EFFECT OF CONDENSER CONDITIONS ON PERFORMANCE OF A STEAM POWER PLANT

by

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CERTIFICATION OF APPROVAL

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September 2012

CERTIFICATION OF ORIGINALITY

This project 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 reference and acknowledgments, and that the original work contained herein have not been undertaken or done by un- specified sources or persons.

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Syed Haider Ali Shah

ABSTRACT

The need for electrical energy will certainly continue to grow, and it has become imperative to lower cost of electricity and enhance the operational economy of the power plant. Most of the electricity being produced throughout the world today is from steam power plants and improving the performance of power plant is a trending topic. The conventional steam power plant working under the Rankine cycle and the steam condenser as a heat sink and the steam boiler as a heat source have the same importance for the power plant operating process. Energy efficiency of the thermal power plant strongly depends on its turbine-condenser system operation mode. The cold end conditions of condenser are of the great influence on the maximum generated power and heat rate value. In this project, an endeavor has been made to study the condenser; different variables which affect the performance of condenser, various energy losses while condensation and impact on overall performance of steam power plant.

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NOMENCLATURES

h_1 – Enthalpy at Inlet of turbine [KJ/Kg]

h_2 – Enthalpy at exit of turbine/inlet of condenser [KJ/Kg]

h_3 – Enthalpy at exit of condenser/inlet of pump [KJ/Kg]

h_4 – Enthalpy at exit of pump [KJ/Kg]

Pc – Total Condenser pressure [bars]

Ps – Saturation pressure at measured condenser temperature [bars]

Pa – Partial pressure of air [bars]

v = circulating cold water velocity in tubes inlet (m/s)

C_1 = dimensionless factor depending upon the tube outer diameter

C_2 = dimensionless correction factor for circulating water inlet temperature

C_3 = dimensionless correction factor for tube material and gauge

Q – Condenser heat transfer rate [kW]

m_w – Cooling water flow rate [kg s^{-1}]

m_c – Steam flow rate through condenser [kg s^{-1}]

v – Velocity of cooling water [ms^{-1}]

t_c – Condensing temperature [ºC]

t_{w2} – Cooling water outlet temperature [ºC]

t_{w1} – Cooling water inlet temperature [ºC]

U_o – Heat transfer coefficient [$kWm^{-2}K^{-1}$]

Δt_m – Log mean temperature difference [ºC]

A – Heat transfer surface [m^2]

C_w – Specific heat of water [KJ/KgK]

CHAPTER 1

INTRODUCTION

1.1 Background

Most of the electricity being produced throughout the world today is from Thermal power plants and improving the performance of power plant is a never ending subject. The need to increase the energy efficiency is a trending topic of the present times. Most power plants that use a heat-generating fuel as the power source use a steam cycle referred to as a "Rankine cycle," in which water is heated into steam in a boiler and the steam is then passed through a turbine.

The Rankine cycle is the standard for steam power plants that are built around the world. The basic Rankine cycle consists of four main components: Steam Generator, Turbine, Steam Condenser and Pump.

The actual Rankine cycle used in a modern steam power plant has many more components, but the above components are common to all power plants. In this cycle, water is heated in the steam generator to produce a high temperature and high pressure steam. This steam is expanded in a turbine connected to an electricity generator. The exit steam from the turbine is condensed back to water in the **condenser.** The pump then returns the water to the steam generator. Thus, the main purpose of the condenser is to condense the exhaust steam from the turbine for reuse in the cycle, and to maximize turbine efficiency by maintaining a proper vacuum.

Condenser performance and reliability have a significant impact on the electric generation of a power plant. Basically, a condenser is a device where steam condenses and latent heat of evaporation released by the steam is absorbed by cooling water.

By monitoring the condenser conditions the performance of the power plant can be optimized.

1.2 Problem Statement

The optimal values of energy efficiency or heat rate for power plants depend on the proper functioning of all systems and equipment. Within these systems one of particular importance is the condenser and performance deviation or malfunction of system component can significantly affect the overall efficiency of the whole unit. The overall efficiency of a steam/thermal power plant is strongly influenced by the performance of its condenser(s). Poor condenser performance results in thermodynamic losses and thus reduces the profitability of the power plant Research should be done to study the various availability loss components in the condenser. An example of such deviations is the high absolute pressure of the condenser due to one of the following factors: fouling of tubes, air in-leakages, and excessive thermal load from steam turbine exhaust, low water flow rate and high water temperature at entrance, among others.

1.3 Objectives and Scope

- To understand different types of condensers used in power plants.
- Analysis of different parameters/variables affecting the performance of steam power plant condensers.

- Performance analysis of condenser on the efficiency of steam power plant.
- Optimal use of condensers and reduction of the energy losses in order to increase the efficiency of steam power plants.

CHAPTER 2

LITERATURE REVIEW

Much of the electricity used in the world is produced in steam power plants. Despite efforts to develop alternative energy converters, electricity from steam will continue, for many years, to provide the power that energizes the world economies. Need for electrical energy will certainly continue to grow, and it has become imperative enhance the operational economy to lower the cost of electricity [2].The conventional steam power plant working under the Rankine Cycle, the steam condenser as a heat sink and the steam boiler as a heat source have the same importance for the power plant operating process.

The Rankine cycle is standard for steam power plants around the world. The common Working Fluid is water. The ideal cycle consists of four processes as shown in Figures 1. [5].

1 to 2: Isentropic expansion (Steam turbine): An isentropic process, in which the entropy of working fluid remains constant.

2 to 3: Isobaric heat rejection (Condenser): An isobaric process in which pressure of working fluid remains constant.

3 to 4: Isentropic compression (Pump): During the isentropic compression process, external work is done on the working fluid by means of pumping operation.

4 to 1: Isobaric heat supply (Steam Generator or Boiler): During this process, the heat from the high temperature source is added to the working fluid to convert it into superheated steam.

According to the T-S diagram shown in Figure 1, the work output W_1 during isentropic expansion of steam in the turbine, and the work input W_2 during isentropic compression of working Fluid in Pump are:

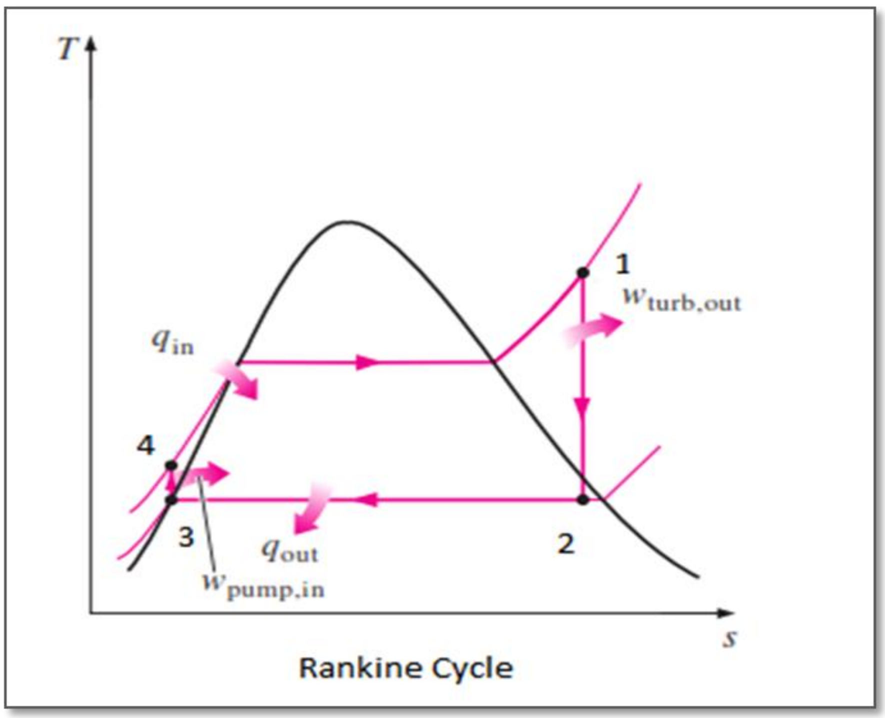

Figure 1 T-S Diagram of a Rankine Cycle

$W_1 = m\,(h_1 - h_2)$

$W_2 = m\,(h_4 - h_3)$

Where m is the mass flow of the cycle and h_1, h_2, h_3, h_4 is enthalpy.

Heat supplied to the cycle (steam generator or boiler) Q_1, and heat rejected from the cycle (condenser) Q_2, are:

$$Q_1 = m\,(h_1 - h_4)$$
$$Q_2 = m\,(h_2 - h_3)$$

The basic Rankine cycle used in a steam power plant consists of the following main components: 1. Steam generator; 2. Turbine; 3. Steam condenser; and 4. Pump. Figure 1 represents the key components of a thermal power plant working on a Rankine cycle and the pressure volume relation of condensing fluid i.e. steam. The actual Rankine cycle used in a modern steam power plant has many more components, but the above components are common to all power plants [4]. In this cycle water is heated in the steam generator to produce a high temperature and high pressure steam. This steam is expanded in a turbine connected to an electricity generator. The exit steam from the turbine is condensed back to water in the condenser. The pump then returns the water to the steam generator. Thus, the main purpose of the condenser is to condense the exhaust steam from the turbine for reuse in the cycle, and to maximize turbine efficiency by maintaining a proper vacuum [5].

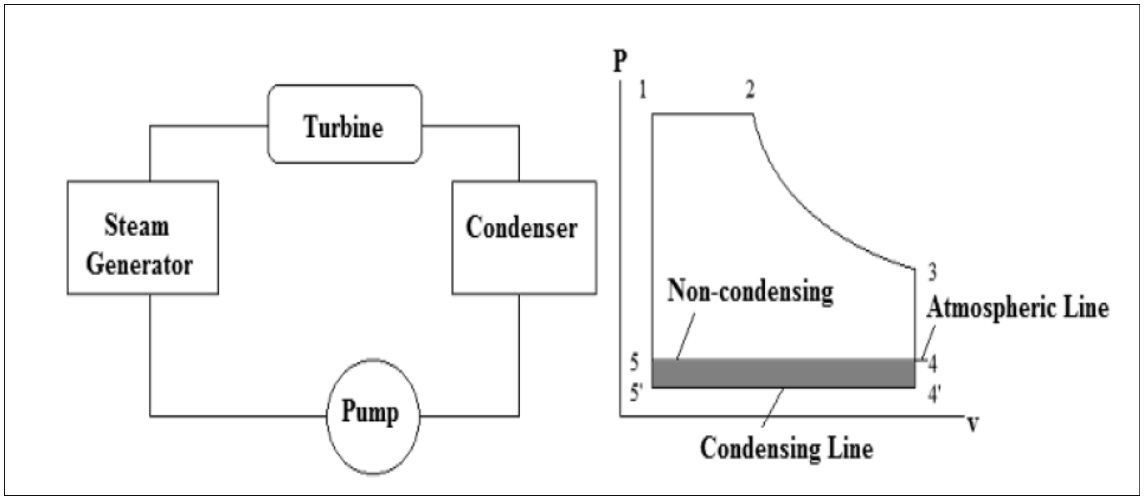

Figure 2 Key Components of a Rankine Cycle

2.1 Working Principal of Condenser

Basically, a condenser is a device where steam condenses and latent heat of evaporation released by the steam is absorbed by cooling water. Thermodynamically, it serves the following purposes with reference to the P-v diagram shown in Figure 2. It maintains a very low back pressure on the exhaust side of the turbine. As a result, the steam expands to a greater extent and consequently results in an increase in available heat energy. The shaded area shown in the P-v diagram exhibits the increase in the work obtained by fitting a condenser unit to a non-condensing unit for the same available steam properties [2]. The efficiency of a condenser unit is higher than a non-condensing unit. [5]

Steam turbines extract power from steam as the steam passes from high pressure and high temperature conditions at the turbine inlet to low pressure and lower temperature conditions at the turbine outlet. Steam exiting the turbine goes to the condenser, where it is condensed to water. The condensation process is what creates the low pressure conditions at the turbine outlet. The steam turbine outlet or exhaust pressure (which is often a partial vacuum) is a function of the temperature maintained at the condensing surface (among other factors) and the value of the exhaust pressure can have a direct effect on the energy available to drive the turbine. The lower the exhaust pressure, the greater the amount of energy that is available to drive the turbine, which in turn increases the overall efficiency of the system since no additional fuel energy is involved [13].

There are **two primary types of condensers** that can be used in a power plant:

i. Direct contact or jet condenser
ii. Surface condenser

Steam surface condensers are the most commonly used condensers in modern power plants [2].

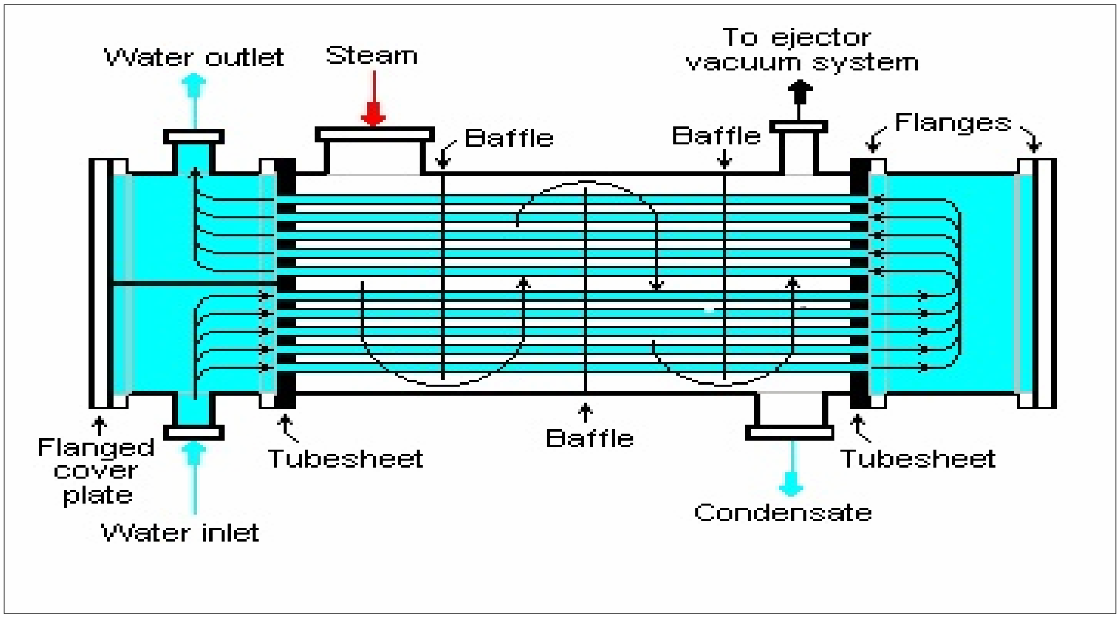

Figure 3 Inner View of a Surface Condenser

Direct contact condensers condense the turbine exhaust steam by mixing it directly with cooling water. The older type Barometric and Jet-Type condensers operate on similar principles. Steam surface condensers are the most commonly used condensers in modern power plants. The exhaust steam from the turbine flows in the shell (under vacuum) of the condenser, while the circulating water flows in the tubes [6].

The heat transfer rate Q between the cooling water and steam vapor is the key parameter of thermal analysis of the heat exchange steam condenser. Practically, the condensers can be classified in various categories on the basis of the relative direction of the flow of hot and cold fluids. There are three basic categories i.e. parallel flow, counter flow and cross flow. Condensation takes place at essentially constant temperature, therefore, the mean temperature difference between these configurations will be marginal or negligible, but mode of heat transfer varies [9].

5.2 Condensation Effects

A number of studies have been carried out in the field of availability analysis and assessment of irreversibility's for various devices and plants but mostly in studying the irreversibility's in the cycle, boiler, furnaces, and in the processes of expansion, compression, and combustion etc., for steam power plants and cogeneration systems, there exists a void as far as the study on different availability losses in a condenser and also the effects of condenser conditions on performance of the power plant [10].

The overall efficiency of a power plant is strongly influenced by the performance of its condenser. Poor condenser performance results in thermodynamic losses and thus reduces the profitability of the power plant. The use of a condenser will greatly increase efficiency of the steam power plant, as by using a condenser the steam cycle loop is closed allowing a great increase in efficiency by the recycling of water and recovery of heat that would otherwise be lost [3].

The condenser provides a closed space into which the steam enters from the turbine and is forced to give up its latent heat of vaporization to the cooling water. It becomes a necessary component of the steam cycle as it converts the used steam into water for boiler feed water and reduces the operational cost of the plant. Also, efficiency of the cycle increases as it operates with the largest possible delta-T (Temperature difference) and delta-P (Pressure Difference) between the source (boiler) and the heat sink (condenser) [5].

5.3 Factors affecting the performance of condenser

Generally the condenser pressure is maintained below the atmospheric pressure so there is always a chance of air leakage in condenser. The leakage of air is up to 0.005% and 0.5% in case of jet and surface condenser respectively [15].

Multiple pathways for air to leak into the steam path are inherent to the sub-atmospheric side of steam turbine power plants. Air in the steam path, along with deficiencies in condenser configuration, are major causes for a number of plant related problems such excess back pressure, dissolved oxygen, corrosion, and low cleanliness factor. Quantifying this air in-leakage is essential for maintaining plant operations [15].

The condenser never receives pure seam from the turbine. A mixture of steam and non-condensable gases (Air-steam mixture) enters the condenser. The ratio of the quantity of gas that enters the condenser to the quantity of steam is called the relative air content [5].

$$\varepsilon = \frac{\dot{m}_{air}}{\dot{m}_{c,s}}$$

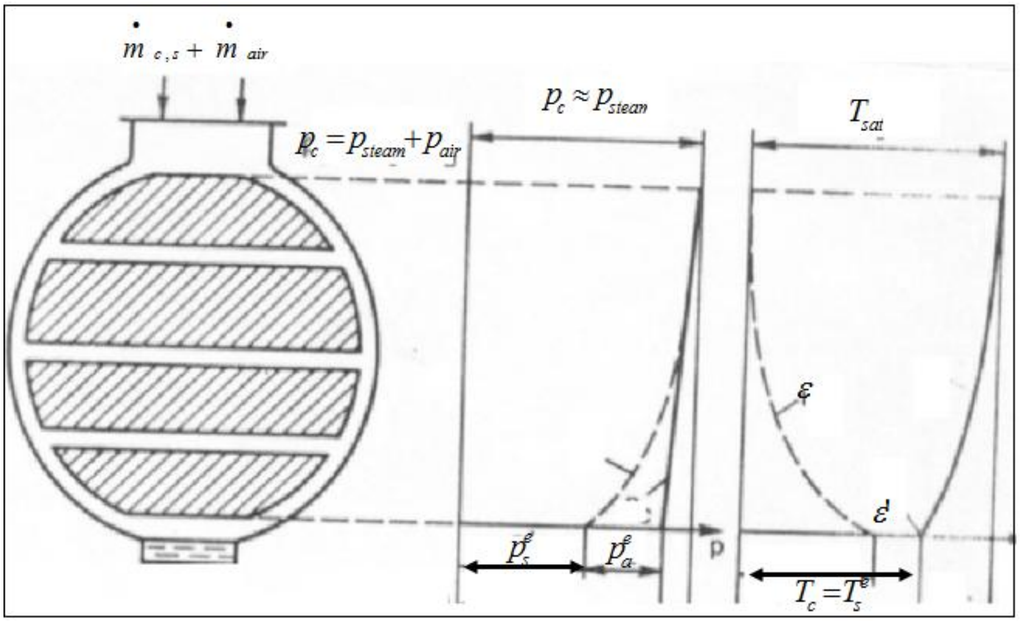

Figure 4 Effect of Air Leakage on Condenser Performance

The temperature of steam is a function of condenser pressure. As the air-steam mixture moves through the condenser and the steam is condensed, its temperature decreases owing to decreasing partial pressure of saturated steam. This is due to increase in relative content of air in the mixture. The pressure also decreases due to resistance to flow of steam [15].

The main factor in condensers performance is maintaining most efficient of the back pressure with the condition of available cooling water [9]. Decreasing the steam pressure at the exit of turbine (the condensation pressure) is one of the possibilities for improving steam cycle perfection, because that reduces quantity of heat that is transferred to the environment. Maintenance of low condensation pressures is realized by steam condensation in vacuum. Because of that, steam heat of condensation ought to be continually taken away. Heat of condensation is taken away by water circulating across the condenser. With condensation pressure decreasing the quantity of heat that ought to be taken away in the condenser increases, which demands more intensive circulation of water in power plant cooling system [10].

Although reducing of the condensation pressure increases produced power, it also increases energy consumption in cooling system for driving circulating pumps. This causes increasing of auxiliary energy consumption in the power plant, so the power plant overall efficiency can be reduced although the thermal efficiency is increased. Because of that, the regular choice of the working regime of the condensation system, i.e. the cooling system is very important for the economic work of the power plant [5].

The factors which affect the back pressure of a condenser for low vacuum are:

i. Air Ingress through the air leakages
ii. Insufficient cooling water flow
iii. Fouling of cooling water tubes
iv. Malfunctioning of vacuum-pulling
v. Excessive Thermal Loading of the condenser due to leakage of drainage Valves

The main function of a condenser is to only remove the latent heat of vaporization so that the temperature of condensate becomes equal to the saturation temperature of steam corresponding to the condenser pressure. The condenser efficiency is given as the ratio of actual rise in the temperature of outlet cooling water to the maximum possible temperature rise in a saturated temperature at condenser pressure corresponding to the inlet cooling water temperature.

Condenser efficiency = Actual rise in the cooling water temperature / (Saturation temperature at condenser pressure – inlet cooling water temperature)

The temperature of steam is a function of condenser pressure. As shown in figure 5 the air-steam mixture moves through the condenser and the steam is condensed, its temperature decreases owing to decreasing partial pressure of saturated steam. This is due to increase in relative content of air in the mixture. The pressure also decreases due to resistance to flow of steam [11].

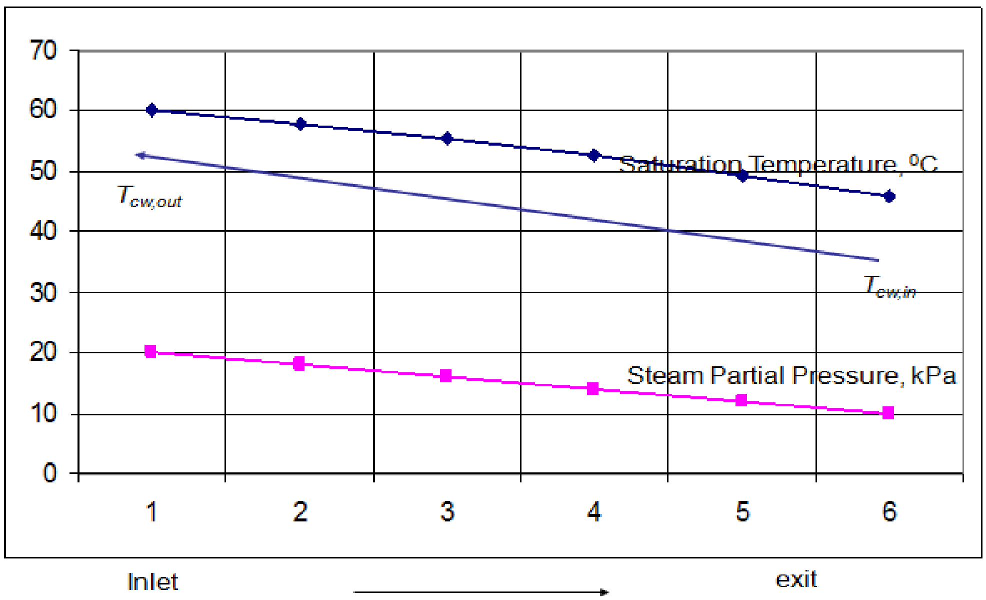

Figure 5 Variation of Steam Partial Pressure & Saturation Temperature

The considerable effect that condenser performance have upon the hate rate there is a need to apply a strict control over its operation [9] , as the main performance component is back pressure measured at turbine exit but [4] the following parameters should also be recorded and measured for better performance.

i. Cooling water inlet Temperature
ii. Cooling water outlet Temperature
iii. Loss of pressure across condenser
iv. Mega Watt load on unit
v. Steam pressure and temperature
vi. Reheat Temperature and Pressure
vii. Feed water Final Temperature
viii. Weather all feed water heaters are in service or not
ix. Condenser exhaust Temperature
x. Condensate Pressure

CHAPTER 3
METHODOLOGY

6.1 Project Work

1. Research was done on different journals to have better understanding about condensers, their types and the effects of Condenser conditions on the overall efficiency of steam power plant.
2. Identification of different variable affecting the condenser conditions. Mainly the performance of condenser is affected by its Cold end conditions [9] which effects:

- Pressure in condenser and thus saturation temperature
- Flow rate of steam through condenser
- Flow rate of cooling water
- Rate of heat transfer

Air leakage in condenser is also an important prospect for the condenser performance which is also part of the analysis.

3. Development of mathematical model of condenser using MS Excel equation solver platform and water/steam thermodynamic properties simulator based on IAPWS Industrial Formation 1997 (settled in excel add-in component). This formulation is proposed by International Association for the Properties of Water and Steam. The mathematical model of the proposed thermodynamic formulation was created as a type of steady state simulation. Flowsheeting

formulation (given all input information, determines all output information was developed by applying the laws conservation for mass and energy balance [4].

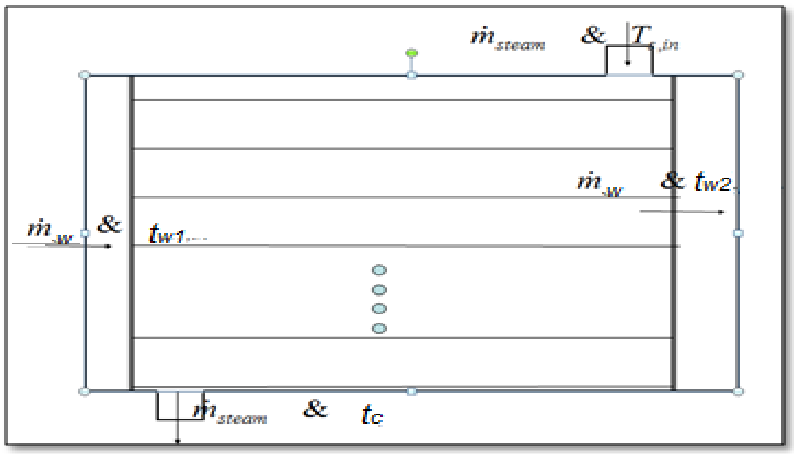

Figure 6 Thermal model of condenser

a. Mass and energy balance equation

$$\dot{m}_w c_w \left(t_{w2} - t_{w1}\right) = \dot{m}_c \left(h_1 - h_2\right)$$

b. The overall heat transfer coefficient (U_o) can be calculated from [15]

$$U_o = C_1 C_2 C_3 C_4 \sqrt{v}$$

Where

v = circulating cold water velocity in tubes inlet (m/s)

C_1 = dimensionless factor depending upon the tube outer diameter

C_2 = dimensionless correction factor for circulating water inlet temperature

C_3 = dimensionless correction factor for tube material and gauge

C_4 = values of these factors are given in table (Appendix B)

c. Log mean temperature difference

$$\Delta t_m = \frac{(t_{w1} - t_{w2})}{\ln \frac{(t_c - t_{w2})}{(t_c - t_{w1})}}$$

d. Heat transfer rate of the condenser

$$Q_c = U_o A \Delta t_m$$

e. The heat transfer rate of the condenser, depending on cooling water temperature and flow rate, condensing temperature (*i. e.* condensing pressure) and steam flow rate through the condenser, can be calculated from equations as follows:

$$\dot{Q}_c = \dot{m}_w c_w \left(1 - e^{-\frac{AU}{m_w c_w}}\right)(t_c - t_{w1})$$

$$\dot{m}_c = \frac{\dot{m}_w c_w \left(1 - e^{-\frac{AU}{\dot{m}_w c_w}}\right)(t_c - t_{w1})}{h_1 - h_2}$$

Where:

Q – Condenser heat transfer rate [kW]

m_w – Cooling water flow rate [kg s^{-1}]

m_c – Steam flow rate through condenser [kg s^{-1}]

v – Velocity of cooling water [ms^{-1}]

t_c – Condensing temperature [ºC]

t_{w2} – Cooling water outlet temperature [ºC]

t_{w1} – Cooling water inlet temperature [ºC]

U_o – Heat transfer coefficient [$kWm^{-2}K^{-1}$]

Δt_m – Log mean temperature difference [ºC]

A – Heat transfer surface

C_w – Specific heat of water [KJ/KgK]

f. The amount of air infiltrating into the condenser can be estimated by Dalton's law of partial pressures [4]

$$p_c = p_s + p_a$$

Pc – Total Condenser pressure [bars]

Ps – Saturation pressure at measured condenser temperature [bars]

Pa – Partial pressure of air [bars]

g. Efficiency of the cycle according to Figure 1

$$\eta_{cyc} = \frac{(h_1 - h_2) - (h_4 - h_3)}{(h_1 - h_3) - (h_4 - h_3)}$$

h_1 – Enthalpy at Inlet of turbine [KJ/Kg]

h_2 – Enthalpy at exit of turbine/inlet of condenser [KJ/Kg]

h_3 – Enthalpy at exit of condenser/inlet of pump [KJ/Kg]

h_4 – Enthalpy at exit of pump [KJ/Kg]

4. Analysis of condenser parameters/conditions and their effect on the performance of steam power plant was done using the model developed in Ms Excel.

6.2 Project Activities

The method that being used to achieve the objectives of this research work are shown as below

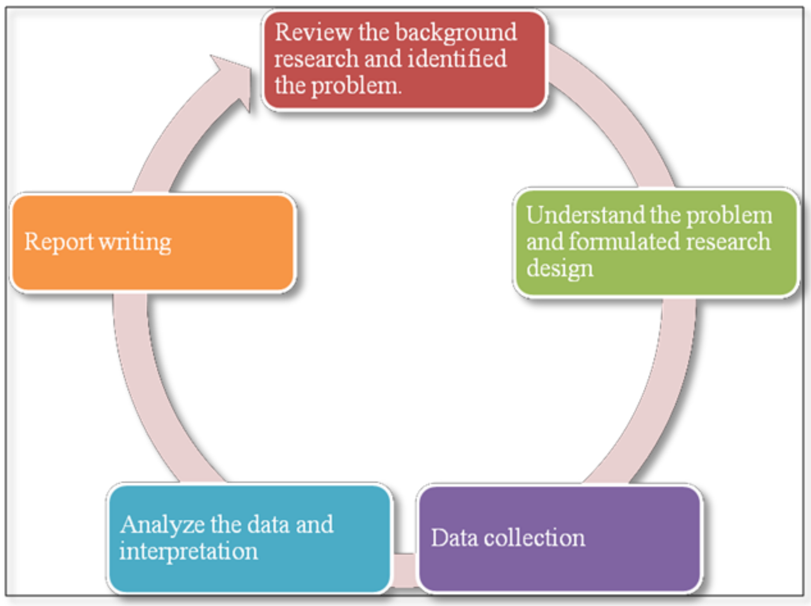

Figure 7 Project Activities

The flow of the methodology goes as the above flow chart. Throughout the research process, preparation for the simulation work was done in order to save time and finish the project within the given time period.

CHAPTER 4

RESULTS AND DISCUSSION

Herein certain of the obtained results are given and discussed. Cooling water parameters have major affect on the performance of condenser; in this chapter the effects of cooling water temperature and flow rate on the performance of steam power plant condenser are given and discussed.

4.1 Influence of cooling water parameters on the performance of Condenser

Condensing pressure, cooling water flow rate and temperature affects the condenser heat transfer rate. In an ideal situation, when the venting system properly removes air from the steam condenser i.e. zero air leakage, the achievable condensing pressure is determined by temperature of the cooling water. The steam power plant with once-through cooling system the temperature of cooling water is determined by natural water source (i.e. river) temperature. This means that cooling water temperature is changing with weather conditions in particular region, and cannot be changed in order to achieve better condenser performances (*i. e.* higher vacuum in the condenser). Still, cooling water temperature directly affects condenser performances. Suitable parameter for on-line control is cooling water flow rate, and it can be varied in a wide range, with appropriate circulation pumps. In that manner, cooling water temperature and flow rate are considered variable parameters in the simulation of the plant operating conditions.

4.2 Heat transfer rate and condensing pressure

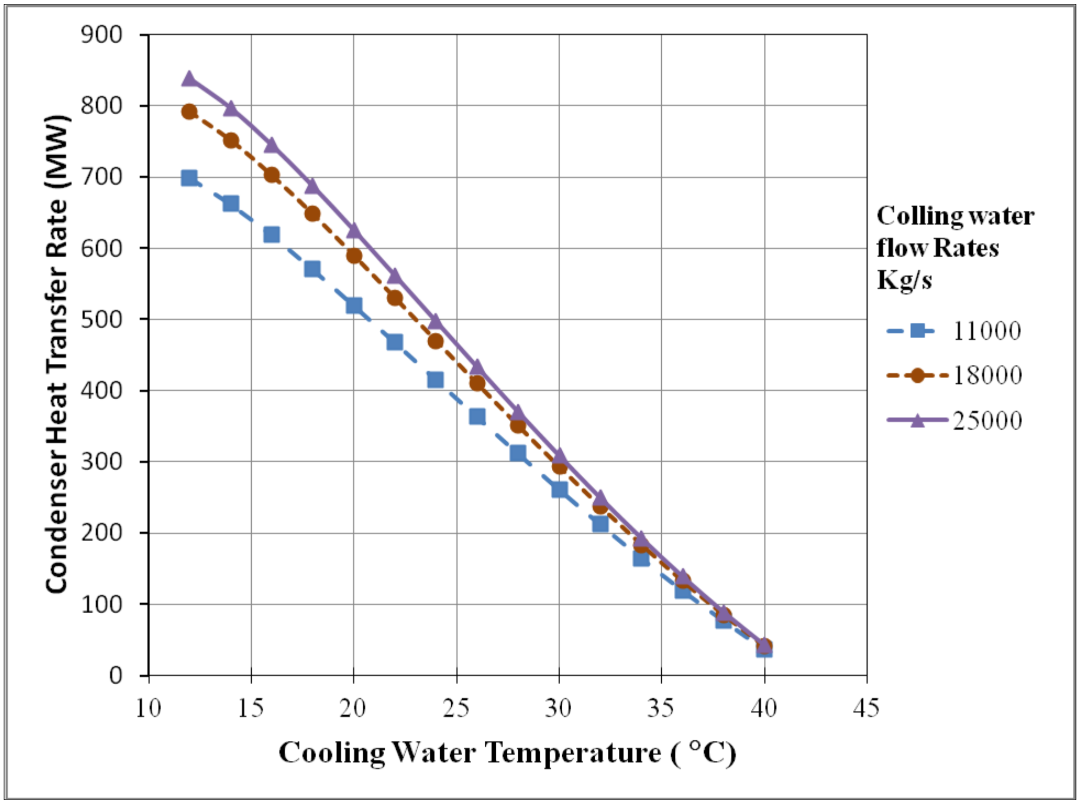

Figure 8 Change in rate heat transfer due to change in inlet cooling water temperature

If the saturation temperature is constant, with cooling water temperature rise, the mean temperature difference (Δt_m) in the condenser decreases, and condenser heat transfer rate will also decrease as it is shown in figure 8. In order to overcome this loss in the heat transfer rate increasing of cooling water flow rate will increase the condenser heat transfer rate for the given cooling water temperature.

Condenser pressure is a function of cooling water temperature [9]. Condensing pressure dependence on cooling water temperature is obtained for the given water flow rate and constant steam load of the condenser as it is shown in figure 9.

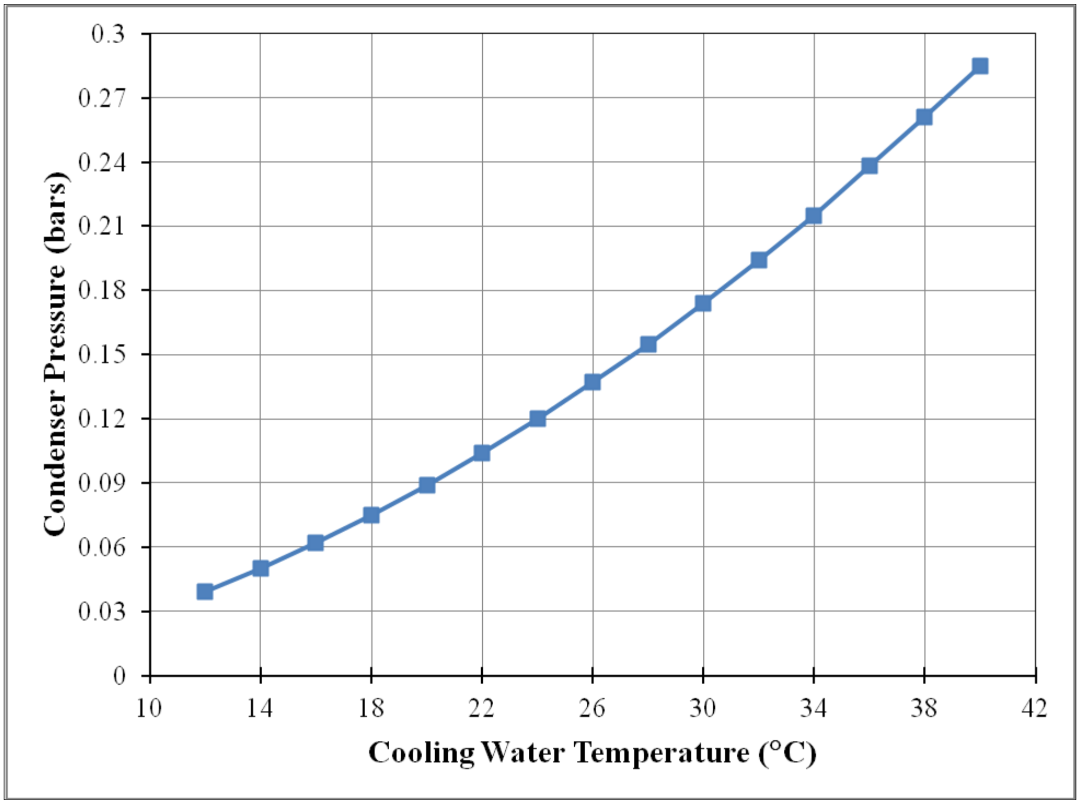

Figure 9 Cooling water Temperature vs. Condenser Pressure

It is obvious that with cooling water increasing, pressure in the condenser will also increase. The increase in condenser pressure results in high back pressure of turbine and hence reduces the work done by turbine which results in low net power of the cycle; therefore it has a direct impact on the overall efficiency of the plant.

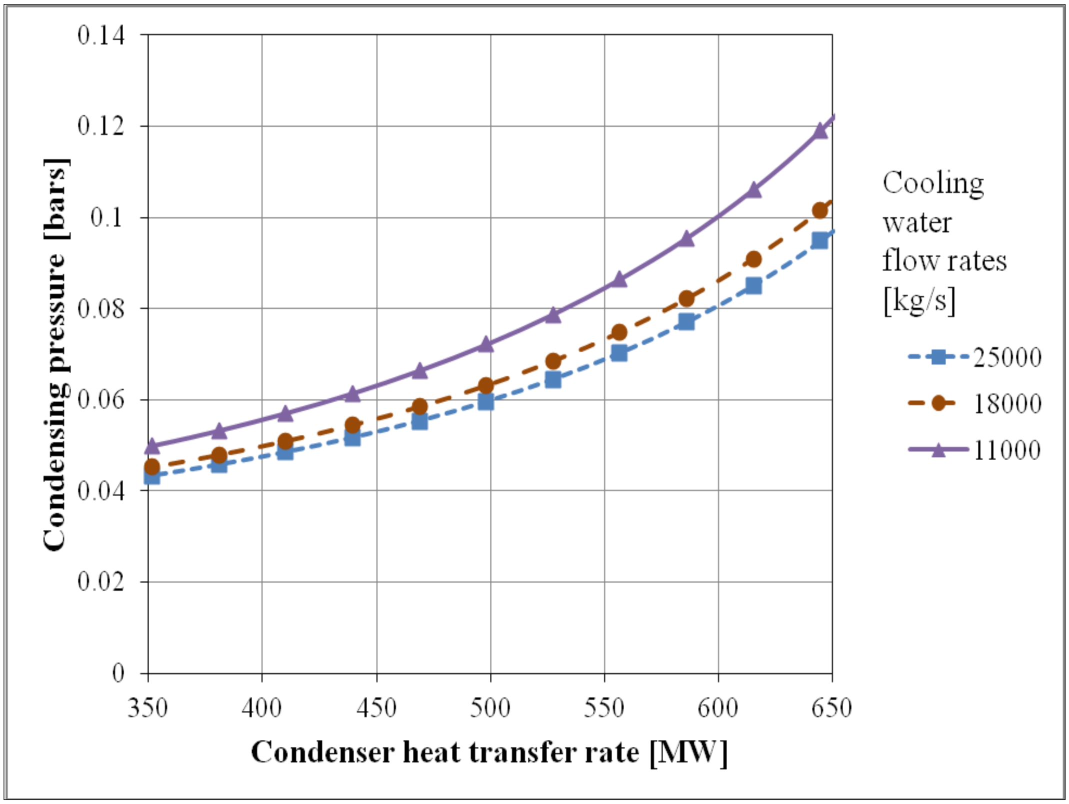

Figure 10 Condenser heat transfer and condenser pressure

The heat rate of condenser increases with increase in pressure for the constant temperature, but with variable flow rates of water. As shown in figure 10 the higher flow rate will result in lower pressure, maintaining the design heat transfer. Figure 10 shows the relation between heat transfer rate of condenser and condensing pressure, different values of water flow rate were taken to analyze the effect of condensing pressure on rate of heat transfer at constant inlet water temperature.

4.3 Steam Load of Condenser

With cooling water temperature increasing, in order to maintain designed heat transfer rate of the condenser, condensing pressure will increase.

The turbine governor will increase the throttle and exhaust flows in order to set the generated power at the designed level, but with increasing of heat rate, figure 11 shows the steam load of the condenser dependence on condensing pressure, at a constant cooling water temperature as for different values of cooling water flow rate.

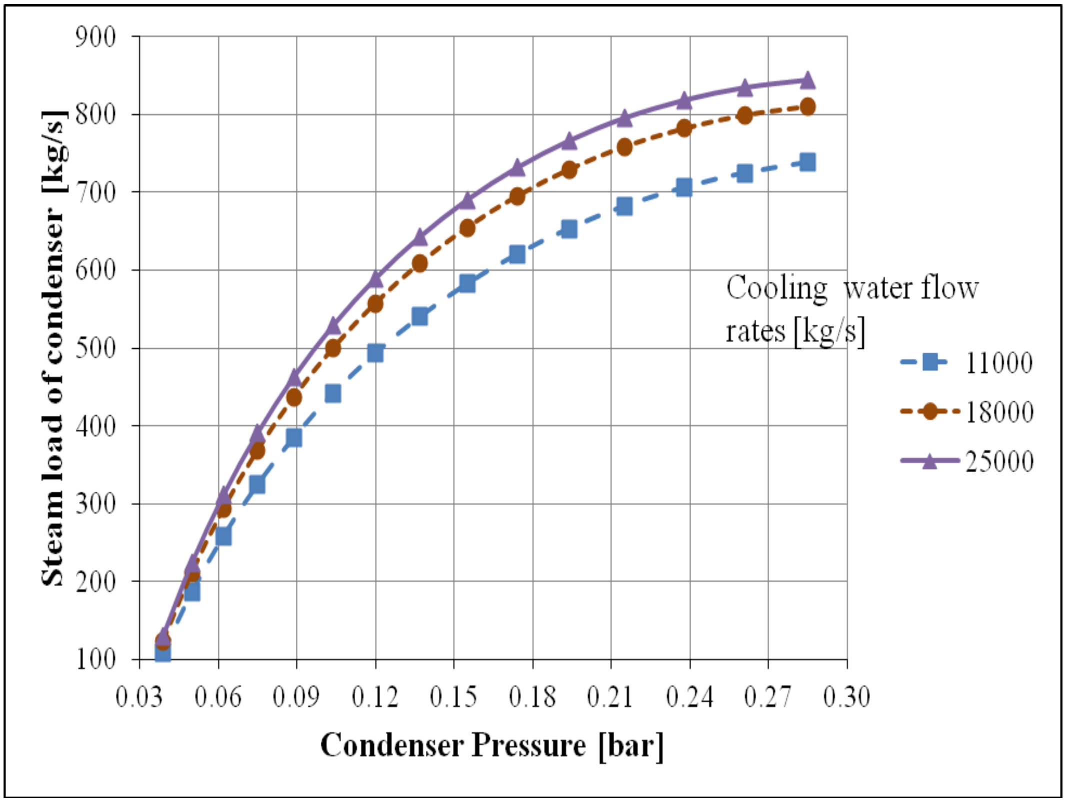

Figure 11 Steam load dependence on condenser pressure

4.4 Load Lost Due To Excess Back Pressure

Air leakage in condenser causes the condenser pressure to increase. In an ideal situation when there is zero air leakage condenser pressure is equal to saturation pressure, whereas the air leakage results in high back pressure and this increase in pressure affects the rate of heat transfer and this increase is a cause of load lost in the cycle. The condenser pressure is lower than atmospheric pressure so there is always an opening for air leakage. Total pressure in condenser can be found by Dalton's law of partial pressure [4].

Air leakage causes reduction of the work done per kg of steam as it increases back pressure. Also the quantity of water required for the condensation of steam increased due to lowering of partial pressure of steam due to the air pressure in condenser. Mainly air leakage increase the pressure of condenser due to which the latent heat of steam to be released increased.

Figure 12 shows the load lost [Mw] due to the air leakage in condenser. The air leakage is sources of excess back pressure in condenser and the performance of condenser is directly affected by pressure increase.

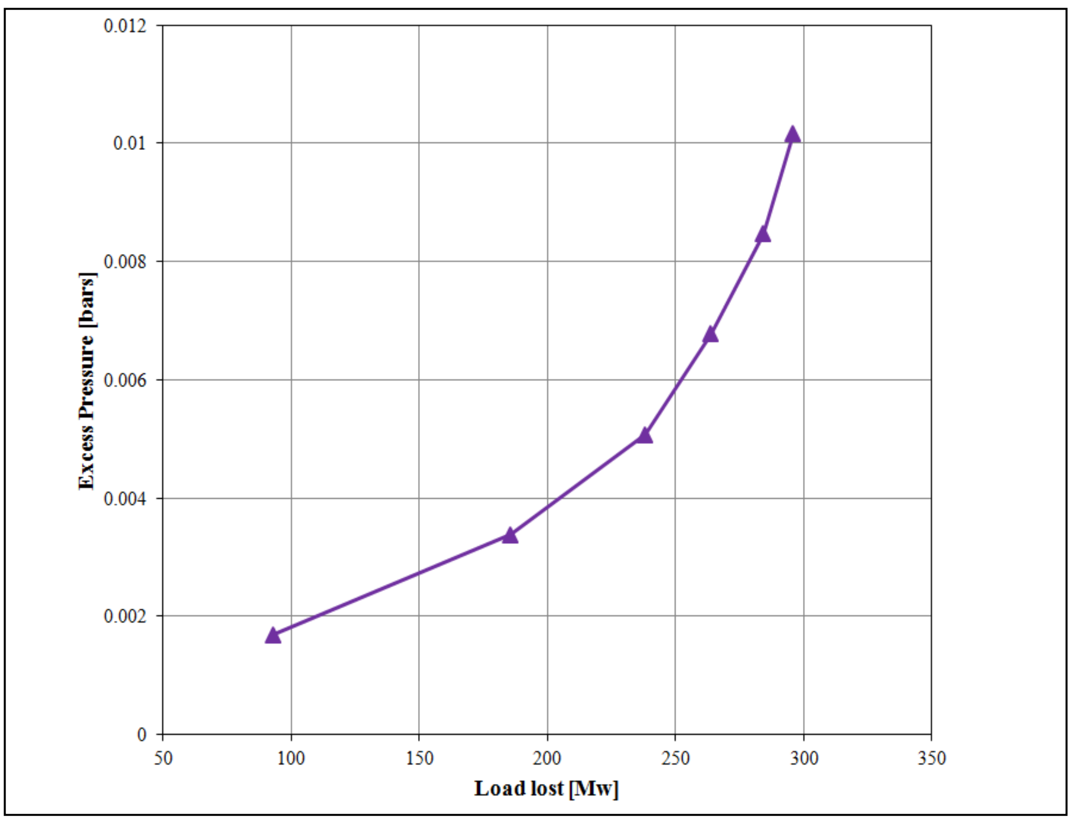

Figure 12 Excess pressure vs. load lost

4.5 Net Power and Condenser Pressure

The turbine outlet enthalpy is a function of condenser pressure. Decreasing the turbine outlet enthalpy causes the turbine output work to increase. Therefore in order to increase the turbine work, condenser pressure should be reduced. However there are limitations in the reduction of condenser pressure. Reducing in pressure is also a cause of turbine outlet losses and it also decreases the steam quality i.e. Increase in water droplets at turbine exhaust. Therefore based on all the factors the condenser optimal pressure should be chosen.

The condenser pressure is a function of cooling water temperature (figure 9). Increase in cooling water temperature will increase the pressure of the condenser Figure 13 shows the condenser pressure Vs. Net power.

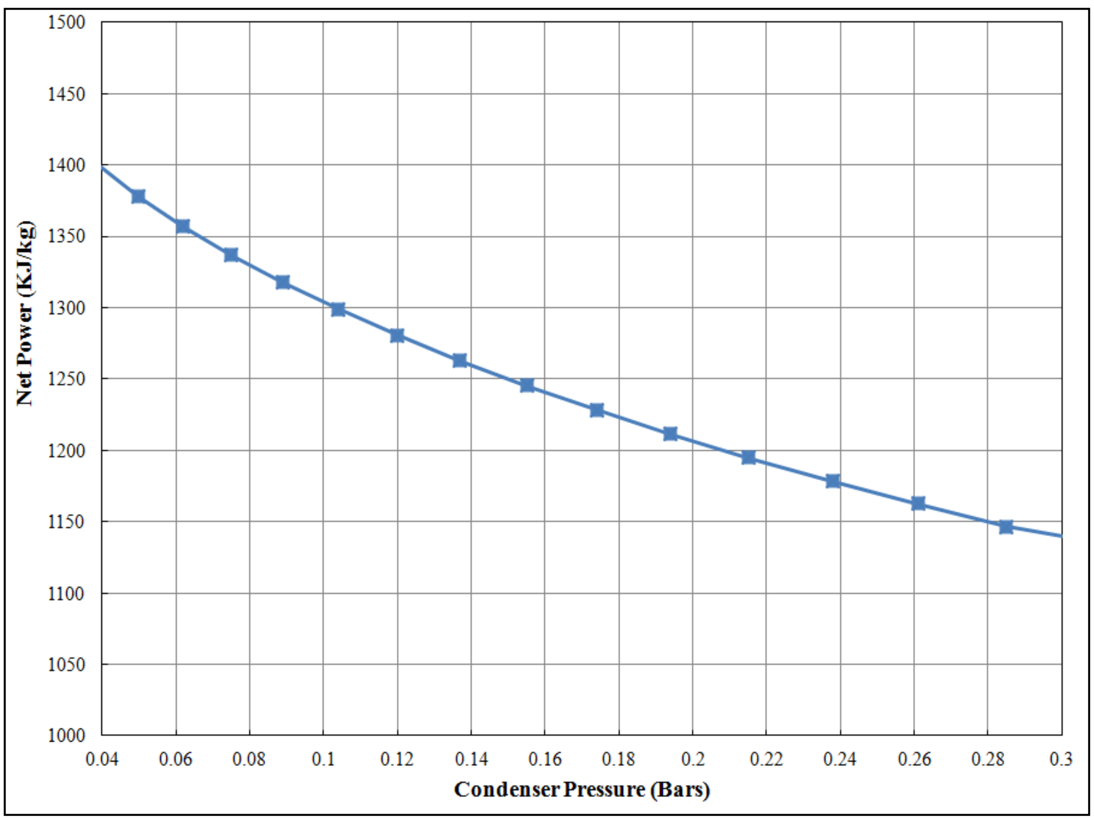

Figure 13 Impact of Condenser pressure on net power

4.6 Effects of Condenser Pressure on Efficiency of Power Plant Cycle

It is evident that the efficiency decrease with an increase in the condenser pressure parameters (figure 14). Decreasing the condenser pressure and temperature will result to a higher power output for the same mass flow rate of steam and fuel input into the boiler, resulting in higher work output of the turbine.

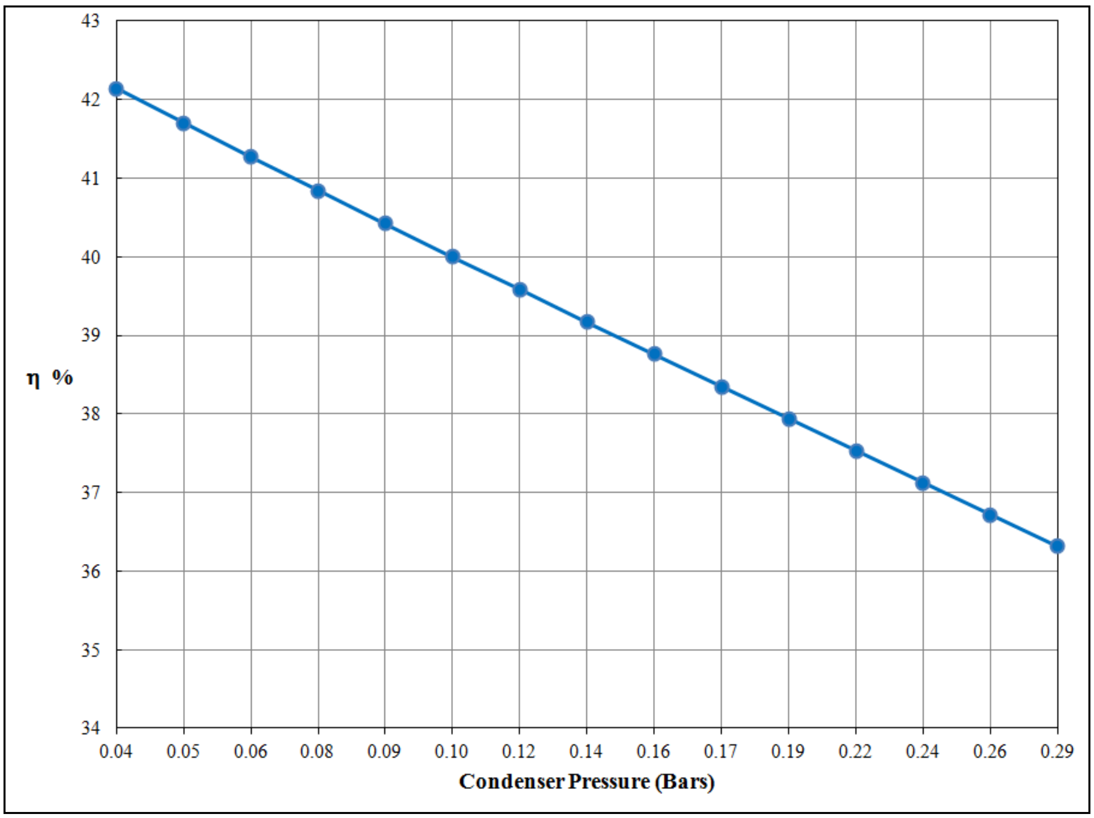

Figure 14 Condenser pressure vs. cycle efficiency

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

It can be concluded that the steam power plant strongly depends on its cold end operating conditions, where the condenser is the key of the heat exchange system. On the other hand, operating conditions of the cooling water system determine condenser operating conditions. Lower pressure of condenser results in higher efficiency of the power plant whereas the pressure of condenser is a function of the cooling water. The outlet enthalpy is controlled by the vacuum in condenser. The turbine outlet enthalpy is a function of condenser pressure. Decreasing the turbine outlet enthalpy causes the turbine output work to increase. Therefore in order to increase the turbine work, condenser pressure should be reduced. The performance of steam power plant is strongly influenced by the condenser conditions.

5.2 Recommendation

The condenser operating conditions are of the great influence on the maximum generated power and the heat rate value. In the same time, the operating conditions of the cooling water system determine the operating conditions of the condenser. There are several improvements which can be done to get better reuslts of the condenser performance. For future work it is recommended that the material of the condenser should be considered for calculating the heat transfer. The surface area and number of tubes also play an important role in condenser performance. Tube fouling and thermal resistance of tubes are also important considerations. Dissolved gases, corrosion, cleanliness factor of tubes also play an important role in improving the condenser performance.

Performance of condenser can be monitor by a scheduled energy audit. More research needs to be done to study the effects of variable and fixed parameters on the performance of steam power plant condenser.

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Appendix A
Project Gantt Chart and Project Milestones

FYP I

No	Detail/Week	1	2	3	4	5	6	7	Mid-semester break	8	9	10	11	12	13	14
1	Selection of Project Topic: " Effects of condenser conditions on performance of steam power plant "	■	■													
2	Preliminary Research Work: Research on literatures related to the topic		■	■	■	■										
3	Submission of Extended Proposal						●									
4	Proposal Defense									■	■					
5	Project Work Continues: Study on the research scope and method											■	■	■		
6	Submission of Progress Report														●	
7	Submission of Interim Report															●

FYP II

No	Detail/Week	1	2	3	4	5	6	7	Mid-semester break	8	9	10	11	12	13	14	15
1	Project Work Continues	■	■	■	■	■	■	■									
2	Submission of Progress Report									●							
3	Project Work Continues									■	■	■	■	■			
4	Pre-EDX												●				
5	Submission of Draft Report													●			
6	Submission of Dissertation (soft bound)														●		
7	Submission of Technical Paper														●		
7	Oral Presentation															●	
7	Submission of Project Dissertation (hard bound)																●

Appendix B

Standard factors ($C_1C_2C_3C_4$) values

Tube outer diameter (mm)	19				22			25 .4					
C_w	2777				2705			2582					
Water temperature (^oC)	1.66	4.44	7.22	10	12.77	15.55	21.11	26.66	32.22	37.7	-	-	-
C_2	0.57	0.64	0.72	0.79	0.86	0.92	1.00	1.04	1.08	1.10	-	-	-
Tube material	304 Stainless steel		Admiralty arsenic copper		Aluminum brass, muntz metal			Aluminum bronze 90-10 Cu-Ni		70-30 Cu-Ni		-	
C_3	0.58		1.00		0.96			0.90		0.83			-
C_3	0.56		0.98		0.94			0.87		0.80			-
C_3	0.54		0.96		0.91			0.89		0.76			-
C_4	0.85			for clean tubes, less for algae covered or sludge tubes									

Appendix C

Condenser Data and Efficiency Calculation

P_i	Ti	h_1	A	P_s	P_c	h_2	h_3	W_p	t_{w1}	t_c	t_{w2}	U	m_s	m_w	v	η_{cyc}
60	500	3422.95	8468	0.039	0.04	2041.92	119.58	4.01	12	28.52	19	3.84	214.76	11816	1.95	42.14
40	500	3445.84	8468	0.05	0.05	2064.05	137.77	4.02	14	32.88	21	3.92	260.38	12000	1.95	41.70
40	500	3445.84	8468	0.062	0.07	2084.99	154.00	4.02	16	36.76	23	3.95	295.10	13000	1.95	41.27
40	500	3445.84	8468	0.075	0.08	2105.03	168.76	4.02	18	40.29	25	3.95	320.78	14000	1.95	40.84
40	500	3445.84	8468	0.089	0.10	2124.34	182.36	4.03	20	43.55	27	3.92	338.86	15000	1.95	40.42
40	500	3445.84	8468	0.104	0.11	2143.06	195.03	4.03	22	46.58	29	3.86	350.49	16000	1.95	40.00
40	500	3445.84	8468	0.12	0.13	2161.28	206.91	4.04	24	49.42	31	3.79	356.64	17000	1.95	39.58
40	500	3445.84	8468	0.137	0.15	2179.07	218.13	4.04	26	52.10	33	3.70	358.12	18000	1.95	39.17
40	500	3445.84	8468	0.155	0.17	2196.48	228.78	4.04	28	54.65	35	3.60	355.60	19000	1.95	38.76
40	500	3445.84	8468	0.174	0.19	2213.56	238.94	4.04	30	57.08	37	3.48	349.69	20000	1.95	38.35
40	500	3445.84	8468	0.194	0.21	2230.34	248.65	4.05	32	59.40	39	3.36	340.88	21000	1.95	37.94
40	500	3445.84	8468	0.215	0.24	2246.85	257.98	4.05	34	61.63	41	3.23	329.62	22000	1.95	37.53
40	500	3445.84	8468	0.238	0.26	2263.32	267.34	4.05	36	63.87	43	3.09	316.94	23000	1.95	37.12
40	500	3445.84	8468	0.261	0.28	2279.36	275.97	4.05	38	65.93	45	2.94	301.77	24000	1.95	36.72
40	500	3445.84	8468	0.285	0.31	2295.19	284.31	4.06	40	67.92	47	2.79	285.23	25000	1.95	36.31
40	500	3445.84	8469	0.31	0.34	2299.16	292.39	4.06	42	69.85	49	2.64	269.14	26000	1.95	36.05

Where: P_i Pressure of steam leaving turbine/Inlet pressure of condenser [bars]

T_i Temperature of steam leaving turbine/Inlet temperature of condenser [°C]

W_p Work done by Pump [KJ/Kg]