Performance of an Evaporative Condenser: A Review

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Abstract Involving the proper design of an evaporative condenser to improve, system efficiency is a complex and difficult undertaking. Careful study is required in the construction of an evaporative condenser, since splitting of water, reduced effective cooling, lower power capacity and tubes identification are difficulties to deal with. The study is meant to offer a methodology for engineers to follow whilst working on evaporative-cooled heat exchangers. A method for increasing performance is discovered, and the research with several kinds of evaporative condensers is investigated. As it was discovered, it was possible to boost the system's performance by incorporating features like water beds, forced method, exhaust procedure above nozzles, tapering walls to the sump, dome-shaped fans and elliptical (oval) tube designs. Finally, conclusions on designing improved evaporative condensers are given.

Keywords Evaporative · Condenser · Water pad · Forced · Cooling · Efficiency · Industry

Nomenclature

(Taken as references from papers)

h_w	Film water heat transfer Coefficient, (W/m^2K)
h_d	Air water mass transfer coefficient, (W/m^2K)
G_w	Water mass velocity, (Kg/m^2s)
G_a	Air mass velocity, (Kg/m^2s)
T_{wm}	Mean deluge water temperature, (°C)
T_{wm}	Water Temperature, (°C)

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α_m	Mass transfer coefficient for water vapour, (W/m^2K)
α_{spray}	Heat transfer coefficient between tube surface and water film, (W/m^2K)
m	Mass flow rate, (Kg/s)
$\mathrm{m}_{\mathrm{max}}$	Maximum mass flow rates, (Kg/s)
ε_e	Efficiency of evaporative condenser.
L	Flow rate of liquid, (Kg/s)
G	Flow rate of air, (Kg/s)
T_s	Temperature of heating steam, (°C)
T_w	Wet bulb temperature, (°C)
ε_a	Efficiency of air condenser.
h_o	Outer heat transfer coefficient, (W/m^2°C)
E	Percentage of evaporated water

1 Introduction

Vital factors for the design of cooling systems include water shortage, energy conservation and effluent control. Because of this, the realisation of water uniformity from a single source with fine dispersion of water and minimal use is called for. An industrial unit that is run in accordance with all of these guidelines is known as an evaporative condenser. A machine that takes heat from operating refrigerant and transmits it to the environment using cooling tubes with water sprinklers is known as an evaporative condenser. Acquiring the circulation of air over the surface using axially fitting fans may be done, however these condensers are found in air conditioning plants, water cooling systems and industry facilities. Air velocity range of 1.5–4 m/s is generally accepted for economic design considerations. As the temperature of the air increased from 10 to 20 °C, finally, the air became warm. With a forced flow concept, most evaporative condensers are utilised for cooling purposes since they are needed to have excellent efficiency. However, improvements to the condenser unit's efficiency are currently being explored.

These passive and active type performance-improving factors are analysed first in this study. By contrast, 'active methods' include any alteration to the character design, such as tube modification, expanded surface area or even the addition of elements. To get particular attention, experimental studies are conducted along with condenser losses.

2 Passive Technique

This terminology may describe methods that are concerned mainly with solving design issues for evaporative condensers using numerical simulation, and where software simulations are used without any external changes.

2.1 Numerical Simulation

In the development of mathematical simulations [1–3], several design models with various modifications to size were used. They also included the properties of heat and mass transport in the calculations, using empirical formulas. According to these studies [4], in contrast to the research that concentrated on the heat transfer coefficient for water-only systems, the research on evaporative effectiveness and mass transfer coefficient, as well as air flow, for wet-only systems was performed. When the air flow rises and the coolant and product flow rates increase, heat transfer coefficient for the water side decreases. The calculation was performed with an accuracy of 20% in range, ranging from 13 to <1.7. Hsu et al. [5] did system design work on the improvement of wet surface heat exchanger design for three different buildings. You may chill air by evaporation below the wet bulb temperature range. The main goal was to develop new methods for water wetting on heat exchangers as an evaporative condenser. Zalewski [6] developed a mathematical model for forced air flow type evaporative condenser, he suggested that such condensers be simulated mathematically. To simulate the bare tube condenser, a computer programme may be utilised. Using their colleagues as Zalewski et al. [7] refined the operational and geometric parameters for evaporative coolers using fluid types. Mass and heat transfer models and assessment of air pressure drop have all been used to evaporative heat exchangers. Seeking for low-cost solutions, Manske [8] went on to investigate industrial-based refrigeration system optimization, concentrating on evaporative condensers. In this system, the compressors are reciprocating, and the evaporators are single screw. The main components that influence the overall power consumption of the refrigeration system are the pressure head, condenser fan and condenser size. However, according to Hasan and Siren [9] conducted tests on two distinct evaporative coolers, each with a circular and an oval tube, to explore the influence of these two designs on cooling. A combined thermal–hydraulic characteristic was shown to be superior to a single one when dealing with oval tubes. Working for the sake of tube shape and heat exchanger performance, Min and Webb [10] did some research. As the aspect ratio of the oval tube rises, the pressure drop and heat transfer coefficient fall on the air side and increase on the water side. B. S. Qureshi in addition to numerical and experimental results, Zubair [11] offered a mathematical model for the efficient design and rating analysis of evaporative condensers and coolers. This model was verified using the data from simulations and experiments. Fouling behaviour was used to determine risk-based thermal performance parameters. Both kinds of heat exchangers showed a reduction in efficacy, as well as an increase in fluid output temperature. As mass flow ratio increased, effectiveness went up for both heat exchangers. Heyns and Kröger [12] conducted the evaporative cooler analytical technique evaluation. Evaporative cooler experiments were led with 15 tube rows in 76.2 mm triangular pitch, which had a 38.1 mm outer diameter, on a galvanised steel plate with a plate thickness of 0.0174 in. The following relationships have been established.

'Air mass flow rate and deluge water temperature' is

$$h_w = 470 G_a^{0.1} G_w^{0.35} T_w^{0.3} \tag{1}$$

Here, $0.7 < G_a < 3.6 \frac{\mathrm{Kg}}{\mathrm{m^2 s}}$, $1.8 < G_w < 4.7\mathrm{Kg}/\left(\mathrm{m^2 s}\right)$ and $35 < T_{wm} < 53°C$.

'Air mass velocity and deluge water mass velocity' is

$$h_d = 0.038 G_a^{0.73} G_w^{0.2} \tag{2}$$

Here, $0.7 < G_a < 3.6\mathrm{Kg}/\left(\mathrm{m^2 s}\right)$ and $1.8 < G_w < 4.7\mathrm{Kg}/\left(\mathrm{m^2 s}\right)$.

'Air side pressure drop' is

$$\Delta p = 10.2 G_a^{1.8} G_w^{0.22} \tag{3}$$

Here, $0.7 < G_a < 3.6\mathrm{Kg}/\left(\mathrm{m^2 s}\right)$ and $1.8 < G_w < 4.7\mathrm{Kg}/\left(\mathrm{m^2 s}\right)$.

It was comparable to the research A. Jahangeer et al. [13] investigated the numerical analysis of coefficient of heat transfer for an evaporative cooling condenser, which works with features that are similar to those found in a tropical climate, 13 researchers have presented their findings. Film thicknesses over the condenser tubes have high combined heat transfer coefficients. Increased performance was shown when water droplets were added to a cooler that had decreased temperature lift. Liang Yang, Lei Sun and others were able to drastically change the design, which helped them succeed. According to [14], decreasing average air pressure drop in elliptical tube bundle using these all technique methods is estimated to reduce pressure loss by 20–30%. The results also showed that heat transmission rates rose on average by 8.3–30.9%. They discovered an increase in capacity and COP of 21.3–27.5% and, on average, a 3–7% rise. Mr. Guo feng and Ms. Feng with revolutionary advancements in the construction of the evaporative condenser, Guo feng et al. [15] significantly improved the efficiency, as well as a wide variety of additional advantages, such as improved cleaning speed, less wind resistance and increased energy efficiency. Lowered noise was achieved by the modification of the spray direction; inorganic fillers were positioned to improve heat transfer and heat transfer efficiency; elliptical finned tubes were used in bottom evaporative coils, and air temperature was reduced. Anicalliea and others the detailed experimental thermal study of condensation heat transfer, with a significant impact on the ammonia evaporative condenser, has been suggested by lliea et al. [16]. Heat and mass transport may be accurately represented using the relationships that are available in literature for evaporative condensers. In the study by Liu et al. [17], the water and air flow arrangements have been changed and implemented in order to best use and optimise the water and air flow to find a high efficiency evaporative operating cooler. Cooler structure results in an inclination to the rate of cooling. Studies have shown that corrugated plates improve the cooling effectiveness by 10%. In the counter flow configuration, efficiency is increased by about 30%. Additionally, the expansion of the lengths of channel and air entry in addition to decreasing the width and gap of channel increases the cooling efficiency within a realistic range.

2.2 *Software Simulation*

On the basis of software, Abbassi and Bahar [18] anticipated the consequences of their thermal design. They came to the conclusion that PID controllers can properly model evaporative condensers, with an advantage of faster development of the model and lower process error. In the endeavour to get the most acceptable operating conditions, Fiorentino et al. [19] searched for the heat transfer geometry that guaranteed the maximum heat transfer wettability with lowest pumping cost. The company [Starace] has extensively performed the complex computational and empirical research of evaporative type condensers. Engineers had novel relationships presented to them, which they could use to calculate thermal performance according to their working circumstances. A study on the rig by Fiorentino et al. [20] examined the impact of DBT and RH on evaporative condenser performance. At the greatest DBT, the heat transfer rate is reduced by 30% when relative humidity is increased by 6%. On a psychometric chart, the amount of latent heat compared to perceptible heat falls as the RH level increases.

Active Techniques

Instead of emphasising the modification of the model itself, exterior attachments, additions and modifications are considered active methods. The writers, Bykov et al. [21], wrote this work. As stated before, in evaporative condensers, there are separate areas for the process of heat and mass transfer. A method has been developed to improve thermal efficiency spaces. This results in improved evaporative condenser designs. Goswami et al. [22], modified media pad was attached to the condenser of a 2.5 tonne air conditioner to achieve 20% savings, and this was followed by a two-year reimbursement period. Challenging traditional ways of thinking, Hwang et al. [23] found a new way to alter the conventional heat pump, where the tubes are submerged in water, with the aid of heat-pump-connected discs that spin whilst pumping and air is also pushed over them. According to this result, condenser capacity rises by between 1.5 and 8.3% and also by between 11.1 and 21.6%. He had put copper serpentine sheets wrapped in linen into rectangular ducts. This fabric soaks the water, and as a result, transfers heat more effectively in the heat exchanger. Horacek et al. examined nozzle spacing and discovered that water spray satisfies when spray height is between 11 and 14 mm [24]. This experiment was conducted using the two-spray nozzles. In addition, heat transmission underneath two-spray nozzles was assessed for revealing the region of liquid to solid contact. Additionally, when nozzles were located directly over the surface area, the amount of heat transferred was greater. As the distance from nozzle to surface increases, the heat flow remains constant. Thus, the heat flow is thus directly related to the amount of physical contact, and not the moist area. Whilst following up on the work done above, Royne [25] conducted research on nozzle configurations, investigating short (straight), long (straight), pointed, countersunk nozzles, and contoured, countersunk nozzles. At greater heat transfer rates, countersunk nozzles are preferred over the self-dished kind. With longer nozzles, there is a reduced pressure drop. Larger nozzles provide the benefit of higher pumping power. Pump power demand is about the same when using straight nozzles and sharp-edged nozzles; however, sharp-edged nozzles are utilised since they have a lower flow rate. Spacing and inclination of nozzles are also important since the whole spray area must be covered in order to reduce wasteful purchasing of nozzles. Silk et al. [26] had undertaken a detailed investigation of spray cooling techniques on different kinds of improved surfaces, including nozzles and the nozzles' azimuth. In the experiment, these pin fins, pyramids and straight fins were tested on using PF-5060 fluid at a working pressure of 50 psi. Moreover, the comparison was done at a large inclination angle of 0–45 ° at the maximum CHF. With regard to straight fins, it was determined that they increase performance, increase multiphase efficiencies, reduce heat flux and are also the most cost-effective choice. Only one parameter, volume flux, is adversely influenced by volume flux. Compared to other parameters, this one may be fine-tuned. The most straightforward conclusion was confirmed by Y. Idrissi, and the others complete air-cooled condensers are outlined in [27]. This will boost the overall efficiency of the water-spraying condenser. For the semi-numerical model, the validation showed no evidence of experimental validation although the COP may be enhanced on average by 55%. Vrachopoulos et al. [28] presented a new evaporative condenser slope of 28. Electrical circuit pump and drop clouding computer engaged system for water spraying were the task expected for completely unique innovations like these. Using this new condenser, the COP (or decrease in the operating temperature difference of the compressor) was found to increase to 21.1%. Tissot et al. [29] examined the effect of water spray near the condenser intake on the performance of a refrigerator. 22.4% increase in the COP for the machine equipped with this spraying technique was observed in a numerical study by Ndukaife et al. [30] to go above and beyond normal standards. The study on performance and energy usage was conducted comprehensively and mathematically. Hot air contacting water may result in both rapid heat and mass transfer. Reduction in the air temperature causes an increase in the relative humidity. Thickness of the pad is proportionate to the change in temperature of the air (specifically, dry bulb temperature). This maximum decrease in air temperature occurs when the relative humidity reaches a certain level, at which point the drop in air temperature may be seen. The effort of compression was reduced by 15 cm by using a 15 cm pad, which enables lower mass flow rates. As comparison to other thicknesses, this pad thickness provides 44% increased COP., An increase of 1 °C in air temperature produces a decrease of 0.6 °C in condensing temperature. Approximately 4% of the money collected due to the COP decrease was related to the 1 °C temperature drop. Chien et al. [31] investigated as part of an ongoing research, the flow rate, nozzle spacing and geometric design of the sprinkler were all altered to examine the uniformity of the water spray and the collection ratio of the sprinkler. Whilst about 17 cm between adjacent nozzles is desired, nozzle spacing and nozzle aperture should not be too big.

3 Experimental Investigations in Evaporative Condenser as a Comparison

In order to perform a thermal study for a new closed wet cooling tower to utilise with chilled ceiling, Facao and Oliveira [32] did a thermal research using several thermal models. In order to anticipate improved thermal performance, experimental correlations were shared. These new relationships produced better outcomes,

$$\alpha_m = 0.1703\left(\frac{m}{m_{max}}\right)\begin{matrix}0.8099\\ air\end{matrix} \tag{4}$$

$$\alpha_{spray} = 700.3\left(\frac{m}{m_{max}}\right)\begin{matrix}0.6584\\ spray\end{matrix} \tag{5}$$

Two distinct finned-tube heat exchangers were designed and constructed in tests by Ettouney et al. [33] and may be configured in parallel, series or stand-alone using either water or air cooling. Also, under consideration for the study was the water to air mass flow rate ratio (*L*/*G*) and the steam temperature. Efficiency was greatest for a set configuration of condensers, which was subsequently followed by parallel and single setups. Whilst *L*/*G* ratio is low, and whilst steam temperatures are high, system efficiency improves. External heat transfer coefficient and efficiency were evaluated by considering just the relationship between *L*/*G* ratio and temperature of steam. A good relationship exists between the efficiencies of the evaporative condenser:

$$\varepsilon_e = 98.57 - 1.76\left(\frac{L}{G}\right) - 2.09 \times 10^{-2}(T_s) + 0.27A + 4.83 \times 10^{-2}(T_w) \tag{6}$$

Similarly, the efficiency correlation for the air condenser is

$$\varepsilon_a = 223.03 + 1.81 \times 10^{-2}(T_s) - 0.31A - 5.29(T_w) \tag{7}$$

The correlation for wet heat transfer coefficient is

$$h_o = 0.16(L/G)^{0.23}(T_s)^{2.13} \tag{8}$$

Hosoz et al. [34] performed a comparative study for three kinds of condensers, such as evaporative type condensers, water-cooled condensers, and air-cooled condensers, was done and discovered that evaporative type condensers were better, whilst air-cooled condensers performed worse. Using direct evaporative coolers instead of air-cooled condensers, Yu and Chan [35] placed evaporative coolers in front of the condensers so that the outside air was cooled prior to being condensed and fed directly into the condenser. For all working circumstances, refrigeration was enhanced. It is observed that Leidenfrost et al. [36], in contrast to air side heat transfer augmentation, which works best with evaporative cooling, since heat may be rejected to ambient even when the ambient temperature is higher than the condenser temperature, water-side heat transfer augmentation works best with constant-pressure (suction) cooling. It was verified that the greatest condenser performance can be obtained with wetting of the heat transfer surface, thus a quantity of water should be sprayed that is just sufficient rather than dumping a large amount which saves water and electricity. Adjusting the air flow rates to achieve water-film contact with air–water-film interaction whilst also minimising blower power use is highly recommended. Nasr et al. [37] proposed a novel condenser, which used wick wrapped around the condenser tubes to chill the tubes and to draw water from the basin via capillary action. Theoretical models were created and tested using experiments to test and verify how different factors affect condensing temperature. A condenser that is air-cooled has 13 times higher heat rejection capability as compared to an evaporative cooling condenser. Egtèdar et al. [38] performed experiments using the existing air-cooled condenser to refit it with evaporative cooling. Using this modification, they observed a 20% reduction in power usage, whilst also improving overall performance by 50% Whilst utilising evaporative cooling condensers, it was also shown that rising ambient temperature had no impact on COP.

4 Conclusion

I completed this review study to explore how evaporative condenser operating is used both industrially and domestically.

The overall power expenditure cost of the cooling system is influenced by the operating pressure head, condenser fan and condenser size. Whilst operational design temperature ranges from 29.4 to 34.4 °C, the evaporative condenser yields greater overall efficiency than other types of condensers and consumes the least amount of energy.

Elliptical tubes should be used instead of circular tubes since they result in reduced pressure drop on the air side, and because of this, the total surface area available for transferring heat is enhanced.

To avoid obstruction of nozzles, positioning nozzles at the bottom with a nozzle pointed upward can assist with appropriate cleaning of condenser tubes.

The placement of nozzles positioned at the bottom, directing the flow upwards, may aid to keep the nozzles clear of debris and to assist in appropriate condenser tube cleaning. For greater and lower flow rates, countersunk and sharp-edged nozzles should be utilised.

Evaporation loss and fouling factor should be included into the design of the condenser in thermal calculations.

The best way to cool the refrigerant is to use media pads and water insulation pads. Operating at ambient temperature, the average power consumption will be reduced by about 20%.

To improve the cooling rate of tubes and to decrease wind resistance, we recommend using inorganic polymer composite fillers. Incorporating a neural network controller into a model of an evaporative condenser offers significant advantages in terms of decreased time for model creation.

To decrease the noise level, the spray direction may be changed, and inorganic fillers may be used to help reduce the cooling water temperature. Efforts to enhance the cooling efficiency may lead to more than 10% gains in cooling effectiveness by utilising corrugated plates in evaporative coolers.

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