210	112	210
83	210	113	210
84	210	114	215
85	210	115	214
86	210	116	213
87	210	117	216
88	210	118	212
89	210	119	212
90	210	120	210
		Average	**212**

The average diesel consumption is 212ml/min when the steam boiler is operating without any steam leakage.

Table 5: Diesel Consumption when Steam Boiler runs with 6% steam leakage.

Time, min	Diesel, ml	Time, min	Diesel, ml
1	289	31	286
2	289	32	286
3	285	33	289
4	288	34	286
5	288	35	286
6	289	36	288
7	287	37	286
8	286	38	286
9	286	39	286
10	289	40	289
11	286	41	286
12	286	42	289
13	286	43	286
14	286	44	286
15	286	45	287
16	286	46	287
17	286	47	287
18	289	48	286
19	286	49	286
20	286	50	286
21	286	51	288
22	286	52	286
23	286	53	286
24	286	54	286
25	285	55	286
26	286	56	286
27	286	57	286
28	286	58	286
29	286	59	286
30	286	60	286

Time, min	Diesel, ml	Time, min	Diesel, ml
61	286	91	286
62	286	92	289
63	286	93	286
64	286	94	286
65	289	95	288
66	286	96	286
67	286	97	286
68	286	98	286
69	286	99	286
70	286	100	286
71	286	101	289
72	286	102	286
73	286	103	286
74	286	104	286
75	286	105	286
76	286	106	287
77	288	107	286
78	286	108	286
79	286	109	286
80	286	110	286
81	286	111	286
82	286	112	286
83	286	113	286
84	289	114	286
85	289	115	286
86	286	116	286
87	286	117	286
88	286	118	286
89	286	119	286
90	286	120	286
		Average	**286**

The average diesel consumption is 286ml/min when the steam boiler is operating with steam leakage.