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A Study on Performance Comparison of Air Cooled and Water Cooled Condenser in Vapour Absorption and Compression Refrigeration Systems

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Abstract

The effectiveness of the condenser in the refrigeration system is a crucial parameter that needs to be studied in order to design a highly efficient refrigeration unit. In order to achieve this intention, the comparison of coefficient of performance (COP) between the air cooled condenser and water cooled condenser using evaporative pad in vapour absorption and compression refrigeration systems are reviewed. The evaporative pad which is made of cellulose material drops the condensing temperature up to the great extent and ultimately improves the COP of the system. In this system, a simple fan can be used in case of air cooled condenser which provides the condensing temperature of 40^{o} C and evaporator temperature of -22^{o} C. The refrigerating effect of the water cooled condenser using evaporative pad in front of the condenser is more than the condenser with forced air cooling. The water cooled condenser using evaporative pad placed in front of the condenser rises the cooling effect or cooling capacity by 2.9-14.4% and COP is improved by 1.5-10.2% when compared with evaporative condenser. So, the cooling effect and efficiency of the water cooled condenser by using cellulose pad is much higher than the air cooled and evaporative condenser. It is observed that the coefficient of performance of this particular setup depends upon the temperature drop in the evaporative section. Higher is the temperature drop in the evaporative section, higher will be the COP of the system.

Keywords: *Water Cooled Condenser, Evaporative/Cellulose Pad, Air Cooled Condenser, Vapour Absorption System, Vapour Compression System, Coefficient of Performance (COP).*

1. Introduction

The environment temperature is increasing day by day because of factors such as industrialization effects, pollution from the vehicles. This type of heat is the waste heat that is directly thrown into the environment by the large industries. The waste heat is released by the industries can be utilized to enhance the overall performance of the system and the waste heat is available at a very low temperature. It also helps to reduce the heat input given to the system. The researchers developed a system in which waste heat can be utilized to operate the system called vapour absorption refrigeration system.

The vapour absorption refrigeration system can use the waste heat from various applications such as heat rejected by the engine of fishing ships which produces a large amount of waste heat. So, this refrigeration system has the large applications in the cold storage plants. The working fluid (refrigerant) ammonia, lithium bromide is used in this system. It cannot be directly used in the domestic refrigerators due to its toxic working fluid such as ammonia. This refrigeration system is eliminating the need of compressor and hence, it becomes the effective refrigeration system than the vapour compression system.

The vapour absorption refrigeration system can be used in a cold storage plants and other applications. So, this absorption refrigeration system has the various applications and it is the only system which is able to completely remove the need of compressor by replacing with the components such as generator, absorber and pump which performs the same function as that of compressor in vapour compression refrigeration system. The components replacing the compressor are not so expensive and all the components in the absorption refrigeration system should be completely sealed or closed chambers to prevent the leakage of refrigerant used in this particular refrigeration system (ammonia) which is toxic in nature. So, the refrigerators are the device which maintains the temperature below 0^{o} C.

The objective of the paper is to summarize the literature survey on the analysis of air cooled and water cooled condenser with and without cellulose pad in vapor absorption and compression refrigeration system.

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2. Cellulose Pad

Cellulose pads are prepared for horticultural and agricultural areas where there is a requirement of the sudden drop in temperature. Cellulose cooling pads are designed with a specially formulated cellulose paper, and are capable of insoluble with anti-rot salts, and the cellulose material is used to decrease the temperature of the ambient air. Evaporative cooling pads have a cross fluted configuration that provide maximum cooling when warm air passes through the wet evaporative cooling pads.

3. Literature Survey

The literature review has been done to determine the variations in the coefficient of performance of condenser with air cooling and condenser operates with water by using evaporative cooling pad placed in front of the condenser. The effects of the evaporative pad on the condensing temperature are also reviewed.

Hosaz et al. [1] performed an experiment on the performance comparison of the air cooled, water cooled, and evaporative cooled condenser used in the refrigeration system. For this, a model was developed in which first air cooled condenser was used and result showed the less COP. So, test was performed on water cooled condenser which was implemented to take the heat through water at the condenser which was thrown into the surrounding air. After that, the investigation was done on evaporative condenser. It was inferred that water cooled condenser increased the refrigeration effect and COP by 2.9-14.4% and 1.5-10.2% respectively when compared with evaporative condenser. Furthermore, the refrigerating capacity and COP of a condenser with evaporative cooling were 31% and 14.3% higher when compared with air cooled respectively.

In the study of Seara et al. [2], the performance of ammonia vapor absorption system with flooded evaporator was analyzed and the various effects on the purification of the ammonia refrigerant and blow down from the evaporator was observed in this experiment. The study conducted on the vapor pressure of water which could not be neglected if compared with the ammonia. So, when the vapor refrigerant moved from the generator, it had always some amount of water content which could directly affected the COP of the system. The result showed the variation in COP of 2% by using dry and flooded evaporators.

The study of Zlatanovic et al. [3] was based on the determination of the de-superheating and oil cooling by liquid injection in two stage ammonia refrigeration system. Ammonia refrigerant was not capable of achieving the saturation state by injecting the liquid which was throttled coming from receiver into superheated vapor of the low compression discharge line. For this purpose, de superheating and oil cooling process was obtained. The result showed the reduction in cooling capacity which was dependent on quantity of refrigerant used.

Taboas et al. [4] conducted an experiment on the utilization of waste heat energy rejected by the exhaust gases of the fishing ships in ammonia absorption system. The exhaust gases were leaving from the engine at a high temperature and contained 30% of the complete heat power input which was developed by the fuel. The waste heat which was coming out from the engine could be provided to generator which was used to power the ammonia water absorption refrigeration system. So, this waste heat increased the generator temperature and higher generator temperature could reduce the COP.

In the study of Guillen et al. [5], performance of air cooled ammonia refrigeration system with ammonia lithium nitrate solution was discussed. It was observed that in ammonia water system, a rectifier was required to avoid the water which was entering into the condenser and evaporator. Ammonia-lithium nitrate eliminated the need of rectifier. When the operating temperature was achieved in the heating loop, the heated oil was circulated in the horizontal tubes which were present in generator due to which the generator temperature was increased and hence, increased the COP.

Srikhirin et al**.** [6] analyzed the review of absorption refrigeration technologies. The absorption system was a heat operated system which was able to reduce the problems such as greenhouse effect from the carbon dioxide gas emitted from the combustion of fossil fuels. This refrigeration contained solution heat exchanger which preheated the solution which was leaving from the absorber before entering into the generator which reduced the heat input for generator and then a mathematical set up was prepared to determine the results of single and double effect absorption systems. The result showed that the solution heat device gave the COP rise by 60%.

In the study of Lutton et al. [7], the comparative analysis of evaporative condenser and air cooled condenser in air conditioning systems was discussed. In evaporative condensers, the heat rejected by the refrigerant was absorbed by the latent heat of vaporization of water. Water was flowing over the evaporative pad and air was passed through it resulted in an enhanced its capacity to absorb heat sensibly through the refrigerant.

Huang et al. [8] conducted an experiment on the air cooled condenser and water cooled condenser of a household refrigerators. The water cooled condensers were utilized as a tube in the heat exchanger which was known as tube heat exchanger and had inlet for the purpose of cooling water and hot water was collecting at the exit. The air cooled condenser increased the compressor work that's why COP was higher in water cooled condenser case than air cooled condenser.

In the study of Raghuvanshi et al. [9], the analyzation of vapour absorption refrigeration system was discussed. For this objective, a model was made to calculate the thermodynamic properties such as calculation of enthalpy and energy transfer. The mass transfer and rate of heat transfer were also evaluated. The result showed us with the increase in generator temperature, the COP of the system decreased because of the growth in enthalpy of refrigerant. So, low generator temperature was maintained in this model.

In the study of Chaudhary et al. [10], the analyzation of the air cooled non-adiabatic absorber using low grade energy was discussed. Earlier, the adiabatic absorber was not much efficient and was unable to give high value of COP. To avoid this issue, a non-adiabatic absorber was used using low grade energy. A mathematical model was made to evaluate the effect with the ammonia-lithium nitrate. These models were used for the small capacity absorption systems. It was observed that the COP increased up to 10%.

Hughes et al. [11] performed an experimental research on the comparison of heat pipe and evaporative cooling for wind tower. In this, the research showed the cooling technique which enhanced the efficiency or thermal performance of wind tower. It was observed that the highest temperature drop occurred by evaporating cooling process. The study also showed the addition of cooling device inside the systems which reduced the overall efficiency of system. The research also proposed two designs of cooling systems such as wetted column and wetted surfaces.

Ng et al. [12] performed an analysis on the vapor absorption refrigeration system. The generator and absorber temperature was observed because the generator temperature could directly affect the COP of the system. The effects of single and double stage absorption refrigeration systems were also studied. The analysis also showed the implementation of mass transfer mechanism which increased the cooling capacity.

Finn et al. [13] conducted an experimental research on the heat transfer correlations for low approaching evaporative cooling for the buildings. This experiment showed the feature of the open tower with internal heat exchanger. The study also proposed the observation made on two evaporative cooled heat exchanger. A model was prepared to check the performance of the closed tower by using circular and oval tubes in the heat exchanger. The result showed that the thermal hydraulic performance was better in oval tubes than that in circular tubes.

In the study of the Mariappan et al. [14], the analysis on the R134-DMAC vapour absorption refrigeration system was performed. A test was made on the absorption system using a DMAC refrigerant which was the half effect absorption system in which the COP of the system was 0.4 by considering the evaporator, generator, condenser temperature. A model was developed to perform the half effect absorption chiller and optimized the COP.

Du et al. [15] performed an experiment on recovery of the heat inside the system of the one stage ammonia refrigeration system. For this purpose, a model was developed which showed the graphical representation of the new heat recovery planning's which could be heat recovery by the absorption to maximize the internal heat recovery system. For this, an optimal cycle was developed in which the pinch technology was considered and it was observed that by this technology, maximum internal recovery could be achieved and COP was found to be 20% higher.

Ertunc et al. [16] reviewed the performance of an artificial neural network (ANN) of refrigeration system with evaporative condenser. A model was created to check the performance of the evaporative cooled condenser which combined the function of air and water cooled condenser. ANN applied to the estimated desired output parameters when the experimental data was to be sufficient. For this, the model was developed to check the heat transfer in the fin heat exchanger used for refrigeration system.

In the study of Elgendy et al. [17], the different strategies for improving the overall performance of the desiccant evaporative cooling system by the use of direct/indirect evaporative cooling was discussed. The aim of the study was to optimize the consumption of electricity, cost minimization, minimization of building air temperatures. A simulation model using TRNSYS software was prepared to enhance the performance of ventilation cycle of this cooling system. This experiment also investigated the effectiveness of regenerator and desiccant wheel used for the recirculation cycles.

Coronas et al. [18] conducted an experiment to analyze the behavior of the two stage absorption chiller. For this objective, a set up was generated to first check the observations of a one-step absorption chiller and then double absorption chiller. The different strategies were considered such as energy balance and mass balance in each component in order to evaluate the maximum COP of the system.

Kaushik et al. [19] conducted a model to perform the thermodynamic analysis of vapor absorption system. The other cycles like vapour compression cycle systems were the major cause for ozone layer depletion and green house effects which were harmful. So, the absorption system was employed that used low grade energy. For this, a model was prepared to observe the effects of condenser/ evaporator temperature, enthalpy, heat and mass transfer in order to estimate the COP of the system.

In the study of the Farshi et al. [20], a heat transfer absorption system using different working fluids were analyzed. For this, a model was developed to make the comparison of absorption performance in the form of bubble mode between the different working fluids such as ammonia/water, ammonia/$LiNO_3$, NH_3/NaSCN by using plate type heat exchanger. It was observed that the ammonia/$LiNO_3$ developed the very low value of absorption mass transfer and thermal values but it was able to develop highest COP than others working fluids.

Gazzani et al. [21] developed a model for the purpose of thermodynamic analysis of ammonia (chilled) and carbon dioxide. There was always a problem to handle corrosive solution and solvent degradation. So, to avoid these type of problems, the chilled ammonia capture process was the best solution which could provide the better heat and mass transfer and it exhibited the higher COP by the state of the chilled ammonia.

Gordon [22] performed an experiment on the analysis of vapour absorption chiller with the maximum COP techniques. To achieve this purpose, a mathematical model was prepared to do the evaluation of mass transfer rates on this system because the absorption system required the heat energy to drive the system. So, this model was used to sense the finite mass transfer rate only. The heat losses and working fluids losses were evaluated which helped to know the different strategies to increase the COP.

Hajidavalloo [23] discussed the performance of evaporative condenser over the air cooled condenser in air conditioner, because improving the COP with the air cooled condenser was a major challenge especially was in hot regions. So, a model was developed which showed the cellulose cooler contained corrugated aluminum foil. Test was made to evaluate the results and sudden changed in pressure and temperature parameters. The result showed that the evaporative cooler was able to power saving up to 20% and increased the COP up to 39%.

Hao et al. [24] performed an analysis to increase the energy saving thickness of the evaporative pad and optimized further in order to enhance the energy. For this, a test was performed on the air cooled condenser. In front of that condenser, a water spraying system was placed which reduced the air temperature and could increase the COP up to 55%. So, the result showed that the thickness of the pad could be optimized according to climate conditions and could enhance the energy saving.

In the study of the Horuz et al. [25], the experimental study of the absorption refrigeration system was performed. The study of absorption chiller was done in which cooling capacity was determined which could vary with the parameters such as generator temperature, condenser temperature and evaporator temperature. So, with the growth of the generator temperature, the COP increased.

Litch et al. [26] conducted an experiment on the reduction of charge as minimum as possible in the air cooled condenser in the refrigeration system. For this, a model was prepared in which the efforts were made to develop some correlations for other fluids for the condenser. Furthermore, a model was prepared in which two aluminum condensers were used to reduce the charge generated and determination of correlations for different flow regimes was made and finally result showed the charge reduction of 20%.

Khaliq [27] performed an experimental research on the exergy analysis of combination of the heat and plant for absorption and evaporative cooling. For this purpose, a model was developed which used the evaporative cooling system for gas turbine cycles and showed the evaporative inlet cooling which was acceptable to enhance the power output up to 2-4%. Moreover, a model was developed which proved that evaporative after cooling could increase the thermal efficiency by 35%.

Lin et al. [28] performed a numerical analysis to estimate the two stage absorption system with air cooled condenser. In this, a differential mathematical model was made in which mass and energy balance was done and finally investigated the rate of heat and mass transfer. The effects on the COP in case of plate type absorber were also reviewed.

Jain [29] conducted an experiment to analyze the pump less evaporative air cooler. For this, a model was developed to perform the evaporative cooler so that evaporation of water took place which led to an increase in the cooling effect.

Lostec et al. [30] conducted an experimental work on the simulation of absorption refrigeration system. For this purpose, a model was made to determine the operation results of the absorption system with the air cooling condenser and evaporative cooled condenser. The result showed that COP was increased with the use of heat exchanger.

Manske et al. [31] performed an experiment on the control of the evaporative cooled condenser in industrial refrigeration system. A model was developed to evaluate the pressure losses in the piping. A test was performed to evaluate refrigerating effect parameters in order to increase the overall COP of the system.

In the study of Mckenzie et al. [32], the performance of three air-conditioner systems such as air cooled condensing unit, evaporative pre-cooled and pure evaporative cooler was analyzed. So, a test was performed on three systems in which outdoor air entered the air cooled unit which extracted the heat from condenser and then test was done on evaporative unit.

Moya et al. [33] had made an analysis for the calculation of tri-generation system with various factors such as air cooled indirect fired ammonia system. A model was made to perform the correlations of tri generation in which cooling tower was not desirable and there was a threat of bacterial contamination and several adverse effects were produced on cooling capacity. Then, a model was made to use the exhaust gases of 80KW of a gas turbine cycle and run the double effect absorption chiller which increased the cooling capacity.

In the study of Zaleswki [34], the details of heat and mass transfer in the evaporative condenser were elaborated in order to check the COP of the overall system. The model was prepared to perform the thermodynamic relations.

Najjar [35] performed an experiment on the indirect evaporative cooling in gas turbine cycles. For this, a model was prepared to test the performance of gas turbine cycle in order to decrease the wet bulb temperature and this would enhance the humidity ratio because of the evaporation of the water. It produced the cooling effect on the system. A model was developed to perform the calculations of desired effect and the result showed the improved COP of the system.

Nasr [36] performed the theoretical investigation of innovative evaporative condenser used in residential refrigeration. For this, a model was prepared to check the performance of evaporative cooler by using the media pad through which the air passed and cooling effect produced. The results showed that cooling effect was increased in the evaporative type cooler.

Swarnkar et al. [37] performed an experiment on the absorption refrigeration system based on the combination of ionic liquid ammonia in which water was used as a cosolvent. The model was developed in which the carbon dioxide used as a refrigerant and the ionic liquid used as an absorbent in order to enhance the COP of the system.

In the study of Kong et al. [38], the experimental and thermodynamic investigation of absorption chiller was performed. For this, a model was developed in which the thermodynamic analysis was done in order to calculate the average temperature of the evaporator, generator, condenser and absorber. The result showed that lower the temperature of evaporator, higher was the cooling effect

Qureshi et al. [39] conducted an experimental research on the design of absorption components. For this, a model was made to make the proper design of the evaporator and condenser. The efforts were made to make the design effective in order to achieve the better COP of the system. A model was developed to make the simulation of the absorption components through which all the components were properly designed.

Rattner et al. [40] performed the experiment on the calculation of the thermodynamic properties of the absorption system. The calculation of various properties of thermodynamics to observe the COP of the system was done on the model. The various properties such as enthalpy, specific heat, evaporator temperature, generator temperature were evaluated in order to calculate the COP of the system. These properties were able to enhance the COP of the system up to a certain level.

4. Conclusions

The paper gives the review on the effects on COP of the two different types of condensers named as air cooled condenser and water cooled condenser. The effect of evaporating cooling pads on the variation of COP are also reviewed by comparing the air cooled and water cooled condenser. Some useful conclusions are mentioned below:

- At the same evaporator and condenser temperature, the water cooled condenser is capable of providing the higher refrigeration capacity and coefficient of performance and the refrigerating capacity and COP of a condenser with evaporative cooling are 31% and 14.3% higher when compared with air cooled respectively.
- The waste heat increases the generator temperature and higher generator temperature can reduce the COP.
- The COP is increased up to 10% in case of non-adiabatic absorption system that uses low grade energy
- The chilled ammonia capture process exhibits the maximum COP in the ammonia absorption refrigeration system.

- The evaporative cooler is able to save the power by 20% and increases the COP by 39%.
- A water spraying system reduces the air temperature and increases the COP up to 55%, if employs in front of the condenser.
- An evaporative cooling system enhances the power output up to 2-4% and increases the thermal efficiency by 35%.
- The COP is increased with the utilization of heat exchanger in vapour absorption refrigeration system.

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