DETERMINATION OF STEAM QUALITY AND ITS AFFECTING PARAMETERS ON A STEAM TURBINE

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DETERMINATION OF STEAM QUALITY AND ITS AFFECTING PARAMETERS ON A STEAM TURBINE

ABSTRACT

More than 50% of the world's electricity generation is coming from thermal power plants. Thermal power plants used the heat energy from the steam exiting the boiler to drive the turbine and cause the shaft to rotate which will generate electricity through the generator coupled at the shaft end. The most common equipment added to the system to improve the overall efficiency of the power plant are superheaters and reheaters. Superheaters and reheaters basically improved the thermal efficiency by enhancing the steam quality which means less water droplets in the steam exiting the boiler. Dry steam is preferred to achieve a high enthalpy for higher thermal efficiency and to avoid corrosion and erosion of the turbine blades which can lead to deteriorated thermal efficiency over time. In this work, the steam quality will be measured along the high energy steam flow in a small-scale steam power plant. The impact of the steam quality to the overall performance of the power plant was also discussed. Results showed that the steam temperature decreased as it leaves the boiler, increased when it enters the superheater and decreased along the way between the superheater and turbine inlet. It was also observed that the power output of turbine increased when both the boiler and turbine inlet pressure increased.

Keyword: steam power plant, steam quality, turbine power output, efficiency

PENENTUAN KUALITI WAP DAN FAKTOR-FAKTOR YANG MEMBERI KESAN PADA TURBIN WAP

ABSTRAK

Lebih daripada 50% penjanaan elektrik dunia adalah dari stesen janakuasa haba. Stesen janakuasa haba menggunakan tenaga haba dari wap air yang keluar daripada dandang untuk memacu turbin dan menyebabkan aci berputar yang seterusnya akan menjana elektrik melalui penjana yang dipasang pada hujung aci. Alatan yang paling biasa ditambah pada sistem untuk meningkatkan kecekapan keseluruhan stesen janakuasa adalah pemanas-tinggi dan pemanas semula. Pemanas-tinggi dan pemanas-semula secara asasnya meningkatkan kecekapan haba dengan menambahbaik kualiti wap yang mana bermaksud kurang titisan air di dalam wap yang keluar daripada dandang. Wap kering adalah lebih dikehendaki untuk mencapai entalpi yang tinggi bagi mendapatkan kecekapan haba yang tinggi dan untuk mengelakkan karat dan hakisan pada bilah turbin yang akan menyebabkan kemerosotan kecekapan haba untuk jangka panjang. Dalam kajian ini, kualiti wap air akan ditentukan sepanjang laluan wap air bertenaga tinggi untuk stesen janakuasa wap air berskala kecil. Kesan kualiti wap air kepada kecekapan keseluruhan sistem juga dibincangkan. Hasil kajian menunjukkan suhu wap menurun selepas meninggalkan dandang, menaik selepas memasuki pemanas-tinggi, dan menurun di sepanjang laluan antara pemanas-tinggi dan masukan turbin. Pemerhatian lain ialah kuasa yang dihasilkan oleh turbin meningkat apabila tekanan dalam dandang dan masukan turbin meningkat.

Keywords: stesen janakuasa wap, kualiti wap, kuasa turbin, kecekapan

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LIST OF SYMBOLS AND ABBREVIATIONS

P_1	:	Boiler pressure
P_2	:	Turbine inlet pressure
T_1	:	Boiler exit temperature
T_2	:	Superheater inlet temperature
T_3	:	Superheater outlet temperature
T_4	:	Turbine Inlet Temperature

CHAPTER 1: INTRODUCTION

This chapter describes the background of the study, problem statement, objective, scope, importance of the project, and organization of the report.

1.1 Background

Energy is one of the most important thing that we rely on to sustain our daily life, whether it is to power the transportation, for cooling and heating of our homes or working areas, for lightings of the buildings and roads, and for many other applications. Vigorous growth of energy consumption is mainly seen in some developing countries, especially in non-OECD Asian countries, such as China, India and also Middle East **(Figure 1.1)**.

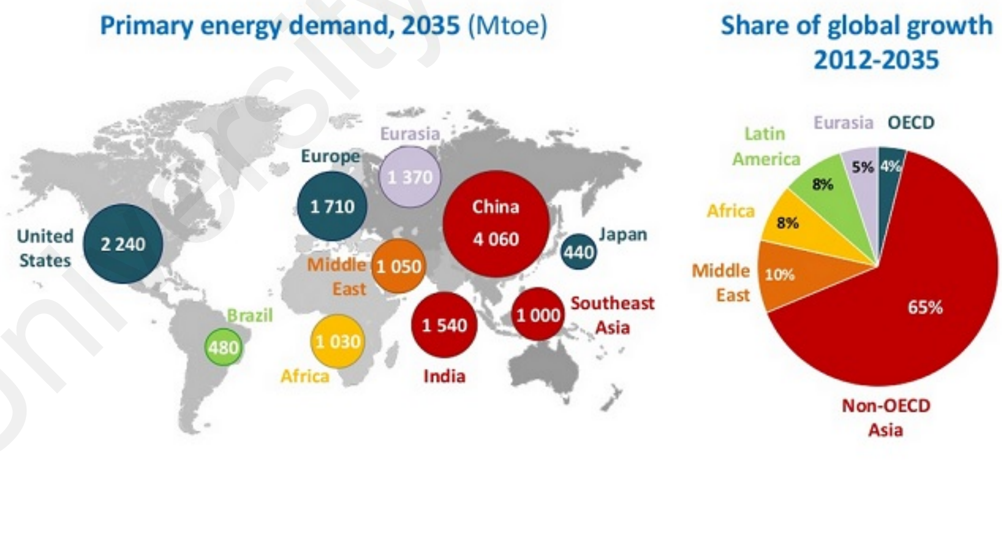

Figure 1.1: World energy consumption by country grouping

(Sustainable Energy Forum, 2013)

However, the concerns on the depletion of non-renewable energy resources and the impact of energy production and consumption to the environment has becoming increasingly threatening since the last three decades and has led the world to come to a global long-term agreement, which is called Paris Agreement, to set the global warming to below 2°C to avoid dangerous climate change should actions are not taken immediately (Cozzi et al., 2015).

One of the primary energy sources in the world is dominated by fossil fuels which supplies about 86% of the total world's energy with oil being the dominant fuel supply totaling about 31% since few years ago **(Figure 1.2)**.

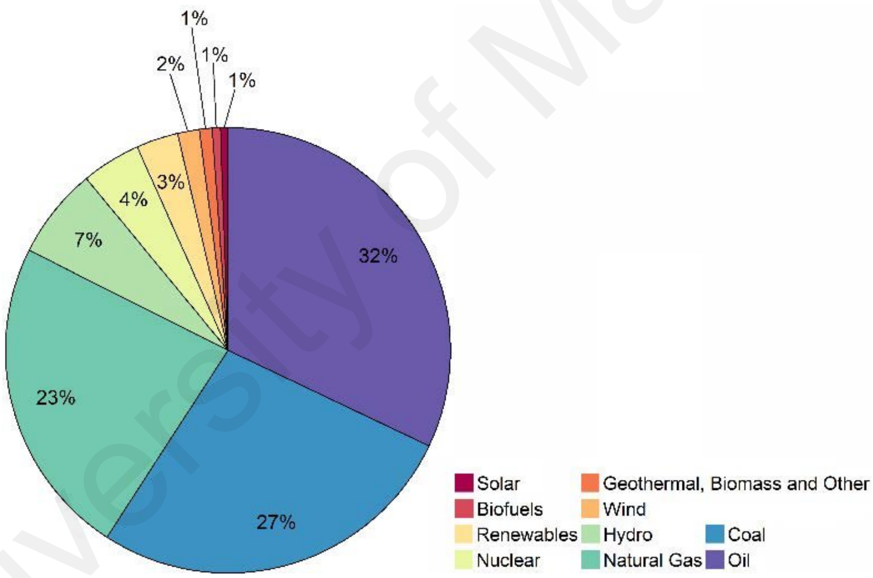

Figure 1.2: World energy consumption by energy source

(Benalcazar et al., 2017)

One of the measures that could be taken into account to achieve the target in Paris Agreement is by ensuring the efficiency of the energy production by a particular power plant is at its highest or optimum level. A steam power plant is one of the method to produce electricity using coal or any fossil source. It is a device that produce electricity by converting the heat energy from the pressurized water to mechanical energy through the rotational movement of the output shaft. The turbine is driven by the high-pressure steam from the water which is heated by several means and using various sources of fuels such as by the burning of fossil fuels (petroleum, natural gas, coal), geothermal power, nuclear fission and also using heat from the solar energy.

Steam power plant operates on Rankine cycle. Water that enters the boiler is heated to create steam to rotate the turbine which will generate electricity through the generator attached to the turbine shaft. The steam exiting the turbine will go into a condenser to be condensed into saturated water which will then be pumped into the boiler to repeat the process. **Figure 1.3** shows the processes and equipment involved in power generation using a steam power plant.

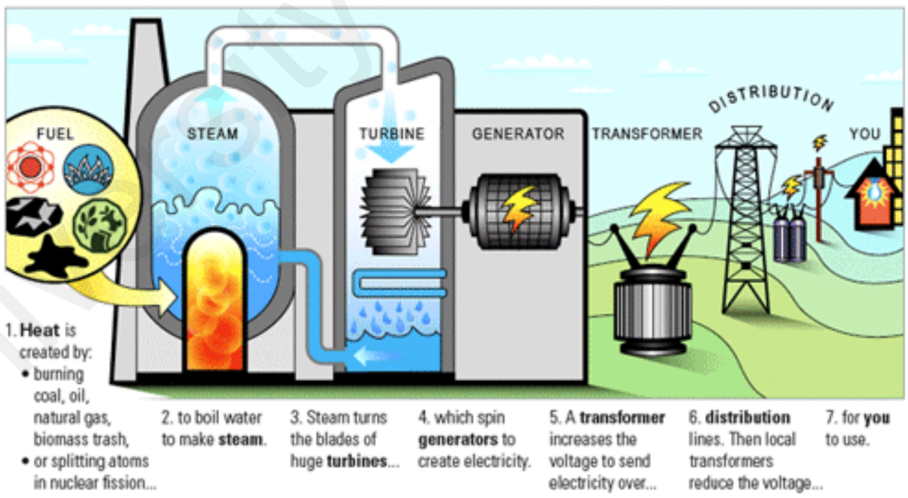

Figure 1.3: Processes in Power Generation Using Steam Power Plant

1.2 Problem Statement

Although there are already numerous researches and works on power generation using renewable energies, there is still a need for the operator of the non-renewable power plant to play their role in addressing the concern on global warming and the depletion of fossil fuel source since the majority of power generation worldwide still rely on fossil fuels. One of the ways is by improving the overall efficiency of a steam power plant which can be achieved by making sure that the steam along the pipeline before entering the turbine is maintained at high quality so that more kinetic energy will be transferred to the turbine for higher power generation at higher overall efficiency.

1.3 Objective

The objectives of the project are:

i. To study the steam condensation or the steam temperature changes along the pipeline between the boiler and the turbine
ii. To study the effect of boiler and turbine pressure to steam quality, power output of turbine & mechanical efficiency of turbine
iii. To study the effect of turbine inlet temperature to turbine mechanical efficiency

1.4 Scope

The scope of the project acts as a guideline to ensure the project is conducted within its intended boundary. The scopes are as follows:

i. Steam flow in the power plant will be until the turbine section with the valve for the steam flow to the condenser closed and the steam released to the atmosphere
ii. The power plant is considered as an experimental small-scaled plant therefore the result may not be compared to full-scaled power plant
iii. Changes of steam quality is due to energy loss and condensation along the piping system.

1.5 Organization of the Report

This report consists of six chapters. Chapter 1 is Introduction that describes introduction to the study, problem statement, objectives, scopes, and the organization of the report. Chapter 2 is the Literature Review section that describes the literature relevant to the topic of study which is the behavior of steam along the pipeline and its effect on the performance of the power plant, which include relevant and recent publications of works that states the information on theories, techniques and findings of the work. Chapter 3 is the Methodology section which describes the procedure of the experiments, the parameter involved and any related information regarding the experiment that is used to obtain the results and generate the findings of the report. Chapter 4 is the Results and Discussion section that contains all the results obtained from the experiments which is presented in tables and figures, along with the data analysis which discussed the experiment result and also compared the findings with previous study and the theories presented in the literature review. Chapter 5 is the Conclusion section that summarized the findings from the study and also some recommendations for future work.

CHAPTER 2: LITERATURE REVIEW

2.1 Components of a fossil-fueled steam power plant

Steam power plants generate power by conversion of chemical energy (fuel) into kinetic (heat) and followed by the conversion into mechanical energy (turbine) and finally into electrical energy (generator). **Figure 2.1** shows the basic components of a fossil fueled steam power plant.

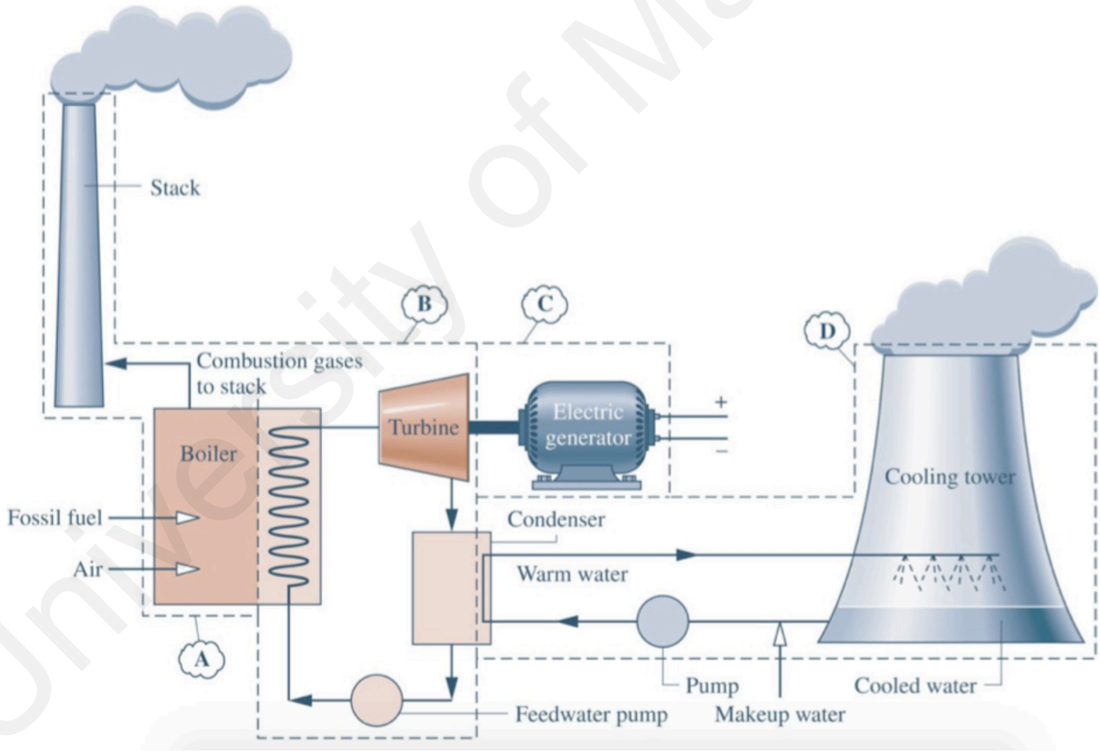

Figure 2.1: Main components of a fossil fueled steam power plant

(Moran et al., 2014)

The power plant components can be divided into four sub-systems which can be represented as a sub-system by the letter A, B, C and D. The function of sub-system A is to supply the energy required to vaporize the working fluid used in the power plant. In this sub-system A, the working fluid, which is usually the water, is heated up by the combustion of the fuel to turn it into vapor which is then will be directed towards the turbine (sub-system B) to generate energy. The turbine is connected to an electric generator (sub-system C) with a shaft to convert the mechanical energy of the turbine into electrical energy. After the expansion process in the turbine, the steam will be condensed in the condenser by releasing heat to the cooling system. The cooling water that has absorbed heat from the steam in the condenser will be transferred to the cooling tower to be cooled again by releasing the heat to the atmosphere and will return back to the condenser to repeat the cooling process. Finally, the cooled steam which has turned into condensate will be pumped back into the boiler to repeat the process of generating power (Moran et al., 2014).

2.2 The thermodynamic cycle of a steam power plant

The fundamentals for the thermodynamic analysis of a power plant include the principles of conservation of mass and energy, and the second law of thermodynamics which apply to each component of the power plant such as the pumps, turbine, heat exchanger, as well as the overall power plant.

A steam power plant basically operates on Rankine cycle. **Figure 2.2** shows the schematic diagram of a basic power plant and ideal Rankine cycle as a temperature-entropy (T-s) diagram.

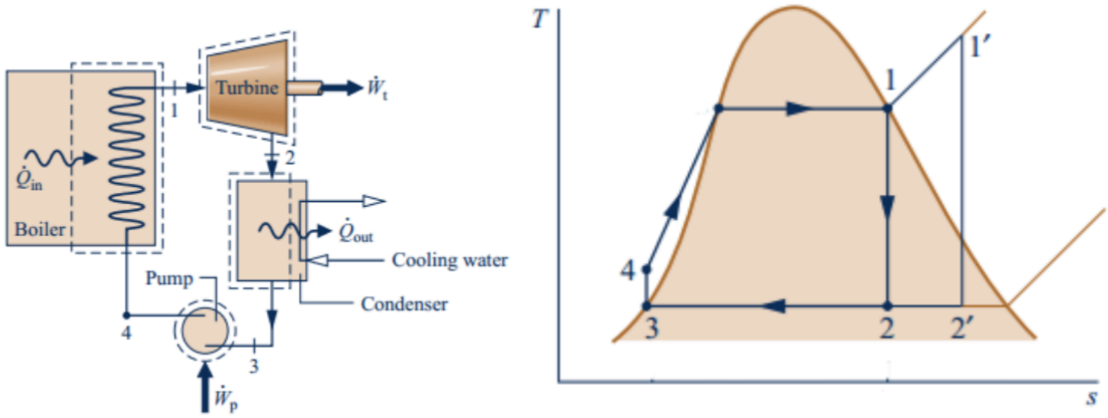

Figure 2.2: Schematic diagram and T-s diagram of an ideal Rankine cycle

(Moran et al., 2014)

An ideal Rankine cycle is represented by process 1-2-3-4 on the diagram with the assumptions that the cycle is irreversible, the boiler and condenser experience no pressure drop, and the processes in the turbine and pump are isentropic. There are four processes underwent by the working fluid as listed below (Moran et al., 2014):

- Process 1-2: Saturated steam from the boiler at state 1 expands isentropically through the turbine until it reached the condenser pressure at state 2
- Process 2-3: The steam losses its heat at constant temperature and pressure in the condenser and turned into saturated liquid at state 3
- Process 3-4: The saturated liquid in the condenser is compressed in the pump isentropically to state 4 until it reached the boiler pressure
- Process 4-1: The working fluid is heated at constant pressure in the boiler until state 1 which means it has reached dry saturated steam state to complete the cycle

2.3 Superheating the steam to high temperature

Some of additional components can be used to increase the power plant's efficiency and power output. One of it is by superheating the steam coming from the boiler to increase the average temperature of the steam. Dry saturated steam from the boiler will pass through a heat exchanger tubes which is called the superheater to raise the steam temperature until it reached the required temperature. This will increase the quality of the steam supplied to the turbine which will result in higher steam quality at the turbine exit and higher power plant efficiency and it can also prevent water droplets from forming inside the turbine which can deteriorate the turbine and affect the turbine's life. The process of superheating the steam is represented as the process 1'-2'-3-4 in **Figure 2.3**.

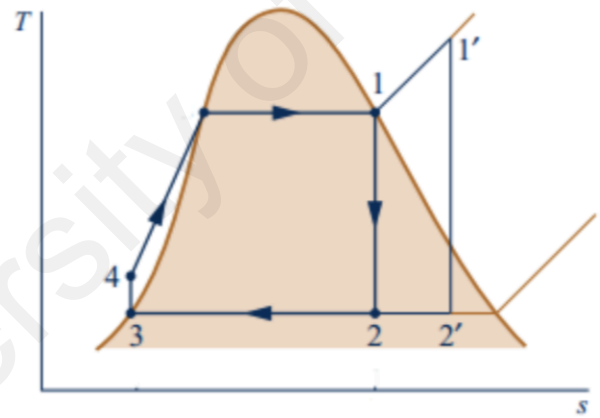

Figure 2.3: T-s diagram of superheated Rankine cycle

2.4 Definition of steam quality

Steam quality is described by its dryness fraction, which is the proportion of saturated steam in a saturated condensate and steam mixture. The steam will be called "wet steam" if water droplets are present in the steam. A steam quality of 0.90 indicates a mixture of 90% steam and 10% of liquid. The formula to determine the dryness fraction is as shown below (Merritt, 2015):

$$Dryness\ fraction, x = \frac{Mass\ of\ steam, m_s}{Mass\ of\ steam, m_s +\ Mass\ of\ water, m_w}$$

Temperature, pressure and entrained liquid content need to be measured in order to obtain the steam quality value. The higher the temperature, the more energy which is called latent heat is carried by the steam which will result in faster rotation of turbine.

2.5 Effect of steam quality to the life of turbine blade

There have been many researches on water droplet erosion of steam turbine blade in the past few decades. Continuous research efforts have been made to attempt to mitigate the impact of this complex phenomenon. The problem of water droplet erosion is encountered by many industries dealing with steam pipeline which include pharmaceutical industries on the pipeline connections and elbows for its sterilization steam line and also power generation industry using steam turbine. In steam turbine, the last turbine or the low-pressure turbine blades are the one that will be most affected by the mist droplets that were formed during steam expansion process (Lee et al., 2003). The schematic for the formation of water droplets that leads to erosion of steam turbine blade is shown in **Figure 2.4**.

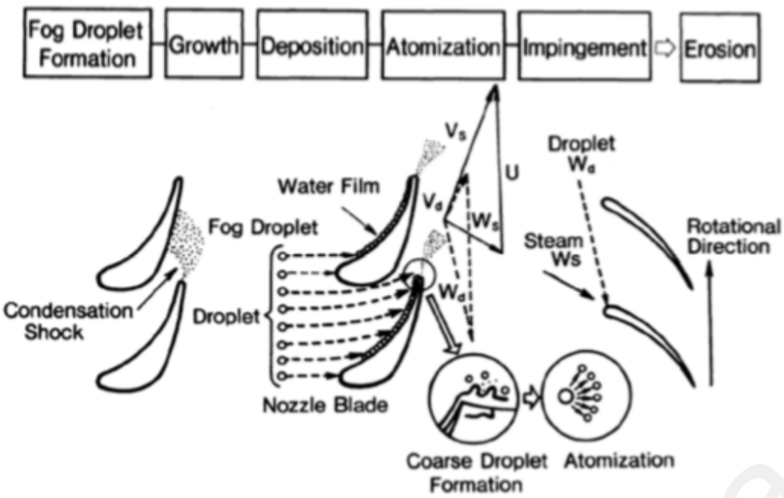

Figure 2.4: Schematic for the formation water droplet on steam turbine blade

(Yasugahira et al., 1990)

There are several stages that will be went through by the water droplet before it starts to damage or destroy the rotating turbine blade. The water droplet will first be in the form of mist droplets with the size of between 0.1 to 4 μm which will deposit on stationary blades. By coalescence, bigger droplets with typical size of 1mm will be formed at the tip of the leading edges as the water droplets departed the stationary blades. The coarse droplets finally will atomize into smaller droplets with the size of between 10 to 400 μm before they flow along with the steam impinging the successive rotating blades, which will lead to erosion (Kirols et al., 2017).

2.6 Effect of steam quality to the problem of steam/water hammer

As soon as steam leaves the boiler, the steam will lose its energy and starts to condensate although it usually occurs in low intensity. However, during start up when the pressure is still low, the situation can get more intense during the initial supply of steam.

With the increasing length of pipe, the tiny droplet of condensate can build up and eventually becomes a mass of liquid as depicted in **Figure 2.5**.

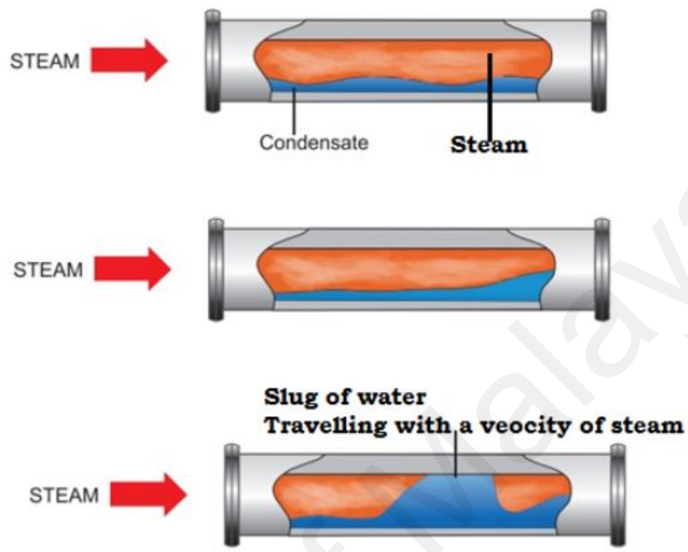

Figure 2.5: Formation of slug of water in pipe

Water hammer occurs when the flow of water that is formed in the steam is suddenly stopped by a change of direction in a pipe, such as a pipe bend or tee, a fitting or valve, or the pipe surface itself. The velocities of water can be much higher than the velocity of steam, especially when water droplets start to form during start up. When these velocities are obstructed by a sudden impact, the water kinetic energy will be converted into pressure energy, and the pressure shock will abruptly be applied to the obstruction. In mild water hammer effect, there will be noise and also some vibration of the pipe. However, in more severe water hammer effect, it can cause the pipe and fittings to fracture or even explode, and eventually letting the steam escape from the pipe through the fractured or exploded part. These fracturing and explosion could potentially cause injuries, property damage or even loss of life (Sarco, 2011).

2.7 Effect of turbine inlet temperature to turbine work / power output

Saturated steam or steam that is completely gaseous and contains no liquid means the steam carries higher latent energy that can be released during the steam expansion stage which will result in more powerful turbine rotation. The faster the turbine rotation, the higher is the energy generated by the electrical generator. This theory is agreed upon by the experiment carried out by (Rout et al., 2013). Experiments were done on three different cycles – regenerative cycle, superheater cycle, and cogeneration cycle to study the effect of turbine inlet temperature to the turbine power output, thermal efficiency, and specific steam consumption. From the experiments on superheater cycle, it can generally be concluded that the increase in inlet turbine temperature will result in increase of turbine power output and thermal efficiency. **Figure 2.6** shows their result for the effect of increasing turbine inlet temperature to the power output of turbine and **Figure 2.7** shows its effect on the thermal efficiency of the power plant.

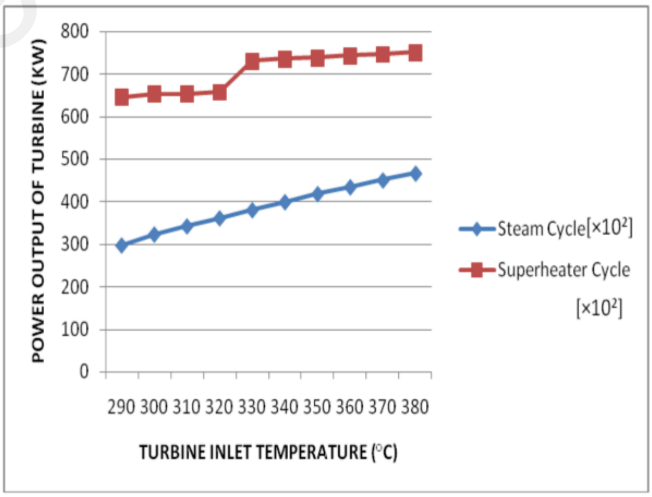

Figure 2.6: Effect of turbine inlet temperature to power output of turbine

(Rout et al., 2013)

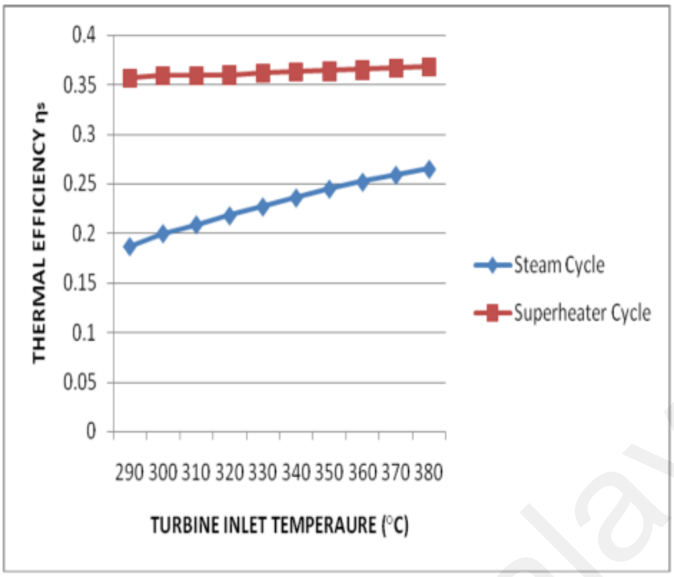

Figure 2.7: Effect of turbine inlet temperature to thermal efficiency

(Rout et al., 2013)

Another analysis by (Hussain et al., 2014) on a steam power plant in Kuwait also shows that the efficiency of power plant and turbine work were enhanced when inlet turbine temperature increases which can be seen from **Figure 2.8.** They also stated that increasing the turbine inlet temperature gives more significant effect in increasing the thermal efficiency and turbine work output compared to increasing the turbine inlet pressure.

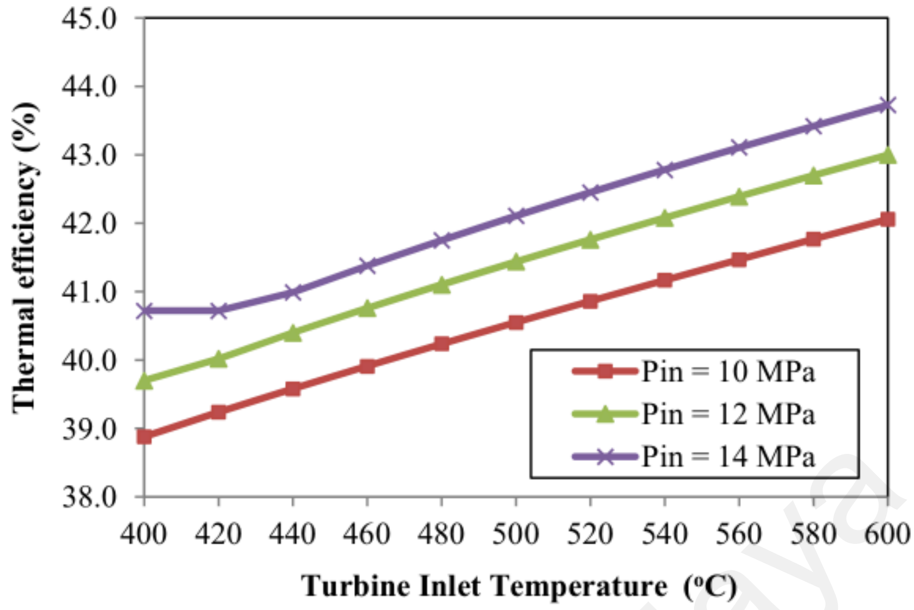

Figure 2.8: Effect of turbine inlet temperature to thermal efficiency

(Hussain et al., 2014)

2.8 Condensation of steam

Steam condensation will begin as soon as the steam leaves the boiler and the rate of condensation will depend upon the temperature of the steam, the ambient temperature, and the pipe insulation efficiency. In most application, the pipeline between the boiler and the turbine are insulated to prevent or minimize heat losses to the surroundings. The heat loss in the pipework between the boiler and the plant equipment should not exceed 5% of the total heat content of the overall system if the system is insulated to the current standard (Sarco, 2011).

The determination of heat loss in the pipeline is a complex task due to the variability in the parameters involved. Firstly, the convection heat transfer inside the steam pipeline is significantly influenced by the structure of the pipeline and the mass flow distribution of the steam. Secondly, the conduction heat transfer of the pipeline will be greatly affected by the material of the pipe, the material of the cladding and the insulation on the pipeline. Thirdly, the convection heat transfer outside the pipeline will be influenced by the variable condition of the environment (Zhu et al., 2013).

An experiment to study the heat loss in insulated pipe by (Stubblefield et al., 1996) suggests that the insulation material and also the contact resistance will contribute to affect the thermal resistance of a steam pipe. In this experiment, 1 inch calcium-silicate with a thermal conductivity of 0.071 W/m.K and fiberglass with a thermal conductivity of 0.05 – 0.06 W/m.K were compared as an insulation on a 2-inch pipe (inner nominal diameter) and it was observed in **Figure 2.9** that the fiberglass gives better thermal resistance on the overall piping system which means it does better job in reducing the heat loss in a steam pipe.

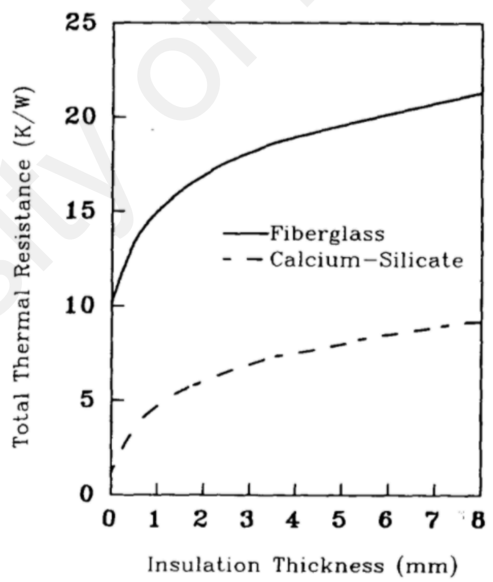

Figure 2.9: Comparison of fiberglass and calcium silicate as insulation material

(Stubblefield et al., 1996)

A simulation study done by (Zhu et al., 2013) shows that heat loss in the steam pipeline reduced significantly with the increase in the thickness of insulation which can be seen from **Figure 2.10**. The results also suggest that an insulation of about 20mm is recommended to improve the conduction resistance of the pipeline.

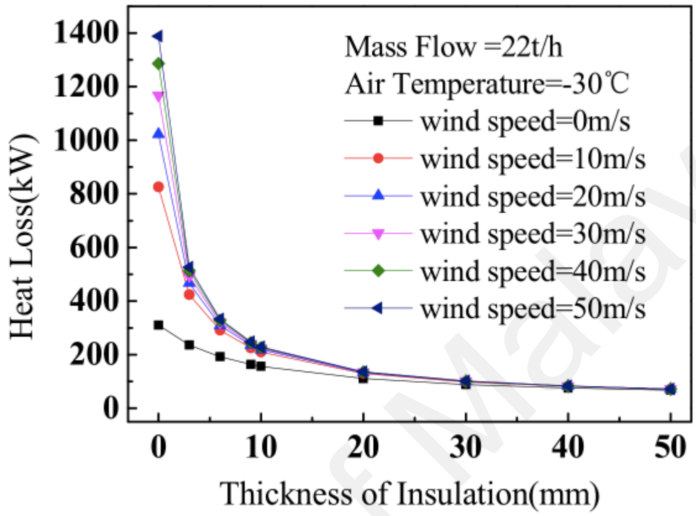

Figure 2.10: Effect of insulation thickness to heat loss in pipe

(Zhu et al., 2013)

CHAPTER 3: METHODOLOGY

3.1 Experimental Setup

A schematic diagram of the power plant is shown in **Figure 3.1**.

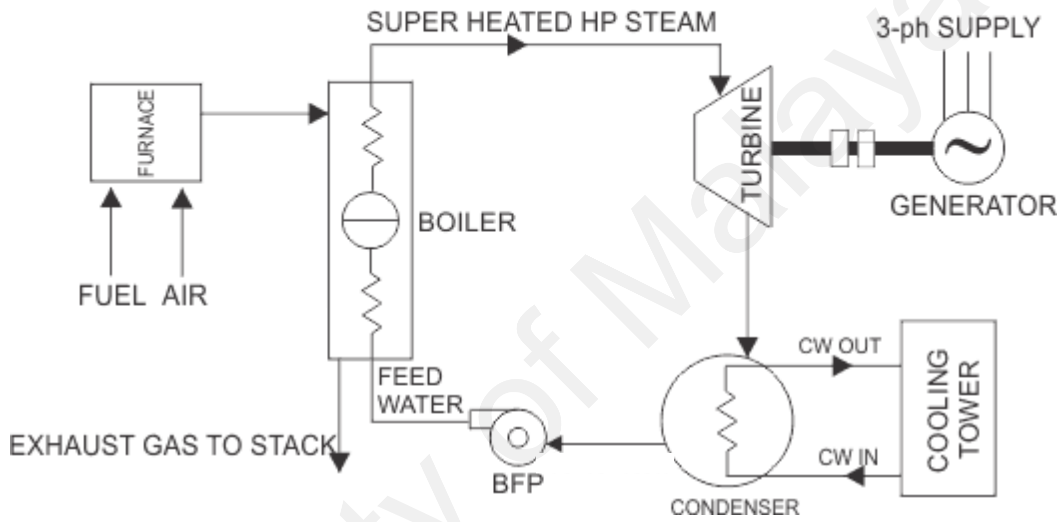

Figure 3.1: Configuration of the actual power plant

Water that enters the boiler is heated to create steam to rotate the turbine which will generate electricity through the generator attached to the turbine shaft. In actual power plant, the steam exiting the turbine will go into a condenser to be condensed into saturated water which will then be pumped into the boiler to repeat the process. However, in this experiment which is performed in an experimental power plant, the valve to the condenser is closed to restrict the flow of steam into the condenser and instead the steam was released to the atmosphere through a separate pipeline. Water droplet is collected in a small beaker for the purpose of measuring the steam quality at the turbine outlet. The temperature along the steam line were measured using a thermocouple that is manually placed at four different locations between the boiler and the turbine **(Figure 3.2)**. The readings of the thermocouples were averaged over a period of 20s.

All the experiments were conducted at almost uniform ambient temperature. After the boiler and the condenser is turned on, the required steam flow rate is adjusted and maintained at 420 kg/h. At initial stage, the boiler pressure is set to maintain at 5 bar and the turbine pressure is set at 2 bar to allow the system to warm up until steady-state condition is achieved. The experiments were run for about 90 minutes in order to achieve a good data recording under seven test conditions. Two parameters were adjusted for the different test conditions which are the boiler and turbine pressure while the steam flow rate is maintained at 420 kg/h. After the steady-state condition established, the readings of the temperature at 4 different locations were measured using a thermocouple, the turbine speed fluctuation was recorded from the value displayed, and the water droplet were collected at the end of each test point which last for 10 minutes for the first four test conditions and 5 minutes for the last three test conditions.

Figure 3.2: Location of temperature measurement

3.2 Experimental Conditions & Accuracies

The temperature readings were estimated to have an uncertainty of ±0.2°C since the thermocouple was calibrated with an accuracy of ±0.1°C. The water droplet weight readings are about ±0.2mg which is the weighing scale accuracy.

CHAPTER 4: RESULTS AND DISCUSSIONS

Experiments under a total of 7 test conditions were carried out in order to analyze the behavior of the steam along the steam pipeline between the boiler and the turbine, the effect of boiler and turbine pressure to turbine inlet temperature and steam quality, and the effect of turbine inlet temperature to the steam quality and turbine rotation.

Details of the experiments including the total mass of diesel consumed has been measured and calculated which is shown below while the results of the experiments are tabulated in **Table 4.1**.

Total experiment time:	90 min
Diesel consumption:	25L
Diesel calorific value:	45.5 MJ/kg
Diesel density:	0.832 kg/L
Mass of Diesel Used:	20.8 kg
Total Heat:	946.4 MJ
Total Heat Input:	175.259 kW
Rate of Heat Input:	116.84 kWh
Steam Flow Rate:	420 kg/h

Table 4.1: Experiment result

TEST NO.	PRESSURE (bar)		Temperature (°C)				Turbine Speed (RPM)	Water Droplet Weight (g/min)
	Boiler, P1	Turbine, P2	Boiler Outlet, T1	Superheater Inlet, T2	Superheater Outlet, T3	Turbine Inlet, T4		
1	5	2	133	118	124	120	615	0.72
2	7	2	122	120	125	135	1200	1.18
3	7	3	137	134	136	140	2300	2.8
4	7	4	141	139	142	148	2850	10.16
5	8	2	130	128	132	135	1300	2.22
6	8	3	136	135	138	143	2400	6.0
7	8	4	145	140	146	150	2900	22.2

4.1 Changes of temperature along the steam pipeline

Table 4.2 and **Figure 4.1** shows the experimental data for the temperature at all four locations along the steam pipeline under 7 test conditions. The first location is after boiler exit, followed by inlet and outlet of the superheater, and last location is at the turbine inlet.

Table 4.2: Temperature of steam along the steam pipeline

	Pressure (bar)		Temperature (°C)			
Test No.	Boiler, P_1	Turbine, P_2	Boiler Outlet, T_1	Superheater Inlet, T_2	Superheater Outlet, T_3	Turbine Inlet, T_4
1	5	2	133	118	124	120
2	7	2	122	120	125	135
3	8	2	130	128	132	135
4	7	3	137	134	136	140
5	8	3	136	135	138	143
6	7	4	141	139	142	148
7	8	4	145	140	146	150

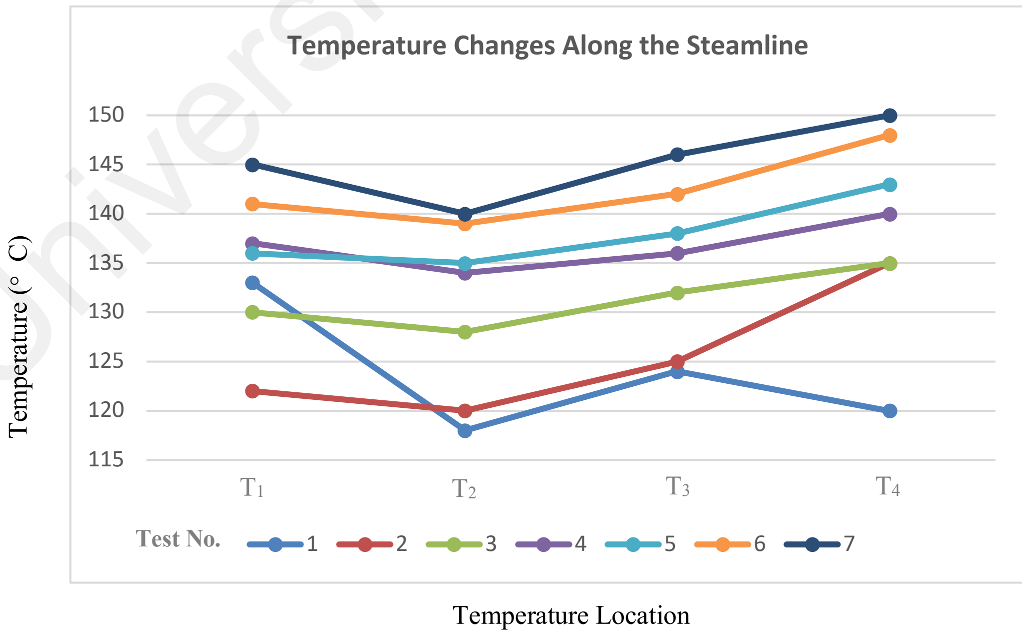

Figure 4.1: Temperature of steam along the steam pipeline

Figure 4.1 depicts that the temperature of the steam starts decreasing after the steam leaves the boiler until before it enters the superheater, and after the steam is superheated, the temperature keeps increasing until before the steam enters the turbine. When the steam leaves the boiler, the temperature starts to drop due to steam condensation or heat transfer to the surrounding and also due to pressure drop along the pipeline. The closer the steam to the turbine inlet, the stronger the effect of the turbine pressure is to the steam which results in higher temperature of steam. This finding however, is not applied to the first test run with the assumption that the power plant did not achieve the steady-state condition yet.

4.2 Effect of boiler and turbine inlet pressure to the steam quality

The experiment was carried out by manipulating the pressure of the boiler and the inlet of turbine. The boiler pressure was set at three different values which were at 5, 7 and 8 bars, while the turbine inlet pressure was set at 2, 3 and 4 bars. The experimental result is tabulated in **Table 4.3** and the graph for the effect of these pressure values is depicted by **Figure 4.2**.

Table 4.3: Effect of boiler and turbine pressure to steam quality

Test No.	Boiler Pressure (bar)	Turbine Pressure (bar)	Steam Quality
1	5	2	0.9999
2	7	2	0.9998
3	7	3	0.996
4	7	4	0.9985
5	8	2	0.9997
6	8	3	0.9991
7	8	4	0.9968

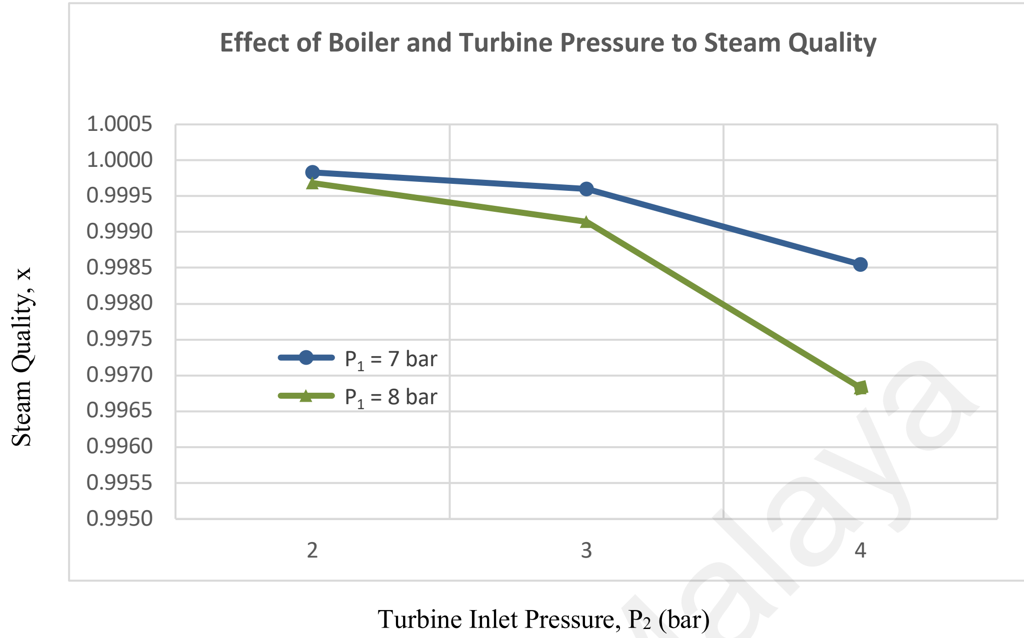

Figure 4.2: Effect of boiler and turbine pressure to steam quality

It can be observed that the steam quality decreased when the turbine inlet pressure increased. This is due to the increased restriction on the steam flow as the valve opening to the turbine inlet was made smaller to achieve higher pressure. It can also be observed that steam quality is higher when the boiler pressure is lower.

4.3 Effect of boiler and turbine inlet pressure to the power output of turbine

The effect of boiler and turbine inlet pressure to the power output of turbine is tabulated and shown in **Table 4.5** and **Figure 4.4** respectively.

Table 4.4: Effect of boiler and turbine pressure to the power output of turbine

Test No.	Boiler Pressure (bar)	Turbine Pressure (bar)	Power Output (kW)
1	5	2	0.5363
2	7	2	1.0465
3	7	3	2.0058
4	7	4	2.4855
5	8	2	1.1337
6	8	3	2.0930
7	8	4	2.4419

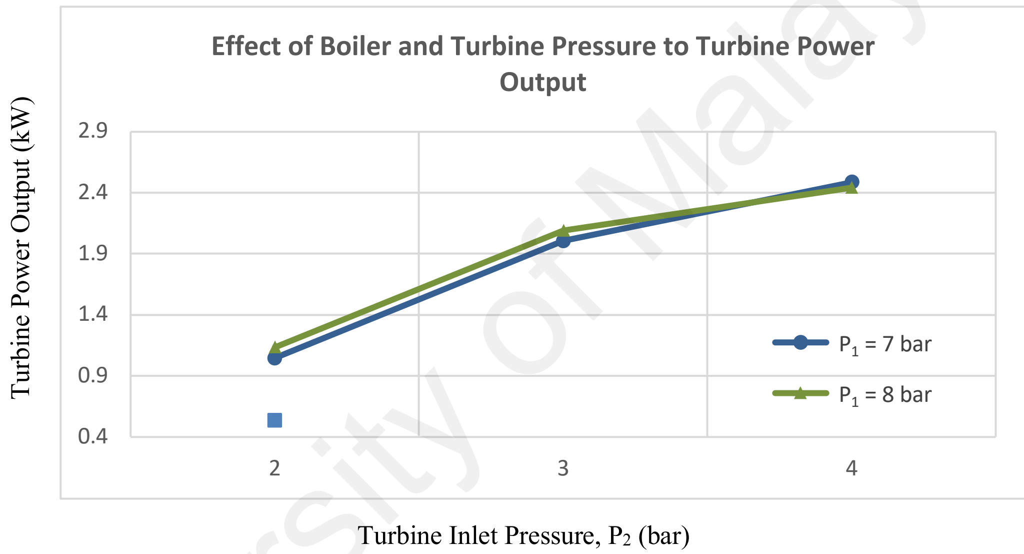

Figure 4.3: Effect of boiler and turbine inlet pressure to the power output of turbine

From the experimental result, it can be said that from this experiment that the power output of turbine increased when both the boiler and turbine inlet pressure increased. Since turbine inlet temperature will increase when turbine inlet pressure is increased, this result agrees well with the work of (Rout et al., 2013) who concluded from their experiment that the power output of turbine increased when turbine inlet temperature increased.

4.4 Effect of boiler and turbine inlet pressure to mechanical efficiency of turbine

Table 4.5: Effect of boiler and turbine pressure to the mechanical efficiency

Test No.	Boiler Pressure (bar)	Turbine Pressure (bar)	Mechanical Efficiency
1	5	2	17.89
2	7	2	34.90
3	7	3	66.88
4	7	4	82.88
5	8	2	37.80
6	8	3	69.79
7	8	4	81.42

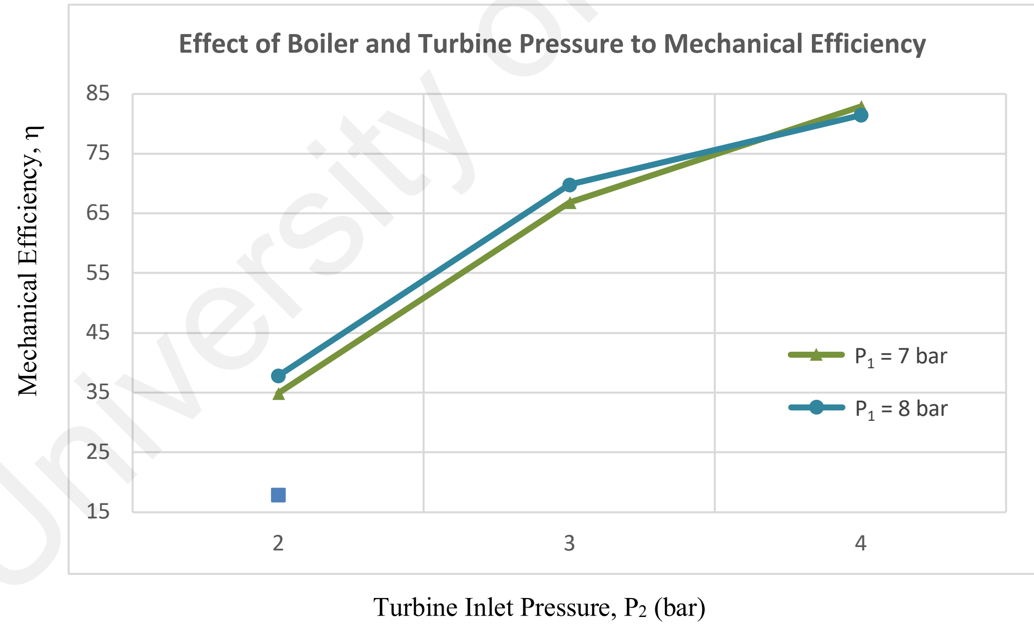

Figure 4.4: Effect of boiler and turbine inlet pressure to the mechanical efficiency

From the trend shown in **Figure 4.4**, it can also be observed that the increase in turbine inlet pressure will result in the increase in mechanical efficiency of the turbine.

4.5 Effect of turbine inlet temperature to mechanical efficiency

Turbine inlet temperature experimental result is sorted from the lowest to the highest to see its effect on the turbine mechanical efficiency. The experimental result can be seen from **Table 4.6** and **Figure 4.5**.

Table 4.6: Effect of turbine inlet temperature to mechanical efficiency

Turbine Inlet Temp. (°C)	Mechanical Efficiency
120	17.88
135	37.80
140	66.88
143	69.79
148	82.87
150	81.42

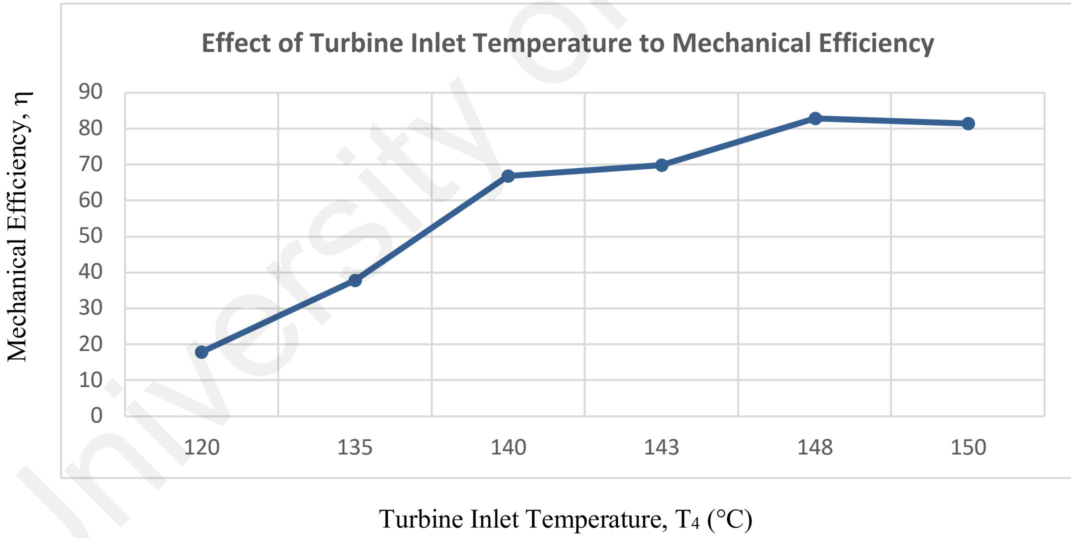

Figure 4.5: Effect of turbine inlet temperature to turbine mechanical efficiency

It can be observed from the graph that the mechanical efficiency increased as the turbine inlet temperature increased. This once again agrees with the work by (Rout et al., 2013) and also (Hussain et al., 2014) which stated that the turbine efficiency increase when the turbine inlet temperature increased.

CHAPTER 5: CONCLUSION

In this study, experiments with a total of 7 test conditions on an experimental steam power plant with a superheater has been conducted, and analysis of the steam in the pipeline have been carried out. It can be stated that turbine inlet temperature played a very vital role on the power plant performance in terms of the steam quality and the power output of the turbine. Thus, the conclusions that can be drawn from the experiment are summarized into the following points:

i. The temperature of the steam decreased as it leaves the boiler due to steam condensation or heat transfer to the surrounding. The steam achieved a higher temperature after it was superheated and the temperature keeps increasing due to the effect of turbine pressure at the inlet of the turbine.
ii. The steam quality decreased when the turbine inlet pressure increased. This is due to the increased restriction on the steam flow as the valve opening to the turbine inlet was made smaller to achieve higher pressure. It can also be observed that steam quality is higher when the boiler pressure is lower.
iii. The power output of turbine increased when both the boiler and turbine inlet pressure increased.
iv. The increase in turbine inlet pressure will result in the increase in mechanical efficiency of the turbine.
v. The mechanical efficiency increased as the turbine inlet temperature increased.

For future work, it is suggested to carry out the experiments in a complete basic cycle of a power plant which include the condenser and also conducting the experiment by manipulating the superheater temperature at constant boiler and turbine inlet pressure.

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