# The effect of varying the condenser pressure on thermal power station efficiency-Doha west power station as a case study

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## ABSTRACT

This paper aims to identify the factors that lead to reducing the efficiency of the thermal power plant as a result of the change of vacuum pressure in the steam condenser witnessed by the Doha West Power Station as a case study in the State of Kuwait, with a focus on the energy lost due to the change in the vacuum pressure inside the steam condenser as a result of changing loads or forming Slime inside the condenser, thus lowering the efficiency of the steam condenser and increasing the condensate temperature and vacuum pressure. The efficiency of the steam unit depends on the efficiency of the condenser, where the loss in the steam condenser is the biggest loss, reaching 51%. In this paper, an experimental investigation of the thermal analysis and design conditions of the steam condenser in the station was done on reality and the use of the steam unit simulator. This study showed that the thermal efficiency of the station could be improved by improving the efficiency of the capacitor. It showed that the condenser efficiency can be improved by three main variables, which are the vacuum pressure inside the condenser, as well as the cooling water entry temperature and the cooling water flow rate. The results showed that the efficiency of the steam station increases with the decrease in the pressure inside the steam condenser and the decrease in the temperature of water entering the condenser as well as the increase in the flow rate of the cooling water. The study also showed that the increase in the rate of cooling water flow in the steam condenser depends on the cleanliness of the condenser tubes and the performance of the cooling water pump.

**KAY WORDS:** Cooling water, steam condenser, Doha west , power station , vacuum

## 1. Introduction

Most of Kuwait's electricity comes from thermal power station fueled by heavy oil, crude oil, or natural gas. In Kuwait state there are five thermal power stations each of them 8 units, each unit capacity is 300MW (5*8*300=12000MW). The efficiency power station is typically range between 30 to 40 % [1]. Why thermal power station low efficiency? In the ideal Carnot cycle the thermal efficiency is calculated from the mathematical relationship (T1- T2 / T1). This expression of efficiency indicates that the efficiency increases with an increase in temperature T1 and a decrease in temperature T2. The maximum temperature of the main steam entering the steam turbine has limits depending on the metal of the turbine blade. The temperature of the steam coming out of the steam turbine is the amount of heat rejected in the condenser, and the outlet temperature can be reduced if the exhaust from the steam occurs at a pressure lower than the atmospheric pressure [1]. It is known that a closed vessel in which the steam is condensed by absorbing heat from it and where the pressure inside the condenser is kept below the atmospheric pressure, thus the thermal efficiency of the steam station is greatly increased by using the condenser. As in Figure (1), which shows a simple steam station using a condenser. The purpose of the condenser is to remove the latent heat from the exhaust steam from the turbine and condense it into the condenser at a pressure lower than atmospheric pressure. The steam is condensed to be used again in the thermal cycle as a closed system while keeping the pressure of the exhaust steam coming out of the turbine below the atmospheric pressure, thus reducing the saturation temperature of the steam. The Rankin cycle is the standard for steam power plants around the world and is considered an ideal thermal cycle. The overall efficiency of the thermal plant can be measured the basic Rankine cycle used in the steam plant consists of the following main components are the steam generator, turbine, steam condenser and pump. Figure (1) represents the main components of work on the Rankine cycle, and Figure (2) shows the relationship between temperature and entropy. 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. This steam expands in 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 maintain a proper vacuum. The study aims to identify the factors that lead to reducing the thermal efficiency of the Doha West Power Station, with a focus on the losses concerned with the back pressure of the main steam condenser, the causes of the back pressure losses and the steps that were followed to verify and find appropriate solutions through the assumptions that were made in this research. Since the pressure loss in the steam condenser was also the biggest contributor to reducing the overall thermal efficiency of the steam station and it had steadily increased over the past year as shown in Figure (3), it was decided to focus on the potential impact that this loss had on the thermal efficiency of the power plant, Hence, the planning of this research was based on an investigation of intense back pressure loss.

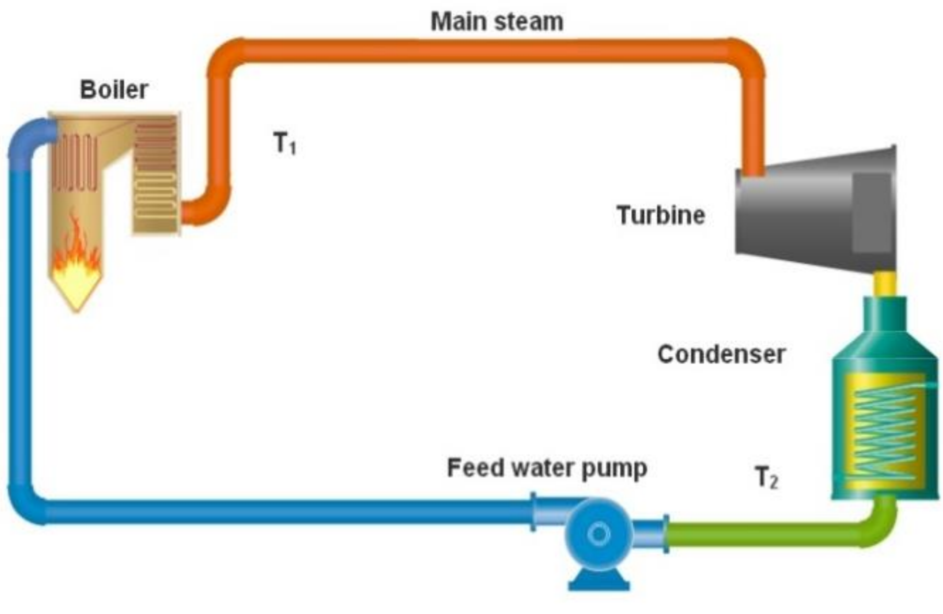


*Figure 1 - simple power station*

*Figure 2-Distrbution of power station energy losses*

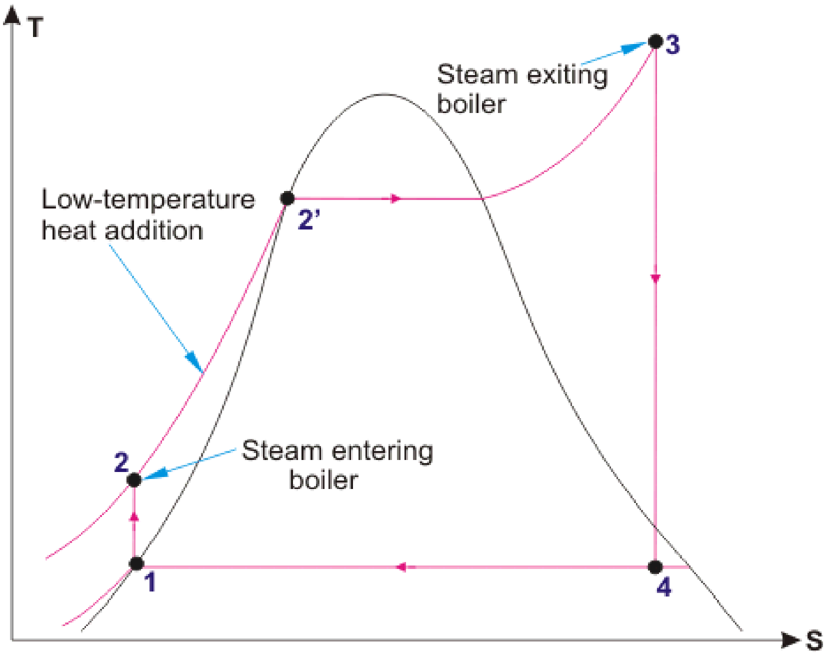


*Figure3 -Rankine cycle*

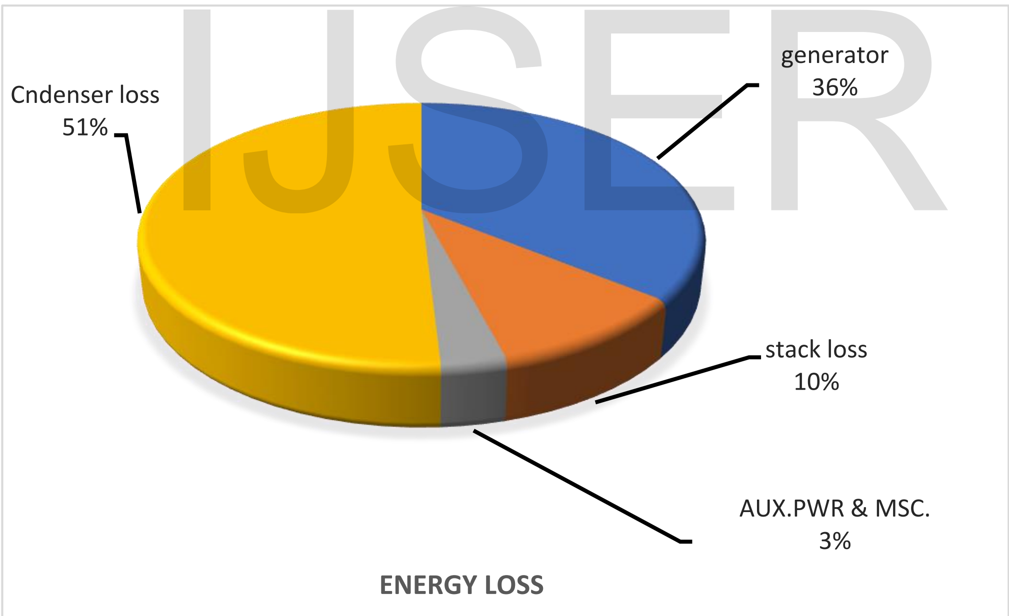


*Figure 4-Distrbution of power station energy losses*

## 2. Literature review

The boiler, turbine, pump and condenser are all four components associated with the Rankin cycle and are necessary equipment for any steam power plant, and thus all four processes that make up the Rankin cycle can be analyzed as the steady state flow process, the thermal energy of the steam changes from one procedure equipment to another in the basic procedures of the cycle. In the United States of America, the efficiency of power plants is expressed by calculating the thermal equilibrium and the rate of heat, which is the amount of heat supplied, in the BTU to generate 1 kilowatt hour of electricity. The smaller the heat rate, the greater the efficiency [2]. In previous research, a relationship was found between the rate of heat and the thermal efficiency to raise the thermal efficiency to the largest possible value, taking into account that 1 kilowatt = 3412 British thermal units and ignoring the losses associated with converting thermal energy into electrical energy, [3]. Improving the condenser performance to reach its optimum performance requires improving the performance of the circulating water pumps in terms of flow rate and inlet temperature. In previous studies, an analysis method based on the theory of thermodynamics has been proposed that determines the coupling properties between the best vacuum and the best water circulation discharge. The proposed method was applied to optimize the operating mode analysis of a cold end system of a 300 MW unit in a power plant [4]. Over the years, the improvement of condensation performance has been well studied, with a focus on studying heat transfer inside pipes, working fluids and operating conditions. Much research has been published relating to the performance of the evaporative condenser with improved understanding of heat transfer systems, pressure drop and cooling water flow in specific cases. Aiming to elucidate theories, correlations, and techniques that may be useful and applicable to this study, the following literature reviews were conducted focusing on the various physical aspects of the research from the two-stage flow during condensation [5]. This study aims to determine the factors affecting the efficiency of the steam condenser and the effect of these factors on the efficiency of the total steam station. The study also aims to find solutions and recommendations to treat the effects of the factors that lead to reducing the efficiency of the steam unit.

## 3. Methodology



In this study, practical experiments were used in the simulator of the steam station inside the Higher Institute of Energy. This is an experimental investigation. The information and data were obtained from the operations book of the Doha West Power Station as a case study for the power stations in Kuwait. Data were taken for a period of 75 days, from a paper operator log unit, and all necessary experiments were performed by the steam simulation plant at the Higher Energy Institute - PAAET, Kuwait.

### 3.1 Simulator description

The steam power station simulator is from ESSCOR - An INVENSYS Company- ASCEND is an acronym for Advanced Simulation Configuration Environment for enhanced Development. ASCEND is ESSCOR's integrated suite of software components for building, running, modifying, and controlling. The simulation software is done through a Java based user interface. The ASCEND Steam Station Simulator program uses all the components of the steam unit completely like the same steam units at the Doha West Station. The ASCEND Steam Unit Simulator also includes the user tools required to implement and analyze the simulation. ASCEND emulator can control steam unit start-up and during operation with high accuracy. The simulation model works in the operation of the equipment as in the real operation inside the steam station, i.e., real time. The time it takes to operate the unit can be accelerated to 10 times the real time or slow down if you wish. A simulation picture of the power station (4) shows the simulation control screen, and (5) shows the log in to the screen, and (6) shows the data base of steam unit simulator.

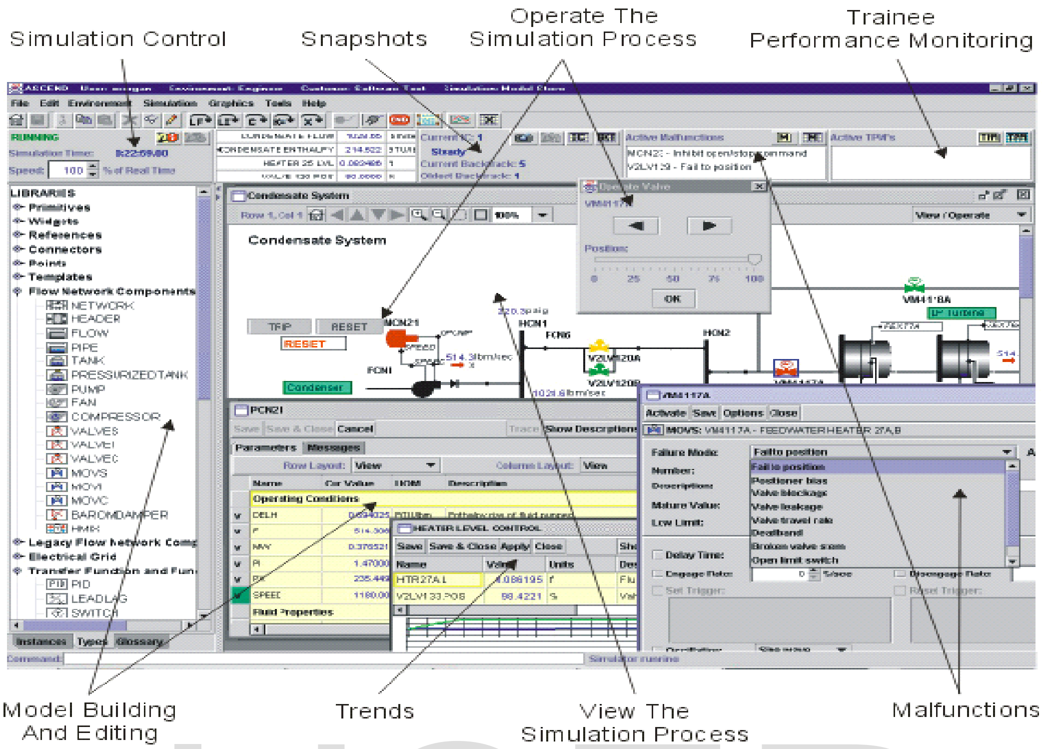


*Figure 5- Simulator Human interface*

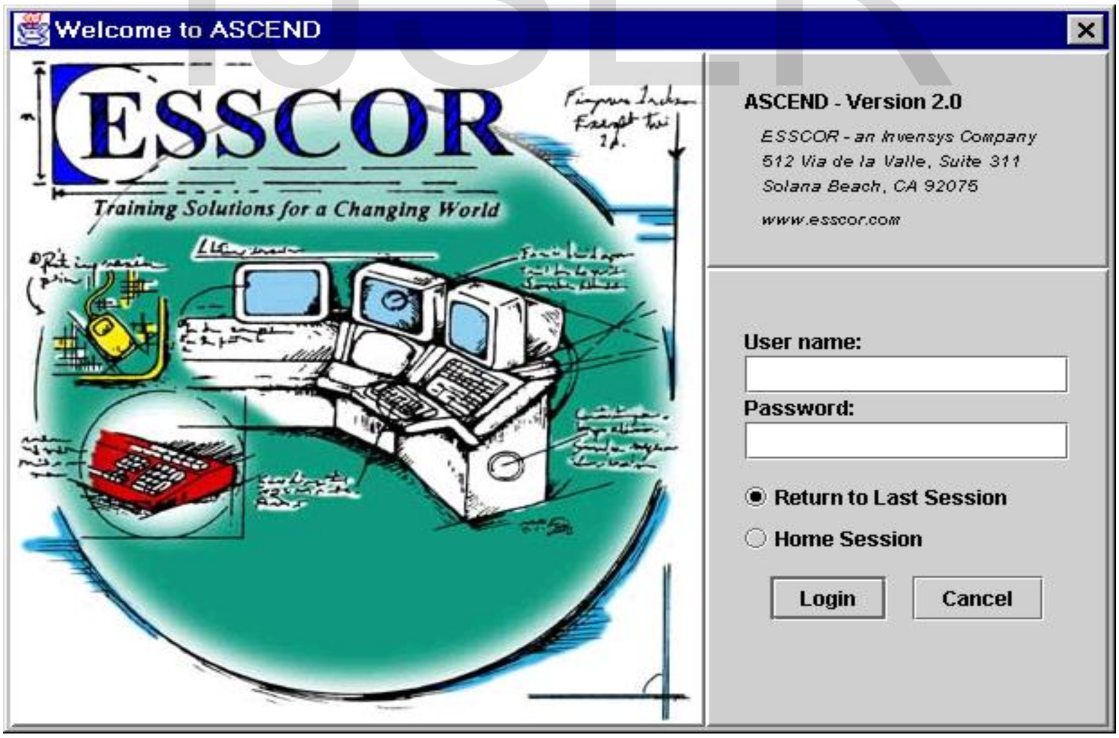


*Figure 6- Simulator Log in screen*

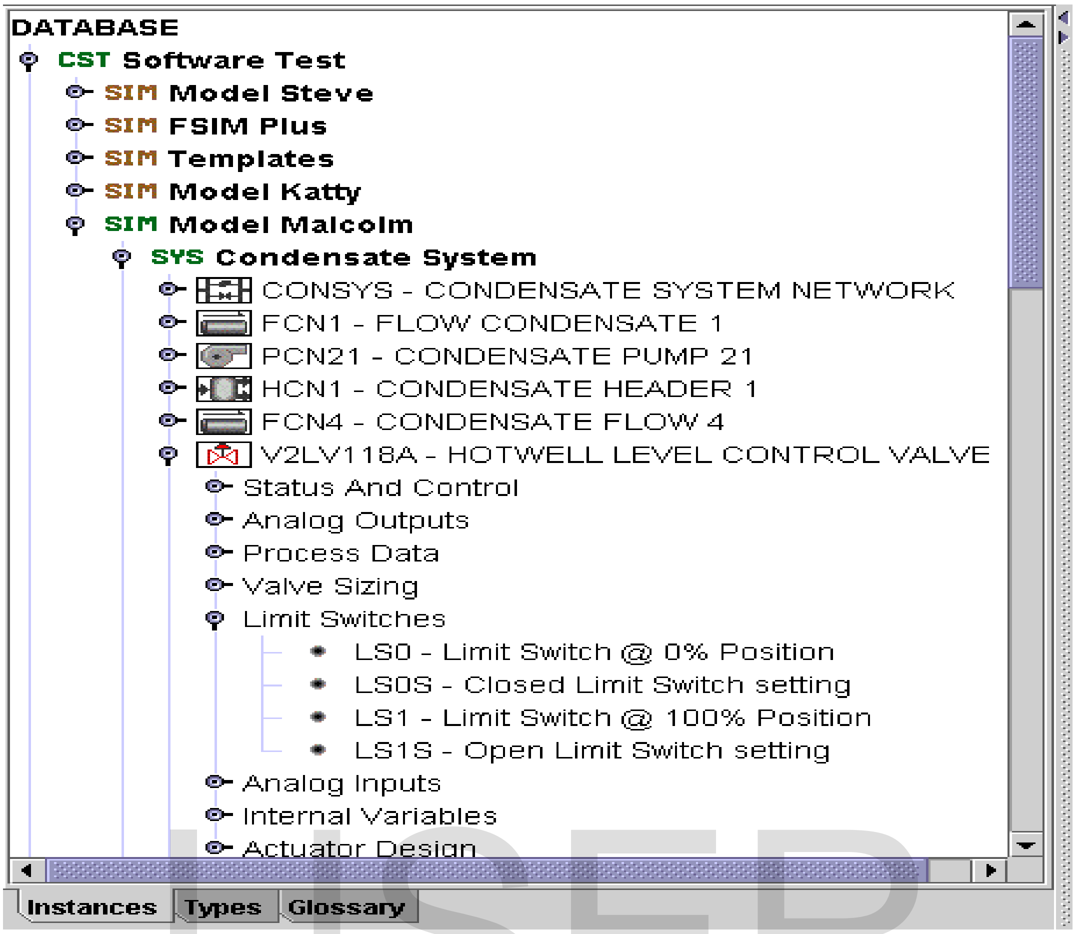




*Figure 7- DSC Simulator data base*

## 3.3 DOHA west power station description

The DOHA west power station which comprises 8 units, each capacity is 300 MW. The first steam unit in Doha West Station was fully operational before the end of 1984, then after that, five gas turbine units with a capacity of 28.2 MW were added each in 2008 and now the total installed capacity of the station is 2541 MW, of which 2,400 MW for the steam turbine and 141 MW. For gas turbines [6].

| Unit | Date of commissioning | Installed capacity (MW) |
|---|---|---|
| No.1 | 02/05/1983 | 300 |
| No.2 | 25/06/1983 | 300 |
| No.3 | 15/08/1983 | 300 |
| No.4 | 31/08/1983 | 300 |
| No.5 | 04/04/1984 | 300 |
| No.6 | 26/04/1984 | 300 |
| No.7 | 06/10/1984 | 300 |
| No.8 | 02/12/1984 | 300 |
| Total | | 2400 |

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### 3.2 Condenser performance

The condenser is the equipment in which the steam leaving the steam turbine is converted into water for further use. The condenser is one of the largest equipment in which there is a loss of energy and significantly affects the thermal efficiency of the steam unit. Accordingly, it is necessary to determine the factors that affect the performance of the steam condenser and measure the extent of the influence of each of these factors. A capacitor is a relatively simple heat exchanger whose performance can be described by the following equation: -

- **Calculation of Thermal efficiency:**

$$\eta_{th} = \frac{w_{net}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}} \quad \langle 1 \rangle$$

Where:

$\eta_{th}$ = Thermal efficiency

$w_{net}$ = the work net =w turbine -w pump

$q_{in}$ = the heat adds in boiler

$q_{out}$ = the heat losses

- **Calculation of Heat losses in the condenser:**

$$Q_L = \dot{m}_{cw} \times Cp_{cw}(T_{cw\,o} - T_{cw\,i}) \quad \langle 2 \rangle$$

**Where:**

$Q_L$ = heat losses (MW)

$\dot{m}_{cw}$ = cooling water flow rate (kg/s)

$T_{O.C.W}$ = cooling water outlet temperature (°C)

$T_{I.C.W}$ = cooling water inlet temperature (°C)

$Cp_{cw}$ = specific heat (kj/kg. °C)

- **Condenser efficiency**

$$\eta_{cond.} = \frac{T_{O.C.W} - T_{I.C.W}}{T_S - T_{I.C.W}} \quad \langle 3 \rangle$$

**Where:**

$T_{O.C.W}$ = Outlet temperature of cooling water

$T_{I.C.W}$ = Inlet temperature of cooling water

$T_S$ = saturated temperature

The loss of thermal energy in the steam condenser depends almost entirely on the steam flow coming from the turbine which depends on the change in the electrical load required of the consumers. The loss in thermal energy can be calculated by multiplying the rate of steam flow by the amount of latent heat in addition to the small additional thermal loads entering the condenser from other sources of low-pressure turbines, but these loads are usually insignificant compared to the base load as shown in Figure 7. And (8).

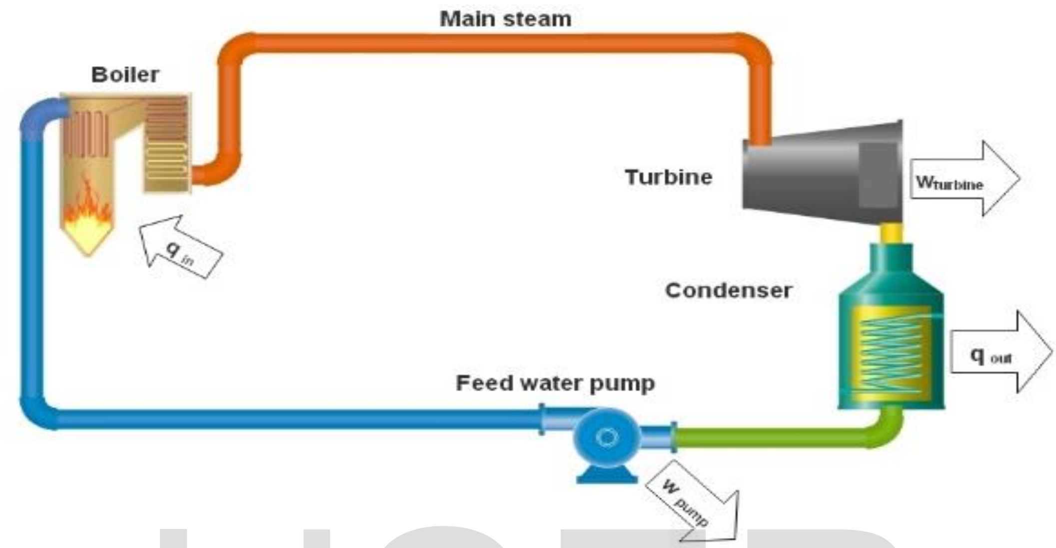


*Figure 8 - Power station Energy balance*

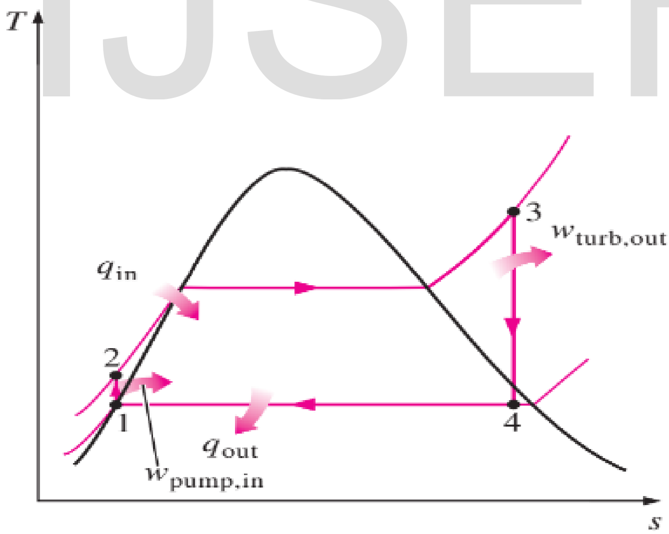


*Figure 9 - T-S Diagram of energy balance*

The steam condenser used in the power plant used in the study, which is the Doha West Station for electric power generation and water distillation, is of the surface steam condenser type and its components are: -

a) Condenser.
b) Air extraction pump.
c) Condensate pump.

d) Circulating cooling water pump.
e) Hot well.
f) Make up water pump.

### 3.4 Surface condensers

Surface steam condensers (9) are used in large electric power plants. In surface condensers, the exhaust steam and the water do not mix, as the cooling water passes into the pipes and the steam is outside the water pipes.

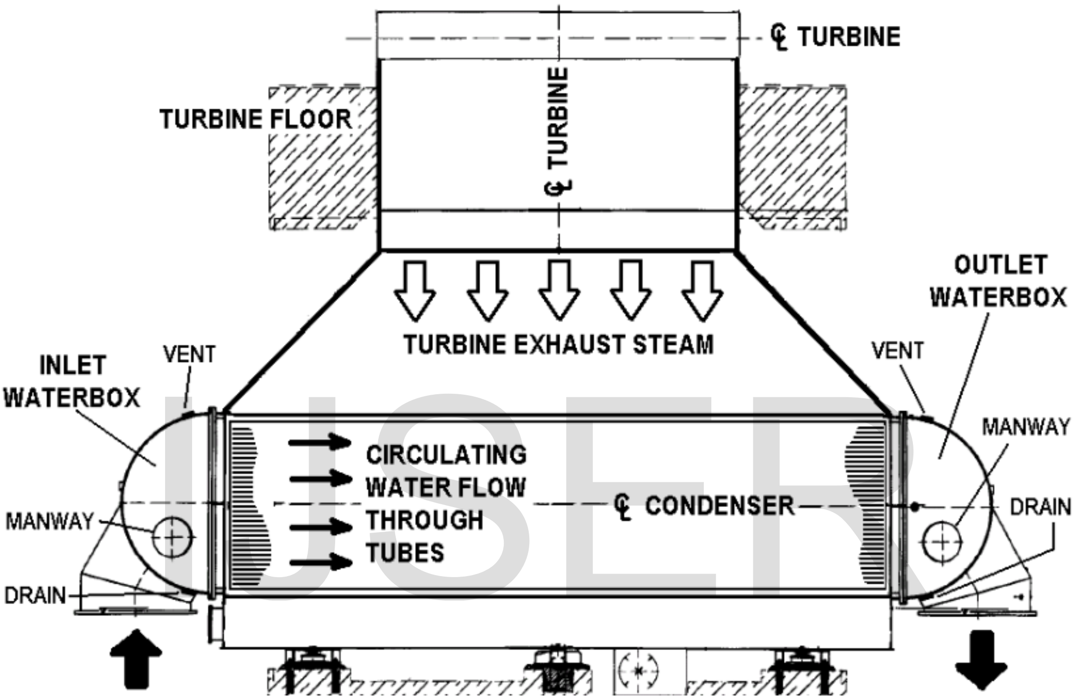


*Figure 9-condenser side view*

### 3.5 Advantages and disadvantage of surface condensers

**Advantages**

- Can be used for large capacity plants.
- High vacuum can be created.
- Condensate is free from impurities and can be reused as feed water to boiler.
- See water can also be used as cooling medium.

**Disadvantages**

- Design is complicated and costly.
- High maintenance cost.
- Occupies more space.
- Requires mor circulating water.

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### 3.6 Condenser efficiency

It is defined as the ratio of difference between the outlet and inlet temperature of cooling water to the difference between the temperature corresponding to the vacuum in the condenser and inlet temperature of cooling water.

## 4. RESULTS

The results showed that the vacuum pressure inside the capacitor is affected by the following factors: -

- The flow rate of the cooling water.
- The entry temperature of the steam condenser cooling water.
- Steam turbine convection.
- Steam condenser cleaner.
- The percentage of air inside the condenser due to leakage or poor performance of the vacuum pump.

Experiments were carried out by the steam station simulator, and the loads of the steam unit were raised to 50%, 60%, 70%, 80%, 90% to 100%, and a study of thermal stability was carried out as shown in the figure (10)

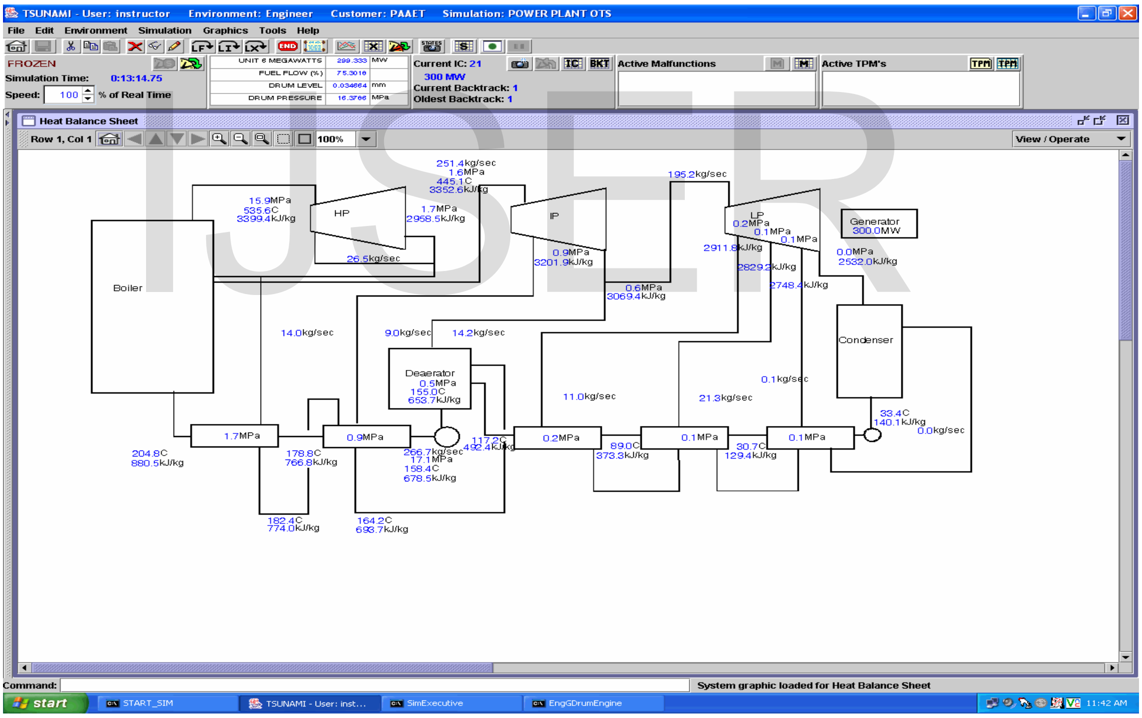


*Figure 10- Heat balance of steam unit by steam power station simulator*

## 4.1 Effect of increasing heat load

When the cooling water flow remains constant and heat load increased, the following variables will:

- Increase saturation pressure and saturation temperature inside the condenser.
- Increase terminal temperature difference.
- Increase temperature rise.

Figure (11) illustrated the effects of an increased heat load on the condenser vacuum pressure, where the heat load increased give rise to increase condenser vacuum pressure because of increasing saturation pressure and saturation temperature inside the condenser.

*Table 2 - Heat load and condenser vacuum pressure at variation temperatures*

| Heat Load | CONDENSER PRESSURE ( mm bara) | | | | |
|---|---|---|---|---|---|
| | At $T_{I.C.W}$=25°C | At $T_{I.C.W}$=28°C | At $T_{I.C.W}$=30°C | At $T_{I.C.W}$=33°C | At $T_{I.C.W}$=36°C |
| 55 | 54 | 63 | 73 | 84 | 98 |
| 60 | 60 | 67 | 78 | 88 | 99 |
| 60 | 64 | 70 | 82 | 93 | 105 |
| 65 | 66 | 73 | 85 | 97 | 105 |
| 70 | 69 | 76 | 89 | 102 | 113 |
| 75 | 72 | 80 | 92 | 103 | 114 |
| 80 | 76 | 84 | 96 | 104 | 116 |
| 85 | 79 | 88 | 101 | 112 | 122 |
| 90 | 83 | 92 | 105 | 115 | 127 |
| 100 | 87 | 101 | 109 | 119 | 131 |

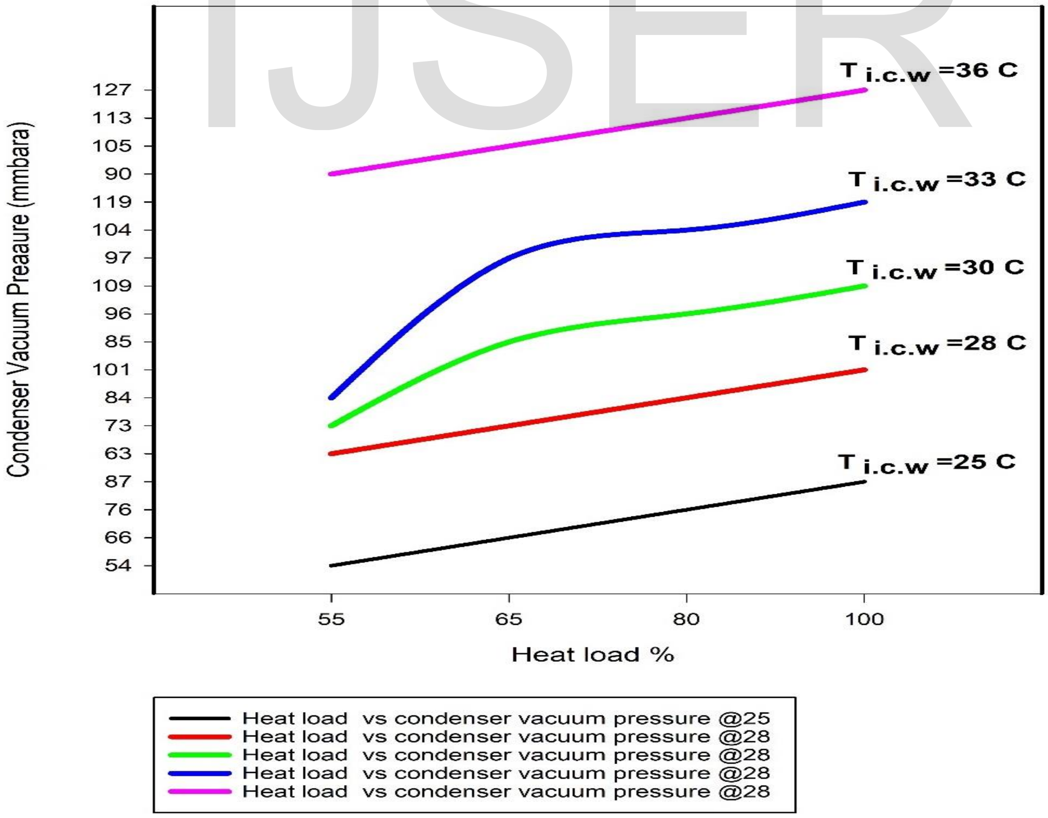


*Figure 10- Effect of increasing heat load on condenser vacuum preassure*

## 4.2 The effect of increasing the incoming cooling water temperature

When cooling water inlet temperature is higher than design cooling water temperature, then the condenser vacuum pressure increases, and the condenser performance is less than design and thermal efficiency is lower than the optimum efficiency (figure 11When the turbine load and the cooling water flow rate of the evaporative condenser are constant factors, the following parameters increase:

- Saturation pressure inside the condenser.
- Saturation temperature inside the condenser.

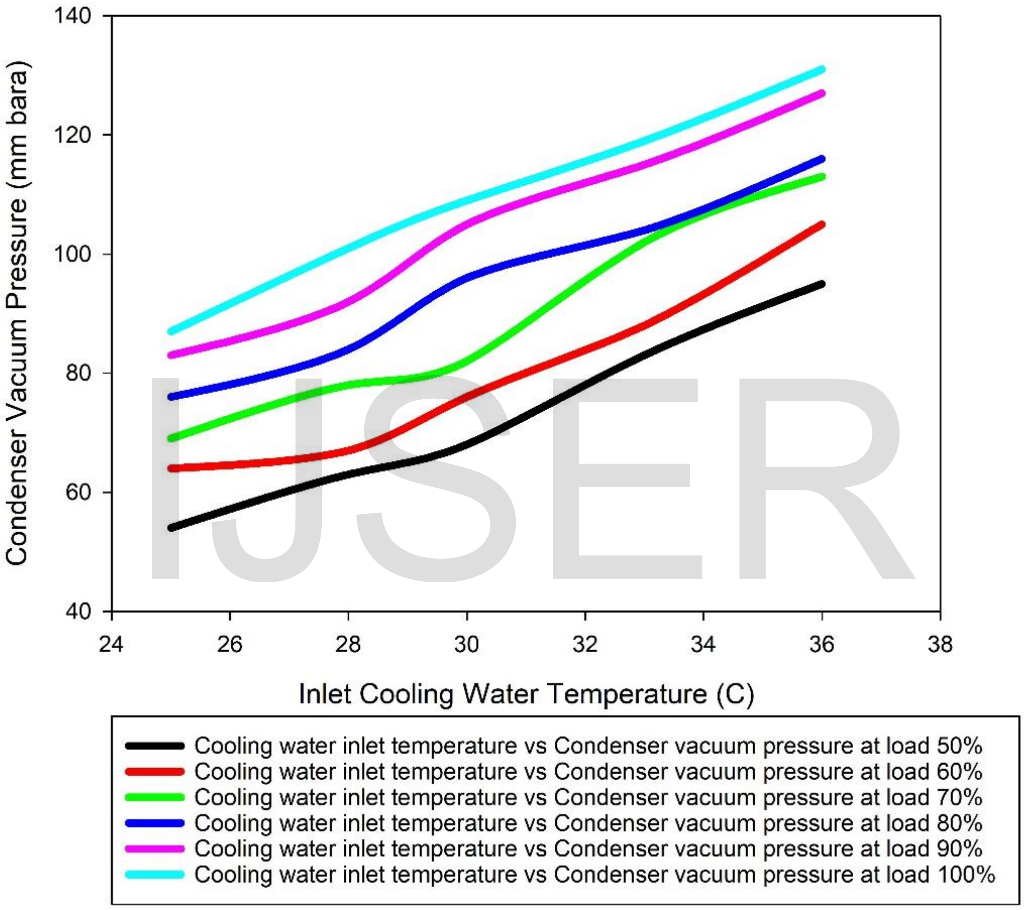


*Figure 11-Effect of increasing in cooling water inlet temperature*

## 4.3 Impact of air leakage or poor performance of vacuum pumps

When the heat load from the turbine is stable, the cooling water flow rate, and the air leakage increases or the vacuum pump does not work efficiently, and these reasons lead to an increase in the saturation pressure and thus the saturation temperature inside the condenser and the temperature difference station. Experiments have shown that the sources of air entering the steam condenser are:

- Air leakage from the atmosphere from the flexible connections connected to the steam condenser.
- Air dissolved in the exhaust steam from the turbine is separated into the condenser upon cooling.

## 4.4 Effect of a decrease in heat transfer

When the heat load and cooling water flow remains constant fouled or plugged tubes causes the following variables to increase

- Saturation pressure and saturation temperature inside condenser
- Terminal temperature difference.

## 4.4 Effect of reduced cooling water flow

The study showed that there are problems in the rotating cooling water pump, or blockages in the steam condenser tubes, or the cooling water inlet valves or water boxes, and when the heat load of the steam coming out of the turbine is stable, the saturation pressure and temperature increase due to the reduction of the cooling water flow. Also, the vacuum efficiency of the capacitor decreases as shown in Fig. (11)

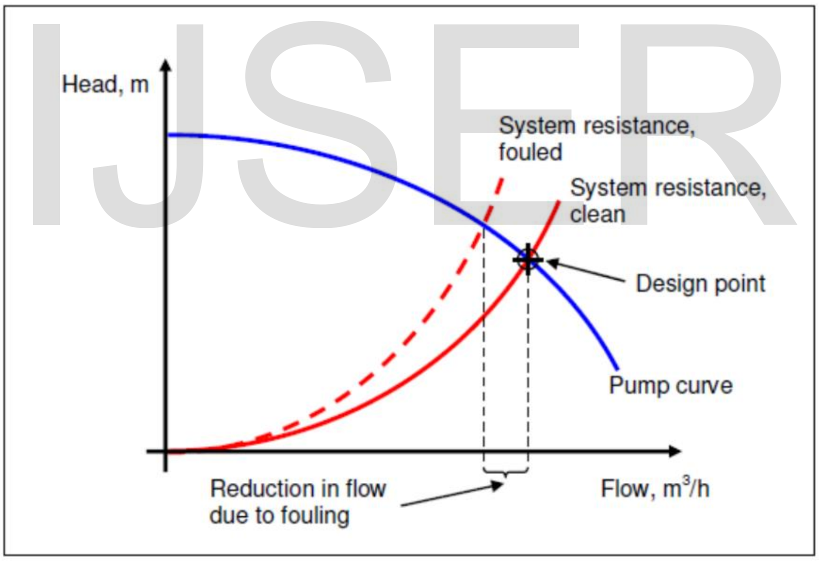


*Figure 12-Pump performance curve and the effect of condenser fouling*

## 5. CONCLUSION

This paper aims to clarify the areas of thermal energy losses in thermal power plants to produce electrical energy, and thus the thermal efficiency of the plant can be improved. The results of the research showed that the thermal efficiency of the station could be improved by raising the efficiency of the steam condenser of the steam unit, by improving the vacuum pressure of the condenser and reducing the temperature of cooling water entering the condenser. The effect of air leakage in the condenser leads to: -

- Lower thermal efficiency
- Increase the flow rate of the condenser rotating cooling water.
- Increased heat energy losses
- Increased chemical corrosion.

To get the highest condenser efficiency and the best vacuum efficiency, we recommend the following: -

- Regular maintenance of vacuum pumps to obtain their highest performance.
- Clean the steam condenser tubes frequently.
- Get cool water with a lower temperature.
- Tightening the flexible connections between the condenser and the pipes entering it.

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