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# A Review on Thermal Performance Analysis of Steam Surface Condenser

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***Abstract* - The steam condenser is one of the important components in a power plant which significantly affect the power generation and performance of unit in terms of heat rate. Deterioration in thermal performance of condenser not only affects the power generation but also thermal performance of unit as a whole. The parameters that are responsible for condenser thermal performance are cooling water (CW) mass flow rate, temperature, heat transfer area, velocity, tube fouling, partially filled water box and air leakage. CW flow rate and condenser pressure changes according to the variation in unit load. The CW temperature at condenser inlet varies according to change in annual temperature cycle of the intake system. During operating condition, the condenser performance is subject to change with variation in exhaust steam and CW parameters. The operating conditions of steam surface condenser are of the great influence on the power generation and the turbine cycle heat rate. At the same time, the operating conditions of the CW system determine the operating condition of the condenser.**

***Keywords*- Condenser effectiveness, Cooling water flow rate, Cycle heat rate, Thermal performance.**

## 1. INTRODUCTION

The condenser is a heat transfer device or unit used to condense a substance from its gaseous to its liquid state, typically by cooling it. In doing so, the latent heat is given up by the substance, and will transfer to the condenser coolant. Use of cooling water or surrounding air as the coolant is common in many condensers. The main use of a condenser is to receive exhausted steam from a steam engine or turbine and condense the steam.

The benefit being that the energy which would be exhausted to the atmosphere is utilized .A steam condenser generally condenses the steam to a pressure significantly below atmospheric. This allows the turbine or engine to do more work. The condenser also converts the discharge steam back to feed water which is returned to the steam generator or boiler. In the condenser the latent heat of condensation is conducted to the cooling medium flowing through the cooling tubes. [1]In practical situations, when power plants are installed there are lots of constraints. This tends to reduce or increase output power and heat rate of thermal power plants. Due to these conditions, the designed power and heat rate are never achieved. [2- 5]

## II. ROLE OF CONDENSER IN THERMAL CYCLE

Condenser is simply not a closing link, but a vital one in the thermal cycle. Constant temperature heat rejection is taking place here. It is the only process similar in Carnot and Rankine cycles. The latent heat of exhaust steam of Turbine is absorbed as sensible heat by the circulating water. To extract maximum work from the steam expanding in the Turbine, expansion of steam should be high. Since the condenser helps in maintaining high vacuum that is practically possible, maximum work can be expected. If the steam had exhausted at atmospheric pressure, this would not have become possible.

## III. LITERATURE REVIEW

Pattanayak et al. (2019) describes the influence of CW parameters on the condenser as well as unit performance. The dependency of CW parameters with heat transfer coefficient, condenser pressure and heat load is established for a 210000 kW power plant condenser. This study shows that the optimum condenser pressure that can be maintained in the condenser at CW temperature of 33 °C is 10.10 kPa. Under this condition the CW flow rate will be 25550m$^3$/h with condenser heat load of 292150.98 kW.

With a fixed CW temperature as 33 °C and steam flow rate of 127.5 kg/s (for 100% load), with increase in CW flow rate from 15000m3/h to 40000m3/h condenser heat load increases with a reduction in effectiveness. Having the dependencies as explained above, it is evident that for a given power generation, with higher CW temperature, the heat rate of the power cycle deteriorates. To optimize the condenser operation and improve the power cycle heat rate, CW flow rate increases to maintain the same heat transfer at higher condenser vacuum. According to Reuter et al. (2018) Paint-based protective films (PPFs) are used to protect condenser tubes from corrosion and erosion but have been shown to be susceptible to biofouling. Here, the biocidal properties of copper-oxide fillers incorporated into PPFs are explored in this research. Specifically, two PPFs filled with 20% and 50% filler (by weight) are tested in parallel with a non-biocidal ordinary epoxy PPF, and bare stainless steel tube. Using double-pipe co-current flow heat exchangers installed at a thermal power plant, actual cooling water exiting the condenser is evenly distributed between the test tubes. Heat transfer in the condenser is simulated by heated water flowing through each annulus of the double-pipe heat exchangers, thereby maintaining repeatable outer convection conditions. An exposure test of 125 days shows that the 50% biocide-filled PPF has the lowest fouling factor of all the tubes.

The non-biocidal epoxy has the highest fouling factor and the 20% filled PPF behaves similarly. Both of these are greater than the bare stainless steel control tube. The 50% filled PPF is compared to the fouling of an existing admiralty brass tube and the shapes of the fouling curves are similar. This evidence suggests that provided the filler concentration is sufficiently high, there is the potential for the copper-oxide filler to reduce the asymptotic composite fouling factor by virtue of its antibacterial properties.Davies et al. (2018) had done the study on condenser with brazed aluminum fins. The condenser measures 10.72 m in length, with a cross section of 214 mm × 16 mm. The condenser tube was cut in half lengthwise and covered with a polycarbonate viewing window in order to provide visualization access simultaneously with the heat transfer measurements. Inlet steam mass flux ranged from 6.2 to 9.5 $kg\,m^{-2}\,s^{-1}$, and condenser capacity varied from 25 to 31 kW. The angle of inclination was varied from horizontal to 75° downward. The experiments were performed with a uniform fin-face velocity of crossflowing air at 2.2 m/s.

Condenser capacity was found to increase linearly with increasing downward inclination angle of the condenser, at a rate of 0.041% per degree of inclination below horizontal. This improvement was found to be the result of improved drainage and increased void fraction near the condenser outlet.Pattanayak et al. (2017) a CCPP consisting of triple pressure steam cycle with reheat is analyzed using both energy and exergy. Effect of ambient temperature, inlet and exhaust pressure loss, CCPP load, excess air percentage, cooling water temperature, and condenser vacuum has been investigated. Energy and exergy- based performances are compared and presented. The simulation results show that efficiency of CCPP decreases with increase in the inlet and exhaust pressure loss and with increase in inlet air temperature to compressor. The total power output of CCPP decreases at higher inlet air temperature with increase of steam flow rate in bottoming cycle and increase in compressor power consumption. The exergy efficiency of combustion chamber, heat recovery steam generator, and condenser are found to be 77.48%, 87.20%, and 29%, respectively; and the overall exergy and energy efficiency of the unit at 100% design and operating condition is found to be 54.09%, 58.26% and 53.92%, 57.10%, respectively. The overall exergetic efficiency of the CCPP can be improved by reducing the losses in bottoming cycle.Masiwal et al. (2017) concluded that condenser back pressure improves due to drop in CW inlet temperature when compared to design CW inlet temperature. Variation in condenser back pressure due to deviation in CW inlet temperature will be considered as negative whenever cooling water inlet temperature would be less than the design cooling water inlet temperature. Significant deviation in condenser back pressure is observed due to lower CW flow than the design; causes for lower CW flow may be poor performance of CW pumps or due to low suction head. It presents off design performance evaluation and calculation methodology of a surface type condenser. Best condenser pressure which can be achieved in actual off design conditions has been evaluated by real time parameters. Condenser performance study has been carried out for cooling water flow, cooling water inlet temperature, and for air ingress/dirty tubes. This method can be proved useful in the case where no curve regarding variation of condenser back pressure verses cooling water inlet temperature is available.

All data for performance has been collected and evaluated from a 525MW operating unit of Bharat Heavy Electricals Limited.Naik et al. (2017) carried out in order to validate the predicted performance data of air cooled and water cooled condensers (using R134a as a refrigerant) from the developed correlation models. The heat rejection capacity is used as a performance indicator for aforementioned condensers. Three correlation based models using DOE, identified parameters and dimensionless groups have been developed for predicting the performances of the air cooled and the water cooled condensers. Comparison of these correlation based models with the experimental data were found to have good agreement and match within ±13%, ±5% for DOE, ±18%, ±5% for identified parameters and ±15%, ±8% for dimensionless groups of air cooled and water cooled condensers, respectively.

Also, a comparison of these correlations with the catalogue data provided by different manufacturers (Trane, Carrier and Clamaveneta) of air cooled and water cooled condensers found to have good agreement. The correlation based models developed in the present study can be extended to any practical applications for continuous online monitoring of the performance of the condensers and also for comparing the performance of the condensers manufactured by different industries. The performance analysis presented in this manuscript can be

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used as a reference tool for estimating the condenser performance of both air cooled and water cooled condensers.Laskowski et al. (2016) formulates two simplified equations for the steam power plant condenser effectiveness and the cooling water outlet temperature as functions of the parameters and reference conditions mentioned above. The proposed relations were verified against data obtained using a steam condenser simulator (written in Fortran), actual measurement data from a power plant, and measurement data available in the literature. One of the proposed relations is explicit but its use is limited to the range of NTU (number of transfer units) between 0.5 and 1.5.

The other one is not limited to any range of NTU, but is an implicit function and has to be solved in an iterative process. The data obtained using the steam condenser simulator, actual measurement data, and data available in the literature allow the conclusion that the proposed equations provide good accuracy.Jianlan Li et al. (2016) presents a comprehensive approach to realize the on-line fouling monitoring for the condenser in thermal power plants. Based on the operational mechanism and the coupling property, an all-condition mechanism model (ACMM) of coal-fired power plants is proposed to simulate coupling operating characters of systems. The simulation results of a 600 MW/16.7 MPa/560 °C/560 ° C supercritical coal-fired power plants indicate that the model is of sufficient accuracy for performance calculations under different off-design conditions. An on-line fouling model of the condenser is presented according to simulation results of ACMM and on-line monitoring parameters from SIS system.

For the fouling model, a correction as a function of the non-condensable gas is implemented to improve the accuracy of the condensation heat transfer resistance in the steam side of the condenser. The results of the on-line fouling monitoring in the field reveal that the fouling of the condenser increased with time and the fouling growth rates kept relative stable. Furthermore, this study also provided an alarm for the leakage fault in the condenser according to the abnormal fouling resistance tend.Attia et al. (2015) presents a methodology for studying the impact of the cooling water temperature on the thermal performance of a nuclear power plant (NPP).

The main findings of this study are that an increase of one degree Celsius in temperature of the coolant extracted from environment is forecasted to decrease by 0.444% and 0.152% in the power output and the thermal efficiency of the nuclear-power plant considered, respectively. The effect of climatic changes is shown to be important in the design of more effective cooling technique and to device methods to compensate for the loss in plant efficiency. Climate considerations will also become even more important when deciding where to build new thermal power plants. So, the paper offers an additional design dimension to be considered when designing new power stations. Laskowski et al. (2015) obtained from a simulator of the steam condenser and the actual measurement data from a 200-MW power plant, an analysis was performed of how the inlet cooling water temperature, the cooling water mass flow rate, and the steam mass flow rate affect the steam condenser effectiveness, the heat flow, the steam pressure in the condenser, and the efficiency and power of the LP part of the steam turbine.

In the case of heat exchangers with a condensation zone, e.g. in a regenerative heat exchanger, the maximum value of the effectiveness ε means obtaining the maximum value of the heated fluid temperature at the outlet. Since the role of the steam condenser (providing the lowest possible vacuum) is slightly different from the role of a classical heat exchanger, increasing the value of ε does not mean better performance of the steam condenser. An even greater disparity exists in the evaluation of the performance of a system comprising the steam condenser and the LP part of the steam turbine. It was therefore suggested to evaluate the performance of the steam condenser and the LP part of the steam turbine using the parameter of efficacy, defined as: $\delta=(1-\varepsilon)=\delta t_{min} /\Delta T_{max}$. Moreover, for practical purposes, the relation (6) was given for the power of the LP part of the steam turbine as a function of the cooling water mass flow rate and its temperature at the inlet to the steam condenser. Knowing the characteristics of the LP part of the steam turbine and of the steam condenser, one can optimize operating conditions of the system.

## IV. CONCLUSION

Manufacturers and researchers have put many efforts for performance enhancement of surface condenser based on design aspectslike flow arrangement, tube configuration and material modification [3,4]. In recent years many studies have been performed whichexamine the effect of CW temperature, CW flow rate, condenser vacuum on the thermal performance of steam condenser [5–15].Assessment of condenser performance is generally performed by two methods: correction method (related to heat transfer surface area based on known CW flow rate and temperatures) and effectiveness method [16,17].

Some models [18–19] have been proposed for condenser performance assessment based on fouling, velocity and material characteristics. In the literature, attempts have been made to investigate or evaluate the condenser performance based on effectiveness method, with function of overall heat transfer coefficient, CW flow rate, heat transfer area, CW velocity, fouling model for design and off design conditions. This requires detailed design information like data related to geometry of condenser, set of equations to determine Reynolds, Nusselt and Prandtl number. Many cases it is difficult to make available complete geometric data, which leads to further difficulties to develop an accurate model.

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