Scientific Journal of Impact Factor (SJIF): 5.71
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406
International Journal of Advance Engineering and Research Development
Volume 5, Issue 04, April -2018

A CALCULATION MODEL FOR THE OPTIMIZATION OF TURBINE BACK-PRESSURE IN AIR COOLED CONDENSER

Vishal Mistry[1], Jitendra Chauhan[2], Sanjoy Paul[2]

[1]M.Tech Student, Thermal Engineering, Department of Mechanical Engineering, Parul University, Vadodara
[2]Assistant Professor, Department of Mechanical Engineering, Parul University, Vadodara

Abstract — *In recent years, direct air cooling units have developed rapidly in India, but in the actual operation, the back-pressure often deviate from the optimal back-pressure, which affect the economy of the unit. In order to figure out the optimum back-pressure multi-objective optimization process should to be carried out using the current parameters of air cooled condenser(ACC) and reducing them to optimum using mathematical modelling and creating algorithms in software to get results. The optimization objective functions will be the turbine back-pressure, and the optimization parameters should be face velocity, windward area of air-cooling condenser and number of transfer units (NTU) or any pairs of these parameters based on the requirements. This review mainly focused on various work carried out in optimization in ACC and the Turbine back pressure optimization.*

Keywords *- Air-cooled condenser, back pressure, multi-objective optimization, initial temperature difference, face velocity*

I. INTRODUCTION

Because of the diminishing accessibility and increasing expense of cooling water, dry-cooling towers or direct air-cooled condensers (ACC's) are progressively utilized to reject heat to the environment in present day power plants incorporating steam turbines. In an air cooled condenser (ACC), the rejection heat from the steam is dissipated directly to the atmosphere without using an intermediate medium such as cooling water. In this arrangement, the steam exhausting the turbine is piped to the condenser by a large diameter duct. The steam condenses in the air cooled tube bundles. The finned tube bundles are mounted in a horizontal, vertical or A- frame configuration and mounted on a steel structure support. The steam enters the tube bundles at the top of the A-frame or vertical air cooled condenser and condenses in the tube. The heat is removed by air blown over finned-tube bundle by one or more fan. The fans can be either forced or induced draft. This depends on the weather where the air is pushed or pulled through the tinned tube bundle. The condensate drains into a collection tank and is then sent back to the steam generator feed water system.

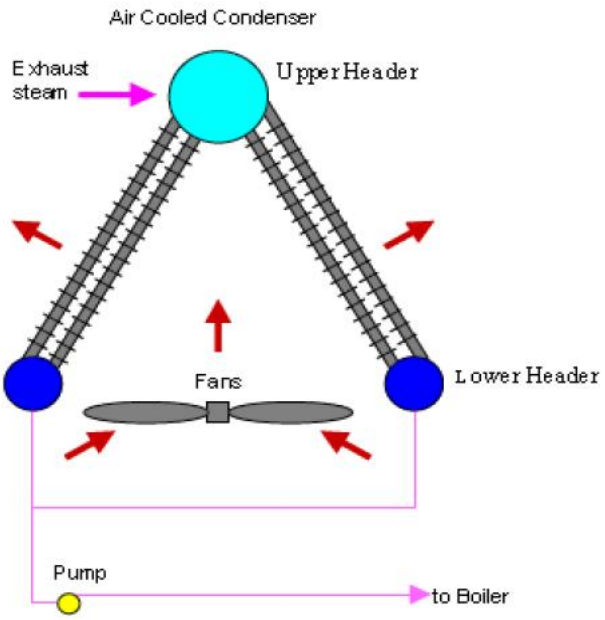

Figure 1. Typical ACC Flow Diagram

In the steam power plant industry, the reduced availability of water as the cooling medium for the condensation of exhaust steam often makes the selection of an air-cooled condenser as alternative to the traditional steam surface condenser. The following are the advantages of dry cooling with air-cooled Condensers:

1. Dry cooling system minimizes the water usage requirements and there will be no issues which are associated with blowdown disposal and plume formation.
2. Air is more abundant quantity compared to water with no preparation costs and this has brought an increase interest in the use of the air as a cooling medium in place of water.
3. ACC minimizes the environmental impacts from withdrawing water and quickly dropping it back to the cooling water source during the summer months, so causing damage to the surrounding ecosystem.
4. Water is a corrosive fluid which requires a chemical treatment to control the scaling leading to a reduction in the heat transfer rate if the deposits are allowed to accumulate. This is in contrast to air which is mostly noncorrosive.
5. Air- cooled condensers make it possible to build a power plant in location without adequate cooling water resources.
6. Maintenance may be reduced due to elimination of water fouling characteristics which could require frequent cleaning of water cooled heat exchanger.

II. OPTIMIZATION AND NET EARNED POWER

John G. Bustamante et al. [1] examined the performance of air-cooled condensers under varying operating conditions. For study a model of a representative air-cooled condenser unit coupled to a baseload steam power plant was developed. It was found that wet-cooling systems generate ~6% more power than the dry ACC system, which was sized to have an ITD of 35 °C at an ambient temperature of 30 °C. Doubling the airside convective heat transfer coefficient and mass flow rate could increase power production by 3.3% and 3.0%, respectively. It was shown that wet-cooled power-plant efficiency levels could be achieved with enhanced ACCs if air flow rates are significantly increased (+68%), convection resistances significantly reduced (+66%), and pressure losses maintained close to conventional levels (+24%). ACC power plants were shown to be particularly sensitive to ambient temperatures, and a 10 °C increase in T_{amb} was found to reduce power production by 4.2%. This sensitivity could be mitigated by using a hybrid wet/dry system, but this would reduce the water savings of the system. This investigation highlighted the potential to meet rapidly growing power demands with reduced water consumption through the use of air-cooled condensers. However, major engineering challenges must be overcome to achieve similar power plant performances to those obtained with wet cooling technologies, particularly during periods of elevated ambient temperatures. Emerging heat transfer enhancement technologies may lead to significant improvements in dry cooling.

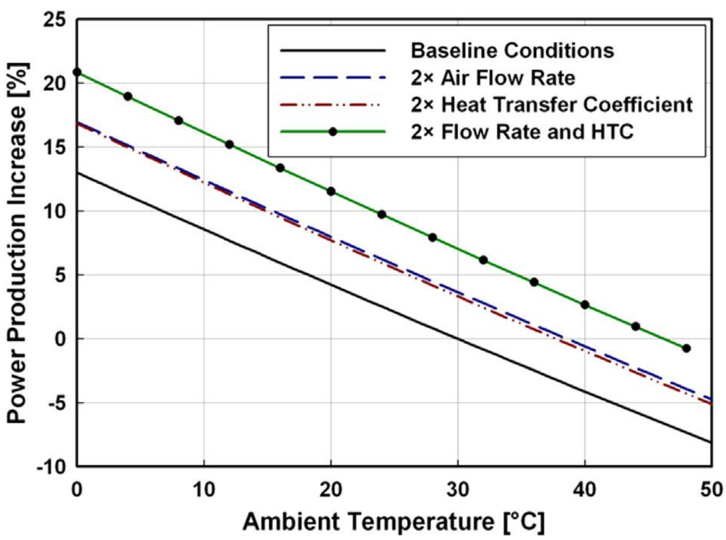

Figure 2. Impact of ambient temperature on turbine power production [1]

Hongbin Zhao et al. [2], on the basis of the method of seeking the optimal back-pressure, this article has researched on the back-pressure optimum operation of direct Air-cooled Condenser in Shenhua Solar power plants combined with air-cooled optimization software. The direct air-cooled condenser is a surface heat exchanger which condenses the steam in tubes by forced convection heat transfer. As the size and structure of the heat transfer area of the direct air-cooled system have been identified, the heat-transfer-unit ($\varepsilon - NTU$) method can be used for the research. Based on the theory, they have established the condenser heat transfer model, and calculated thermodynamic properties of the direct air-cooled Condenser. On model calculation results, using the means of FORTRAN programming language (V1.0) combined with the SQL Server database, on the Chinese windows 2000 or windows XP operating platform, developed production software. Based on data extracted from power plants SIS system and calculation and simulation of the air-cooled optimization software, we can obtain backpressure analysis charts before and after optimization by adjusting the fan operation mode. Through the experiment we can find that coal consumption has decreased compared with back-pressure before adjustment. When the backpressure fall into the fitting scope under current conditions, the coal consumption has

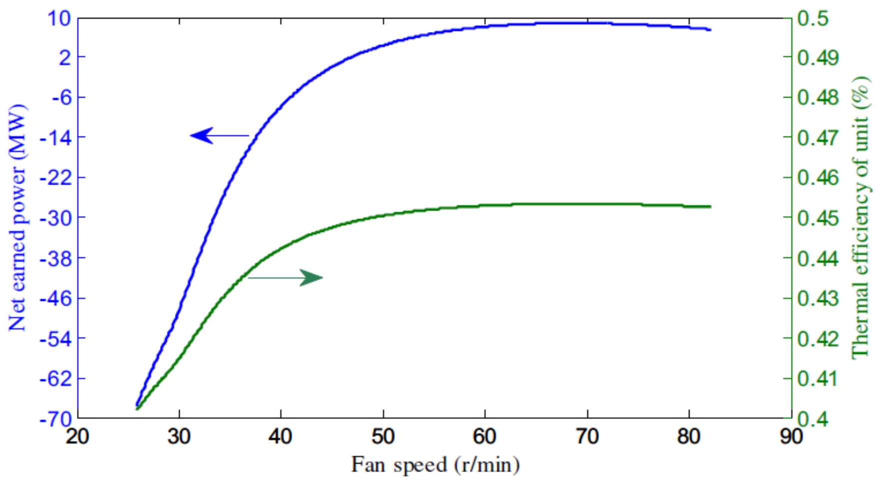

Figure 3. Net earned power of a unit with a change of fan speed [2]

decreased 4.76g/kWh, saving energy, improving the unit thermal efficiency and reducing the cost of the power plant. The optimization software is directly used to the power plant operation, field test to verify the theory, and the back-pressure analysis chart plays a guiding role in the fan running for operators.

Tingting Yang et al. [3] had proposed that to save more energy and quicken the load change speed of air-cooled steam condenser units, the closed-loop optimized control on the fan speed is made. The study presents the static and dynamic models of air-cooled steam condenser, and the characteristics of turbine power output affected by fan speed.

In the second part, the closed-loop structure is designed. The optimum condenser pressure, for energy saving, is solved by the genetic algorithm as shown in Figure 4 [3], and a novel control strategy combining condenser pressure regulation and traditional coordinated control strategy is put forward to accelerate the load change speed. Then, the case study on a 300MW unit proves that our method obtains remarkable result: about 5.54g/kWh coal consumption would be saved on an average through optimum condenser pressure operation and the load change speed would be significantly quickened through combinations of condenser pressure regulation and boiler-turbine coordinated control.

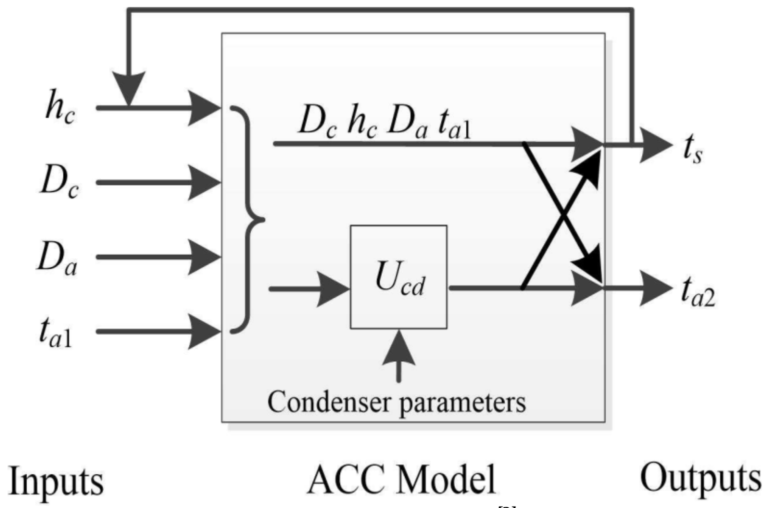

Figure 4. ACC model [3]

Gadhamshettyet et al. [4]**,** proposed a new approach to alleviate the performance decline in air cooled condenser with increasing the air dry-bulb temperature. A chilled water thermal energy storage system is used to pre-cool the inflow air to the ACC whenever the ambient air temperature increases above (20 °C). The proposed procedure used the test 171 MW plant saves (2.5%) of the power (4.2MW) without using any water or incurring any water treatment cost.

Tarrad and Khudor [5] have presented quite a simple and adaptable correlation for the air side heat transfer coefficient in the form of dimensionless group criteria. It depends on the fin geometry, row and tube intensity and operating conditions. They concluded that their correlation predicts the heat duty and overall heat transfer coefficient of the case study heat exchangers with total mean absolute errors of (13%) and (10%) respectively.

Ali Hussain et al. [6] presents work outline of a simple procedure for the thermal design of air cooled heat exchanger. They found that thermal rating model for the ACC can be built successfully to predict the thermal load and temperature distributions across the heat exchanger. It showed excellent agreement between the experimental and predicted data of the exit air dry bulb temperature and condensation load.

The simulation model results showed that the local overall heat transfer coefficient is changed slightly with the increment and row position. It is conservative to assume that overall heat transfer coefficient is of a constant value for each row. When the air flow rate was doubled, the ACC average steam mass flow rate is increased by (17.5%) and the average condenser thermal load is increased by (17.6%) with air dry-bulb temperature reduction of (42 to 20.7) °C.

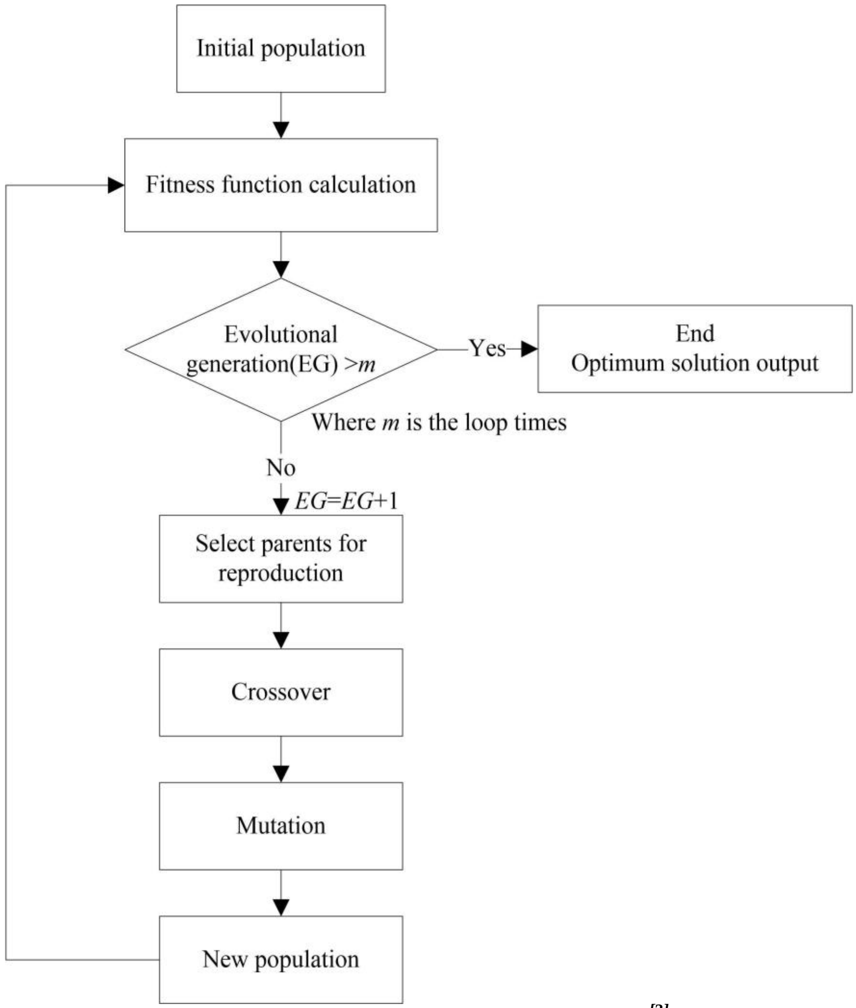

Figure 5. Flowchart of genetic algorithm [3]

Julio Juarez et al. [7] presented presents a solution to the droplet routing problem by means of an Evolutionary Multi-Objective Optimization algorithm (EMO-DR). The EMO-DR algorithm is based on the NSGA-II framework where the crossover operator is not used. New mutation operators and a new scheme of biased random generator of solutions are proposed. Results from computational experiments show multiple competitive solutions compared with two state-of-the-art droplet routing planners, over two well-known Benchmark Suite sets of instances. Several resulting solutions were found with equally evaluated *"twin" solutions*, which can differ from one another in as little as a single cell of a droplet route at the same time stamp to a whole route. "*Twin*" solutions might benefit the fault tolerance of the DMFB. Initialization of population is the bottleneck for this problem, as it spends most of the computational time of a run of the evolutionary algorithm, with no guarantee in generating a feasible solution.

Chen Lijun et al. [10], in order to improve the technical economy of direct air-cooled system, based on the thermodynamic model of the air-cooled system, taking the annual total cost as the objective function, the face velocity of air and the ITD (initial temperature difference) value as parameters.

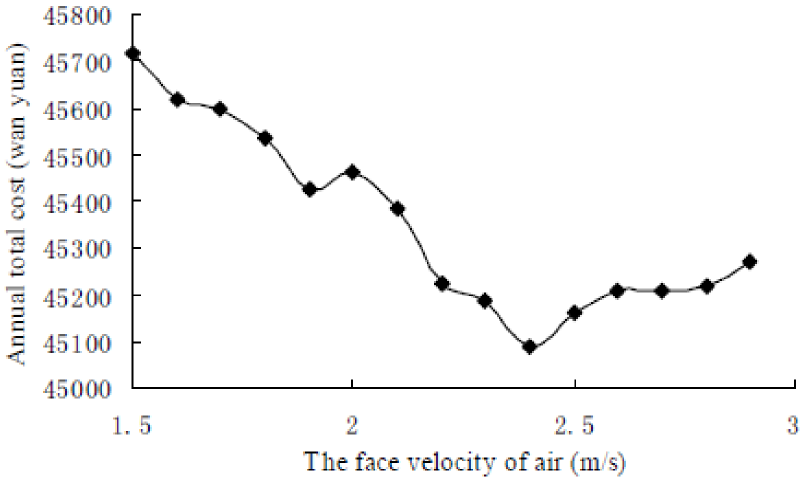

Figure 6. The relationship between annual total cost and the face velocity of air [10]

For a 600 MW air-cooled unit when the ITD is varied, the face velocity of air of air-cooled condenser during the range of 1.5~2.9 m/s. The results show that the annual total cost decrease first, and then increase with the increase of the face velocity of air, this is because the increased face velocity of air decreases the exchanger area and initial investment, but leads high power consumption of axial-flow fan and increases running expenses. When the face velocity of air increased to a certain numerical value which is the optimized face velocity of air about different ITD, the increment of running expenses will greater than the decrement of investment cost, the annual total cost will increase. When the face velocity of air is 2.4 m/s, the annual total cost is least, so the optimized face velocity of air is 2.4 m/s.

III. MATHEMATICAL MODELLING

According to the thermal system of the turbine and the structure of the direct air-cooling system as shown in Figure 7, energy balance equation and heat transfer rate equation can be given.

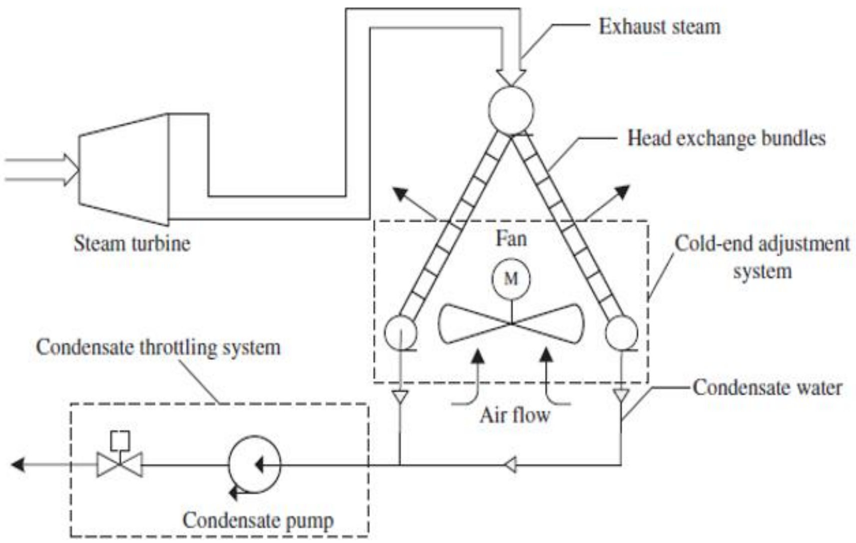

Figure 7. Structure of the direct air cooling system

a. Heat transfer rate equation:

$$Q = UA\,\Delta t_m \tag{1}$$

b. Latent heat of condensed steam inside the tube:

$$Q_a = m_{es}(h_{es} - h_{wc}) = m_{es}(h_{es} - C_{pw}\, t_n) \tag{2}$$

c. Heat absorption by air outside tube:

$$Q_b = m_a C_{pg}(t_{a2} - t_{a1}) = \rho A_F v_F C_{pg}(t_{a2} - t_{a1}) \tag{3}$$

Where; U = Heat transfer coefficient of the air-cooled condenser,
A = Heat exchange area of the air-cooled condenser and
Δt_m = Logarithmic mean temperature
Q_a = Heat released by the exhaust steam,
m_{es} = Exhaust steam flow rate,
h_{es} = Enthalpy of the exhaust steam,
h_{wc} = Enthalpy of the condensed water,
t_n = Saturation temperature of the condensed water and
C_{pw} = Specific heat capacity of condensed water
Q_b = Heat absorbed by the cooling air,
m_a = Cooling air flow,
t_{a1} = Inlet air temperature,
t_{a2} = Outlet air temperature,
V_F = Face velocity of finned tube,
C_{pg} = Specific heat capacity of cooling air and
A_F = Windward area of air-cooling condenser

d. In the process of heat transfer between exhaust steam and cooling air through an air-cooled condenser, there exist three different heat transfer processes and the heat transfer coefficient of an air-cooled condenser can be expressed as below:

i. Condensing heat transfer inside the tube
ii. Heat conduction of the tube wall and
iii. Convective heat transfer outside the tube

$$\frac{1}{UA} = \left(\frac{1}{h_i} + F_i\right) \cdot \frac{1}{A_i} + \frac{\delta_1}{kA_m} + \left(\frac{1}{h_o} + F_o\right) \cdot \frac{1}{\eta_o A_o} \tag{4}$$

e. At the end, the saturation temperature of the condensed water can be expressed as:

$$t_n = \frac{\dot{m}_{es} h_{es} + t_{a1} \cdot A_F v_F \rho C_{pg} (1 - e^{-NTU})}{\dot{m}_{es} C_{pw} + A_F v_F \rho C_{pg} (1 - e^{-NTU})} \tag{5}$$

f. We can use the thermodynamic properties of water and steam to calculate turbine backpressure at a given saturated temperature or we can also calculate the backpressure according to an empirical formula,

$$p_n = \left(\frac{t_n + 100}{57.66}\right)^{7.46} \times 9.8 \times 10^{-3} \text{ (kPa)} \tag{6}$$

IV. CONCLUSIONS

The primary focus of this study is to study the multi-objective optimization methods to improve the performance of Air-cooled condenser under various conditions. From above review study it is proved that various authors had success in improving the performance of their field by using various methods. Similarly, any preferred method can be used in extensive ACC study using above mentioned mathematical modelling to improve the overall performance of plant.

REFERENCES

[1] John G. Bustamante, Alexander S. Rattner, Srinivas Garimella, “Achieving near-water-cooled power plant performance with air- cooled condensers”, Applied Thermal Engineering, pp. 1–10, 2015.
[2] Hongbin Zhao, Haixia Wu, Ling Cao, “Analysis on the Back-pressure Optimum Operation of the Direct Air-cooled Condenser”, Power and Energy Engineering Conference, 2011.

[3] Tingting Yang, Wei Wang, Deliang Zeng, Jizhen Liu, Can Cui, "Closed-loop Optimization Control on Fan Speed of Air-cooled Steam Condenser Units for Energy Saving and Rapid Load Regulation", Energy, pp. 1-32, 2017.
[4] Gadhamshetty, V., Nirmalakhandan, N., Myint, M., Ricketts, C., "Improving Air-Cooled Condenser Performance in Combined Cycle Power Plants", Journal of Energy Engineering, pp. 88-95, 2006.
[5] Ali Hussain Tarrad, Damiaa Saad Khudor, "A Correlation for the Air Side Heat Transfer Coefficient Assessment in Continuous Flat Plate Finned Heat Exchangers", Journal of Thermal Science and Application, pp. 1-9, 2015.
[6] Ali Hussain Tarrad, Ali Farhan Al-Tameemi, "Experimental and Numerical Model for Thermal Design of Air Cooled Condenser", Global Journal of Researches in Engineering, pp. 1-17, 2015.
[7] Julio Juarez, Carlos A. Brizuela, Israel M. Martinez-Perez, "An Evolutionary Multi-objective Optimization algorithm for the routing of droplets in Digital Microfluidic Biochips", Information Sciences, pp. 130-146, 2018.
[8] Vikrant C. Aute, Reinhard Radermacher, Mahesh Valiya Naduvath, "Constrained Multi-Objective Optimization of a Condenser Coil Using Evolutionary Algorithms", International Refrigeration and Air Conditioning Conference, 2004.
[9] S. C. Lau, K. Annamalai, S. V. Shelton, "Optimization of Air-Cooled Condensers", Journal of Energy Resources Technology, pp. 90-95, 1987.
[10] Chen Lijun, Xu Chao, Wang Ying, Mi Lijun and Shi Xingcai, "The Optimization of ITD in Direct Air-cooled System", Advanced Materials Research, pp. 1417-1422, 2012.
[11] Zhao Hongbin, Cao Ling, "Study on the Optimal Back-pressure of Direct Air-cooled Condenser in Theory", Power and Energy Engineering Conference, 2009.
[12] Hongbin Zhao, Yonghui Yan, Meng Li, "600 MW Direct Air-Cooling Unit Back-Pressure Optimization and Theoretical Analysis", Advanced Materials Research, pp. 1739-1743, 2014.
[13] https://www.epri.com/#/pages/product/1007688
[14] http://www.eecpowerindia.com/codelibrary/ckeditor/ckfinder/userfiles/files/Subbarao.pdf
[15] Multi-objective Optimization Using Evolutionary Algorithms by Kalyanmoy Deb
[16] Basic & Applied Thermodynamics by P.K. Nag
[17] Kutscher C. Costenaro D., "Assessment of Evaporative Cooling Enhancement Methods for Air-Cooled Geothermal Power Plants", Geothermal Resources Council, 2002