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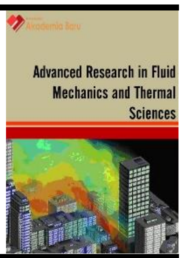

Improvement of Low Performance Condensates in Thermal Power Plants: Case Study

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ABSTRACT

More than 60% decreases in the generating capacity of most electricity generating units has been observed in recent times. This reduction in the performance of steam power plants is higher for part and full load operations. Therefore, in this study, the performance evaluation and calculation methodology of the condenser of steam power plants are presented. The best condenser pressure which can be achieved in ideal operation conditions has been evaluated by real time parameters. Condenser performance study was carried out with respect to the steam flow rate, condenser pressure, and make up water. The result show that increasing the fouling thickness to 3 mm led to increase condenser pressure to 30kPa at the plant full load. A combination of the data acquired of the steam condenser from the simulator, actual measurement, and the existing literature suggests the accuracy of the proposed equations.

1. Introduction

A condenser is a device for heat transfer; it is also used to condense a substance from its gaseous phase to a liquid phase through a cooling process [1-4]. During condensation, the latent heat of the substance is released and transferred to the condenser coolant. Water or surrounding air is mainly used as coolant in most condensers [5-7]. The condenser is mainly used for the purpose of condensing the exhausted steam received from a steam engine or turbine. The reutilization of the steam energy which would have been lost to the environment remains the major advantage of using condensers [8,9]. Steam is usually condensed to a pressure lower than the atmospheric pressure by a steam condenser, thereby allowing the turbine or engine to work more efficiently. The discharge steam is also converted back to the feed water by the condenser, thereby, returning it to the steam generator [10-12]. The latent heat of condensation in the condenser is conducted to the coolant flowing through the cooling tubes. Practically, power plants installation come with several constraints which tends to either increase or reduce the power output of the installed system or the heat rate of power plants. As such, the expected performance of the designed power system may not be [13-15].

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The accumulation of unwanted materials which can reduce the heat transfer capacity of a surface on the surface of processing equipment is known as fouling or fouling. A major problem in heat transfer equipment is the scale of heat transfer surfaces [16-20]. Fouling is a complicated phenomenon and can be fundamentally characterized as a combination of unsteady state, momentum, mass and heat transfer problem with the possibility of chemical, solubility, corrosion and biological processes taking place. Fouling is a major heat transfer problem that is yet to be resolved [21-23]. A new model for the calculation of heat transfer during airflow through finned tubes bank has been developed by [24,25]. The studied parameters were the air flow velocity, the outer equivalent diameter of the bare tubes, ambient temperature, height, number and thicknesses of fins. A mean deviation of 6.5% was reported in 84.8% of the correlated experimental data [26-29].

A test rig made of a rectangular transparent channel was installed. In this rig, electrical heaters were meant to simulate the refrigerant side and PID-controlled Pt100 resistance temperature detectors were installed. The PID controls the outer surface temperature, as well as the water and air operating conditions [28,30-32]. This provides the chance to perform a sensitivity analysis based on the parameters that influence these thermo-fluid dynamic phenomena [33-39]. The results showed a decrease in the cooling rate with the dry bulb temperature and air relative humidity, while increases with temperature and water flow rate. The maximum improvement achieved from the testing case was the increasing water flow rate of 37 % and temperature by 14 % [40-42].

The factors that can cause high pressure as mentioned above include air leakage in the condensation system and parts of the low-pressure turbine deficiencies in the performance of major air repellents, and the failure to put the heat rate through intensive surfaces, resulting from the accumulation of debris on the surfaces of the inner tubes.

The work presented in this paper is a case study on the determination of the cause of high pressure in condensers and the low level of generation of various units.

2. The Study Method

The undertaking to examine the process is not possible because of the precision situation and the impossibility to shut down any unit for a long time to conduct experiments on them. There is also a lack of information from the manufacturer and inaccuracy of the daily operational information due to lack of various sensors in the original design and lack of calibration of the existing ones for long periods. Due to these reasons, it is hoped that the present study on a mathematical model of the condenser and the parts associated with the station can be achieved and compared with the operating information recorded by the station delivered by the company (which will be referred to here as the information design). Then, the model will be used to establish the cause of the problem under study.

3. The Mathematical Model

A study of the initial data on the condenser used in the station was performed where it was found that the intensive was designed within the approved specifications in power plants in most of the paragraphs. Because of the shortage of design specifications as previously mentioned, the standard specifications were adopted whenever necessary. Figure 1 and Table 1 shows a schematic of the condenser in its design while Figure 2 show the heat balance scheme of the condenser and the flow of cooling water in the system. The heat balance produced by the condenser is given as Eq. (1) [43-45].

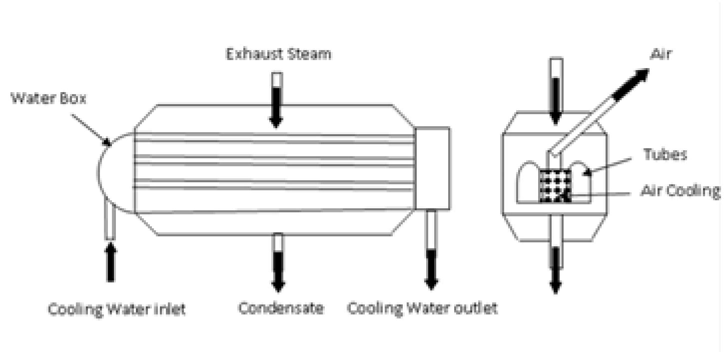

Fig. 1. Schematic of condenser

Table 1
Classification of condensers

No.	Sample	Classifications
1	Tubes Number	5188
2	Pass Water Number	1
3	Pass Type	Across
4	Flow rate Water	10800 ton/hr.
5	Flow rate Steam	Change at power
6	Coefficient of design	0.85

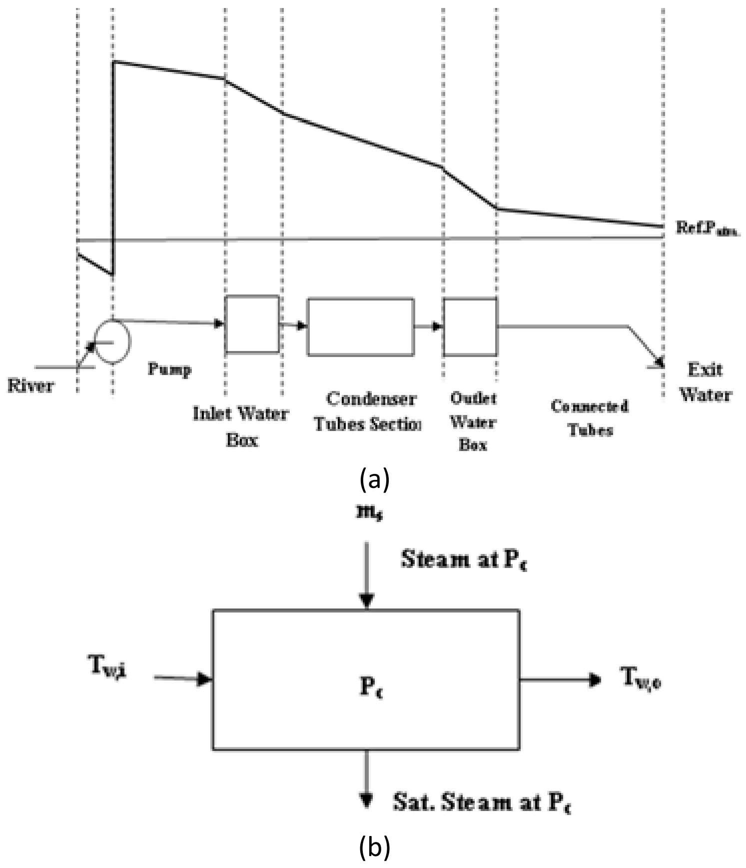

Fig. 2. (a) Pressure drop with cooling water system (b) Heat balance of condenser

$$Q^{\cdot} = U \times A \times LMTD \tag{1}$$

where

Q= The heat rejected in the condenser.
UA= The total value of the thermal conductivity of the condenser.
LMTD= logarithmic difference of temperature between steam and cooling water.
If we assume that the fouling thickness is regular in the tubes, then, *X* equals the millimeter *U* which is equal to

$$U = 1.0/[(1/UC) + (X/k) \tag{2}$$

where

K= Thermal conductivity coefficient of material fouling.
UC= Overall conductivity coefficient cleanliness of the condenser. It is given by the following equation for pipes made of Admiralty metal as used in the condenser in this study [46-48]

$$UC = 263 \times \sqrt{(V_t \times F_t) \times F_p} \tag{3}$$

where

Vt= the velocity of the water flow in the pipes.
Fp= Coefficient engine type.
Ft= Correction factor for the temperature of the water inlet

$$F_t = 0.311 + 0.012T_{wi} - 4.105 \times 10^{-6}\,(T_{wi})^2 - 3.397 \times 10^{-7}(T_{wi})^3 \tag{4}$$

where

Twi: The temperature of the water inlet into the condenser.
It is written as the heat balance of the cooling water and steam produced [49, 50].

$$Q \;= \dot{m}_w Cp\,[T_{(w,o)} - T_{(w,i)}] = \dot{m}_{shfg} \tag{5}$$

where

Hfg = The heat latent of evaporation of water at the condenser pressure, it is derived from the equations shown in Figure 3(a) and (b) and gives the relationship between the velocity of the water flow in the pipes and the water flow rate equation [5, 51]

$$\dot{m}_w = \rho_w \times N_t \times \pi(D_t - 2X) \times V_t \tag{6}$$

where

Nt = Total number of tubes in the condenser.

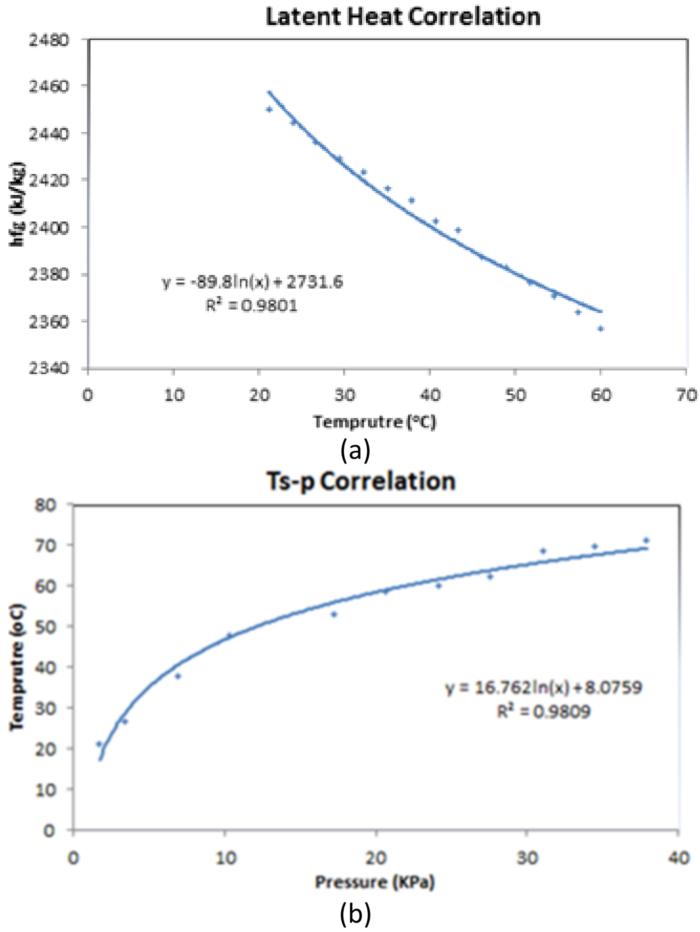

Fig. 3. (a) Latent heat with water saturated temperature (b) Pressure with water saturated temperature

Assuming a constant power to the engine cooling water and the use of the design values of the condenser pump, the amount of water pumping associated with the total pressure drop in the system is given by [52, 53]

$$\dot{m}_w = 556300.8\rho_w(\Delta P_{tot})^{-1} \tag{7}$$

where the drop of the total pressure consists of the total regression pipes and boxes of entry and exit, and the rest of the conductive pipe and is calculated from [45, 54-56]

$$\Delta P_{tot} = \Delta P_{tube} + \Delta P_{boxes} + \Delta P_{sets} \tag{8}$$

And its components are calculated from

$$\Delta P_{tube} = \{0.4 \times X + 8.348 \times 10^{-3}(V_t\ )^{1.792}\} \times L_t \tag{9}$$

$$\Delta P_{boxes} = 0.07263(V_t\ )^{1.5278} \tag{10}$$

$$\Delta P_{tube} = \left[\frac{\dot{m}_w}{21267.73\rho_w}\right]^2 \tag{11}$$

It should be noted here that Eq. (6), (9) and (10) have been introduced to impose usage rates of condensers power plants; Eq. (7) and (11) relates to data delivery to the station under study. For the purpose of linking the above relationship from the operational capacity of the station delivery to the station from the manufacturer's data, it has been studied and represented in Figures 4-6 to show the effect of condenser parameters (steam flow rate, condenser pressure, and make up water) on the unit power generation under ideal conditions.

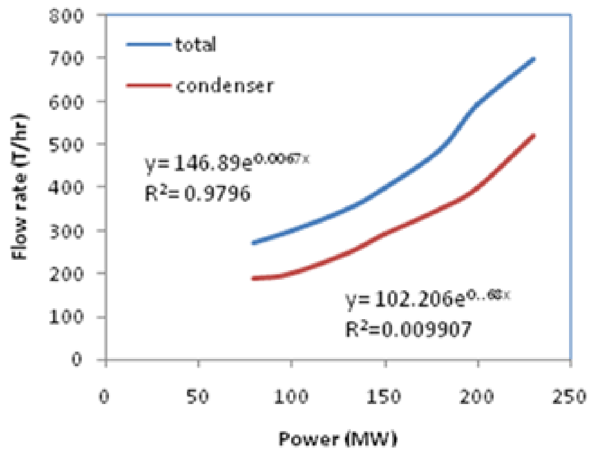

Fig. 4. Flow rate steam with power generated design unit

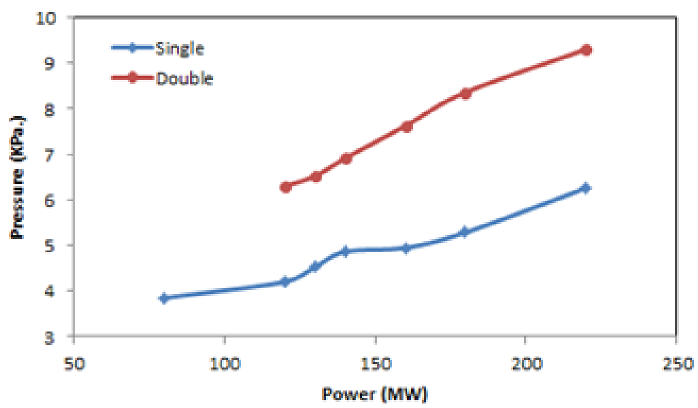

Fig. 5. Condenser pressure with power generated design unit

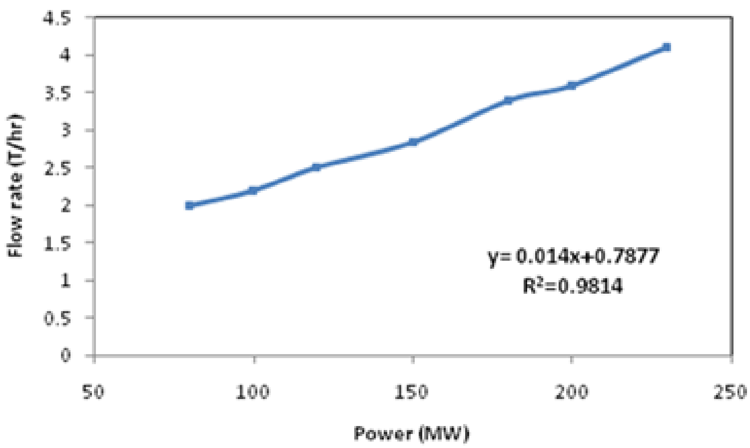

Fig. 6. Make-up water with power generated design unit

4. Fouling Mathematical Model

The performance model was used to find the relation for the calculation of the values of the thermal conductivity and fouling thickness on the inner wall of the tube. From the previous studies on the thermal conductivity value, it was found to be about 1.3-3.3 W/m.°C. To know the real amount of the fouling thickness in the condenser tubes and to complete the performance calculations of the model, the initial values of the fouling thickness was assumed to range from 0 to 3 mm and the following equations were adopted [57]

$$P_{c/predicted} = P_{o/(from\ design\ data)} \tag{12}$$

$$F_c = 0.85 = U_c\ /\ U \tag{13}$$

The best value reached was *k* =2.163 W/m.°C which represent the best estimate of the thermal conductivity of the material fouling in the condenser under study. It gave the best representation of the work pressure of the condenser with the power ranging from 80-220 MW as shown in Figure 7. As it turns out, the thickness of fouling equivalent of (0.1 mm) represents the recognition of the excellent state of intense clean modern construction, as shown in Figure 8. Also, the thermal model achieved these values using the results of accelerated flow in pipes and low pressure in the intensive approach to the design values (upon delivery) which increases the confidence in the model.

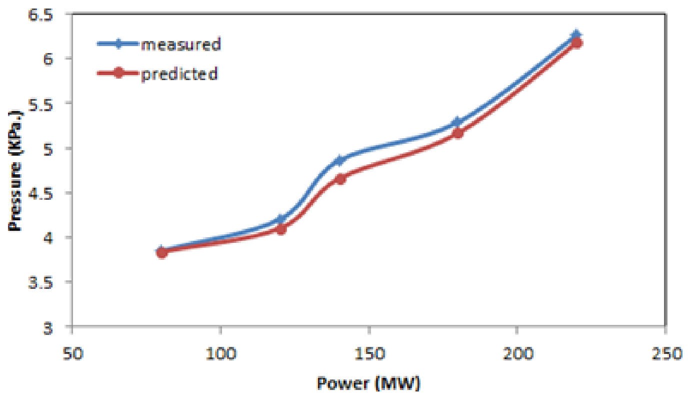

Fig. 7. Comparison of the measured and predicated condenser pressure

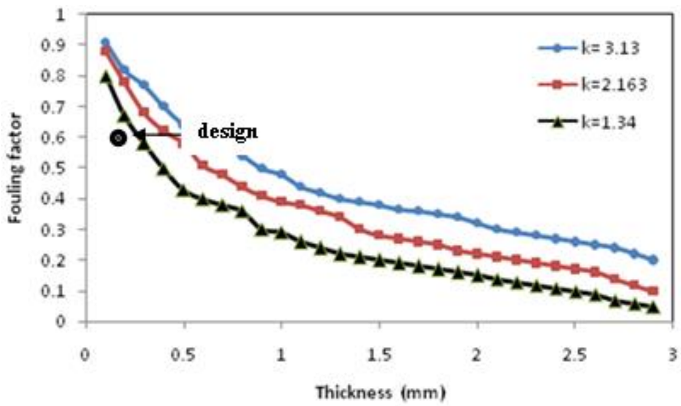

Fig. 8. Variation of the fouling factor with scale thickness at different scale conductivities

5. Results and Discussion

Figure 9 showed that the effect is clearly evident when the thickness causes a high scale (3 mm) to lift the condenser pressure to six times the value of the design at the maximum capacity of the unit. If we consider that the fouling rates in the condensers is up to 4 or 5 mm after an operating period of up to six months, and it's up to 1 mm after about one to two months (according to the obtained information from technical staff and viewing in situ), we can conclude first, that dense fouling is the reason behind the problem following the detailed reasons that fouling causes the reduction of thermal conductivity value to quarter when fouling is up to 2 mm, as shown in Figure 10. Despite an increase in the conductivity value of the surface clean, there was an increase in flow velocity inside the tubes as shown in Figure 11. The fouling also decreased the thermal conductivity value of surfaces condenser but increased the slope of the cooling water pressure through the effect inside the condenser, as shown in Figure 12. It also decreased more than 20% of the amount of cooling water flow through the system, as shown in Figure 13 and increased the temperature by 14% at the maximum power of the unit, as shown in Figure 14.

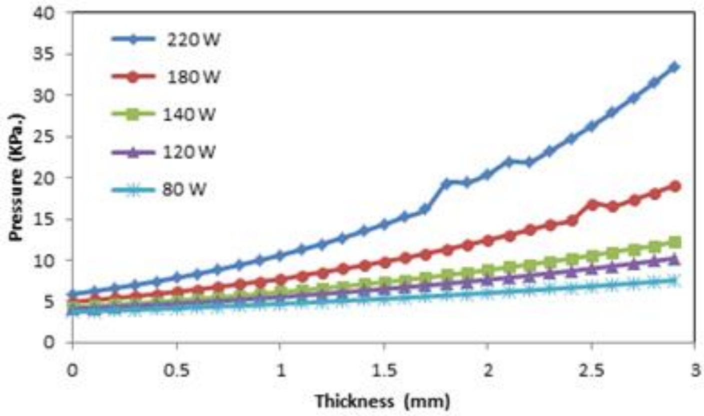

Fig. 9. Variation of the condenser pressure with the fouling thickness at different power generation levels

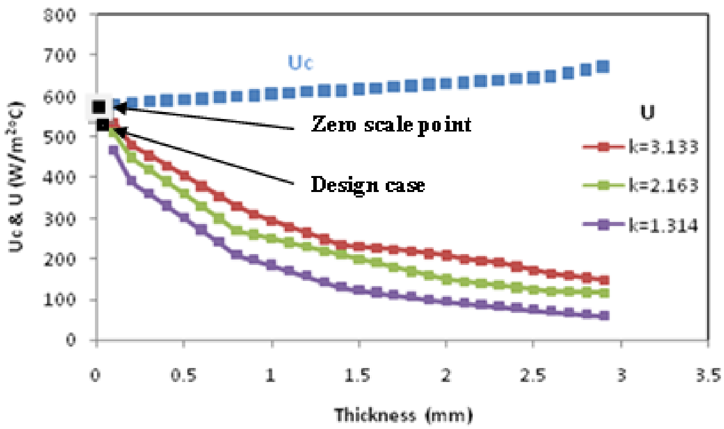

Fig. 10. Overall conductance of the condenser with and without fouling effect

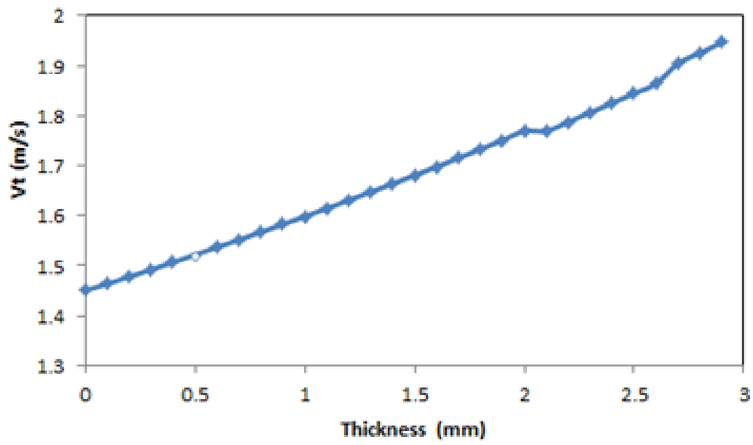

Fig. 11. Variation of tube velocity with fouling thickness

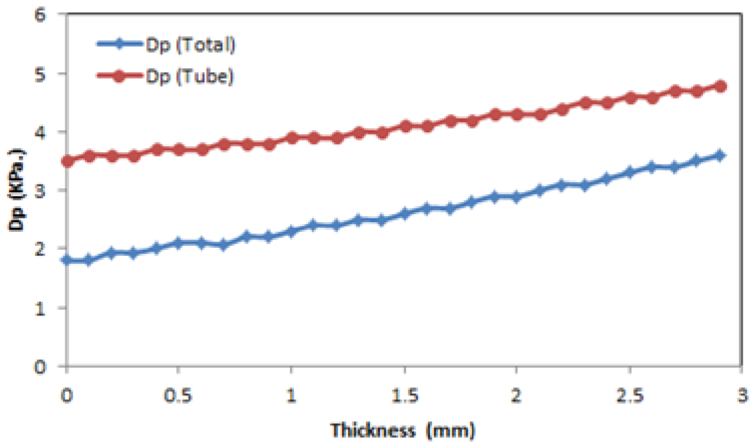

Fig. 12. Pressure drop with fouling thickness for tubes and the whole system

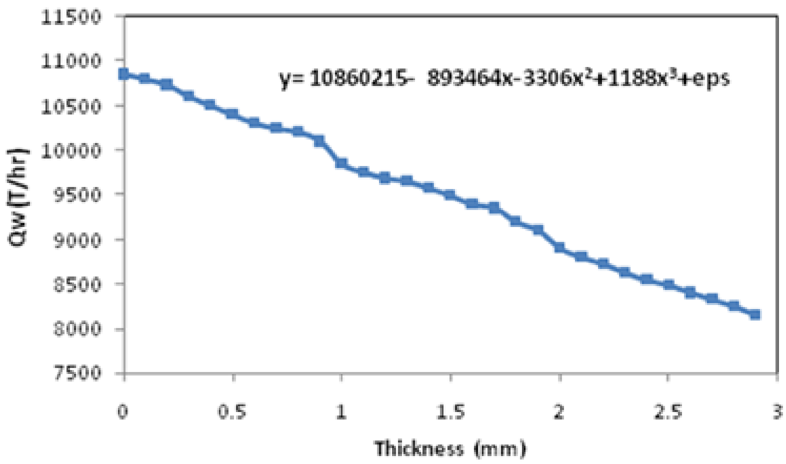

Fig. 13. Variation of the condenser water flow rate with the fouling thickness

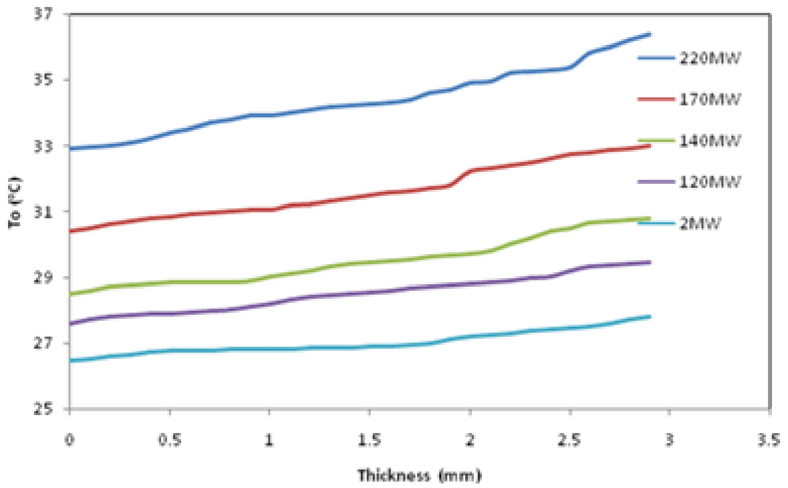

Fig. 14. Variation of water outlet temperature with fouling thickness at different power levels

An increase in the verified results has two different cases for same unit; the first includes the operating data for the unit by the intensive cleaning condenser, and the second after undergoing annual maintenance and condenser cleaning by acids only. Table 2 showed the state of the condenser before cleaning. This table points toward two main points, namely, the rise in the amount of steam required to generate the same power based on the design operation conditions. Meanwhile, the amount of extra steam required to reach to same power generation was about 13.25% and it was clear to note that make up water for boiler was about 12.6 times with respect to the design data. The increase in the amount of steam flowing through the condenser was about 17.5%. The high steam passing through the condenser is as important as the sintering agent. Both works together to raise the condenser pressure to the measured values shown in the table above. The fouling value estimated for this case (2.3 mm) is close to the value seen by the staff operating in the station. Compensatory compensative

Table 2
The results of the condenser condition before cleaning.

Sample	Measured	Model
Power generated	95 MW	95 MW
The amount of the steam through a turbine	320 ton/hr	277.6 ton/hr
The estimated amount of steam through the condenser	258.6 ton/hr	220 ton/hr
The estimated value of fouling		2.3 mm
The value of the sintering plants		0.187
Condenser pressure when the amount of steam flow is measured	14.185 KPa	14.185 KPa
Condenser pressure when the amount of steam flow is estimated from the design data at the same fouling		11.652 KPa
The estimated quantity of water from the design model compensation	30 ton/hr	
The estimated quantity of water from the design model compensation		22 ton/hr

Table 3 shows the comparison of the measured results of one of the units after maintenance and cleaning the condenser with acid using a mathematical model. The results show that the acid washing alone is not enough to clean the fouling after long periods of operation in terms of results recorded (an increase in the value of the steam by 14.7% and an increase in compression ratio by more than 20.8%. This resulted in the increased in the value of the fouling to 0.8 mm after considering that there were 2000 tubes left in the condenser during modeling which is equivalent to 20% of the total surface area of the condenser. This is to say the increase in pressure condensation produced here was for three reasons: the decrease in the surface area of the condensation, the decline in the value of the total thermal conductivity of the surface condenser, and the increase in the amount of steam flowing through the condenser. It is also due to the sharp decline in the amount of cooling water as a result of the closure (20%) of the tracks inside the condenser.

Table 3
The results of the condenser condition after cleaning.

Sample	Measured	Model
Power generated	150 MW	150 MW
The amount of the steam through a turbine	400 ton/hr	401.2ton/hr
The estimated amount of steam through the condenser	400 ton/hr	318 ton/hr
The estimated value of fouling		0.8 mm
The value of the sintering plants		0.466
Condenser pressure when the amount of steam flow was measured	10.132 kPa	9.929 kPa
Condenser pressure when the amount of steam flow was estimated from the design data at the same fouling		7.676 kPa
Value design pressure condenser		4.863 kPa
The value of the decrease in water pressure	0.374 kPa	0.324 a

6. Conclusions and Recommendations

We conclude from all this that the main problem behind the high pressure condensers and low generation capacity of the plant units are rapid and large fouling within the condensate pipeline. This rapid construction is due to three main reasons.

I. Design value is low to accelerate the water flow inside the tubes (1.8m/sec) compared to the values established in the condensers used in the power plants (up to 2.5m/sec). If we know that the fouling rate is inversely proportional to the flow velocity, we know the reason behind the rapid development of fouling.
II. Incoming water quality of the river (loaded with clays). This is clear from the examination of the fouling model which turn out to be composed of fouling mud rather than fouling salt, supporting the reason for the higher assessed value of the thermal conductivity of fouling as the sediment mud carry within them a high amount of moisture which can increase conductivity.
III. The operating officer often close the valves of incoming water flow to the condenser in order to maintain the temperature between the water outside and the water inside. This leads to a greater reduction in the accelerated flow inside the tubes and an increase in the amounts of fouling above the normal value.

To solve this problem, we recommend the following.

I. To maintain the ability of the water pump at the highest level, always use all the river water pumps and maintain the control valves. Leave the work control system according to the difference in the degree of cooling water temperature.
II. Snails monument at the entrance to the pipes for the purpose of increasing the flow velocity to be used in skimming deposits.

III. Add washing systems to the reverse flow during the work station at intervals of not more than one month; reduce the unit load and work with one condenser.
IV. Mechanical cleaning at intervals of not more than six months is needed.

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