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# A REVIEW ON METHODS OF DESIGN OF CONDENSER FOR VAPOUR COMPRESSION SYSTEM

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**Abstract-**A study of the performance of an air conditioning system, with the help of three condensers namely air-cooled, water-cooled and evaporative condenser is presented and investigated. The research incorporates the work done by different authors on the optimization of condensers and bringing about necessary modifications to reduce the power consumption and also to give better efficiency. It is observed that evaporative condensers are optimal for decrease in power consumption and for enhancing COP on a small scale. Air cooled condensers can be modified by shifting the load peak to off-peak period using thermal storage. Moreover various other methods like installing a cooling pad for a water cooled condenser in the cooling tower can be adopted. Also, different materials and refrigerants contribute to the enhancement of performance. Although these techniques improve the performance, the use of a dual condenser might prove to be more beneficial for residential purposes.

**Keywords** – Air conditioner, Coefficient of performance, Design, Dual condenser, Energy consumption, Enhancement

## I. INTRODUCTION

In this era air conditioning has become a necessity. Depending on space and requirement AC units are classified as follows: window air conditioner, split type air conditioner, Central air conditioning, hybrid air conditioner, geothermal air conditioning etc. The governing law of an air conditioner is Clausius statement of the second law of thermodynamics which

states that “an external work is required to extract heat from a cold reservoir and transfer it to a hot reservoir”.

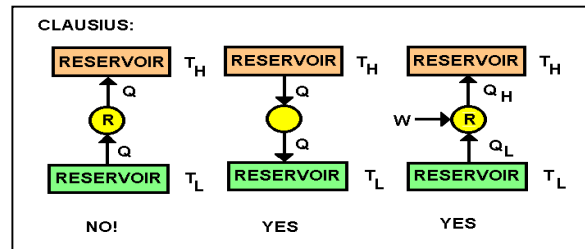


Fig 1 Schematic Diagram Of Clausius Statement [Source: <http://athena.ecs.csus.edu/>]

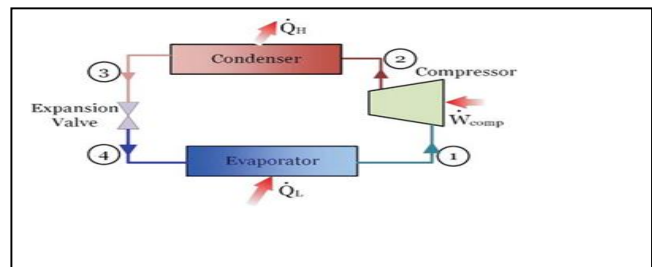


Fig.2 Schematic diagram of ideal vapour compression refrigeration system [Source:10.5772/intechopen.8862]

### A. Working Principle

An air conditioner works on vapor compression cycle and comprises four main parts namely evaporator, compressor, condenser, and expansion valve. Air inside the room is sucked

using a blower to the evaporator. When inside air comes in contact with the evaporator it transfers heat to the refrigerant and approaches to Apparatus Dew Point (ADP). After taking heat from air, refrigerant converts into vapor form and goes into the compressor. Compressor increases the temperature and the pressure of heated vapor and sends it to the condenser. In the condenser coil condensation of refrigerant is taking place by transferring latent heat content of vapor to the ambient air. After condensation heated vapor gets converted into liquid form and flows into the expansion valve where reduction of pressure takes place thereby temperature of liquid refrigerant also gets reduced. When inside air approaches ADP it gets dehumidified and releases its water vapor content in the form of condensed water. Drain pan (tray) is located under the cold evaporator in which condensate gets collected which is then drained using a pipe

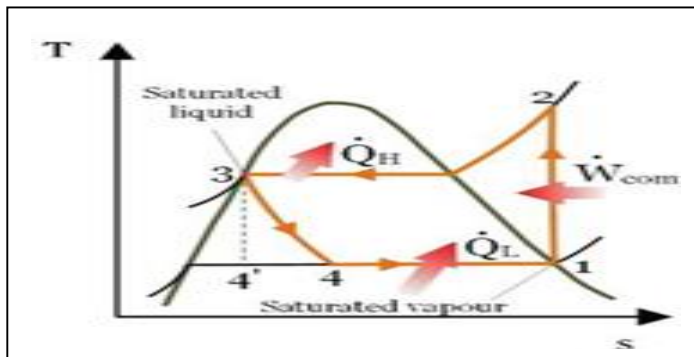


Fig.3:T-S diagram of ideal vapour refrigeration compression cycle [Source: 10.5772/intechopen.8862]

## B. Major components of air conditioner

### Compressor:

A Compressor is a mechanical device which increases pressure as well as temperature of the refrigerant. This can be done by compressing or squeezing the vapour. Compressor is installed in AC units to make sure that the temperature of refrigerant is high enough to transfer heat extracted from inside the room to ambient space. Compressors differ from pumps as they operate only on vapour while the latter one operates on pump. Different types of compressor are available in markets but in air conditioner reciprocating type compressors are used.

### Condenser:

Condenser is a high pressure side heat exchanger in which heated vapor enters and gets converted into liquid form by condensation process. In the condenser coil, gaseous substance is condensed into liquid by transferring latent heat content present in it to the surrounding. In the whole process, mode of heat transfer is conduction in condenser coil and forced convection between refrigerant and condenser. FINS are mounted on the condenser coil to increase surface area thereby increasing heat transfer rate. Condenser coil is generally made up of copper alloy and FINS are made up of aluminium alloy.

### Evaporator:

Evaporator is a low pressure side heat exchanger in which refrigerant enters in liquid form and exits in heated vapor form. Refrigerants being at lower temperature than the air inside the room extract heat from the room and get converted into vapour. Air inside the room is drawn to an evaporator coil using a blower.

**Expansion Valve:** An expansion valve is also known as a metering device and its main purpose is to remove the pressure from liquid refrigerant and allow the refrigerant to change from a liquid to a vapor in the evaporator. It also controls the amount of refrigerant flow that enters the evaporator.

### Refrigerant:

A refrigerant (also known as coolant) is an integral part of refrigeration and air conditioning units. A Refrigerant changes its state from liquid to vapour state and vice versa at appropriate temperature for the refrigeration cycle. After absorbing heat the refrigerant travels to the outdoor unit where the heat is pushed outdoors. Once the refrigerant has dispersed its heat outdoors, it changes back to its gaseous state and travels back indoors to repeat the same cycle again.

## C. Factors affecting efficiency and power consumption

Major concern while selecting a good quality condenser for domestic use is its efficiency and power consumption. There are many factors affecting the efficiency and power consumption of an air conditioner. These include the design of air ducts, age, and condition of unit, weather condition and layout of space. Modifications which include adding spray water above the condenser, wet pad before condenser and presence of water vapor nozzle in the condenser air flow can be used to enhance the performance of residential AC units. Such techniques in order to optimize the performance of different condensers have been suggested in this paper.

## II. LITERATURE REVIEW

The literature survey has been done to explore various works that has been done in the field of condenser cooling and also in the utilization of condensed water from the traditional air conditioners. In this survey US patents, International journal, and some other research papers (1955-2020) have been reviewed and the entire review has been categorized into following categories:

- **Air cooled condenser**

In an air cooled condenser we use a blower which sucks the ambient air and supplies it to the condenser coil. Dissipation of heat is being carried by the process of conduction as well as forced convection.

- **Water cooled condenser**

Water cooled condensers are heat exchangers which take heat from refrigerant and transfer it to water flowing outside of the condenser. The rate of heat transfer in water cooled is more than that of air cooled condensers.

- **Evaporative condenser**

An evaporative condenser is a device that is used for converting refrigerant that is contained within a closed circuit from a heated vapor to a cooled liquid formed by the evaporation of water being sprayed on the exterior surface of the condenser tube.

- **Comparison**

In this topic we compare different methods adopted for condenser cooling. Comparison of these condensers is done on the basis of coefficient of performance, energy consumption, refrigeration capacity, material etc.

- **Material**

The cooling capacity of refrigeration systems is dependent on the material used for making different parts. This topic deals with the material selection of such different parts used in the cooling system of an air conditioner.

- **Optimization**

In this topic various methods have been adopted to enhance the performance of an air conditioning system by retrofitting the existing arrangement.

- **Simulation**

This topic reviews different research in which 3D modelling is done using Pro/Engineer and CFD analysis done in Ansys.

### A. Air cooled condenser

An air cooled condenser (ACC) is a direct heat type heat exchanger in which steam enters and is condensed to liquid inside air-cooled finned tubes. There is no direct contact between the refrigerant and the cooling fluid i.e. the ambient air. The heat of refrigerant is transferred to the surrounding cold air through the walls of the tube. The rate of heat dissipation is increased by the usage of a fan as it increases the velocity of ambient air surrounding the tube of the condenser. The condensing temperature depends on the air dry bulb temperature.

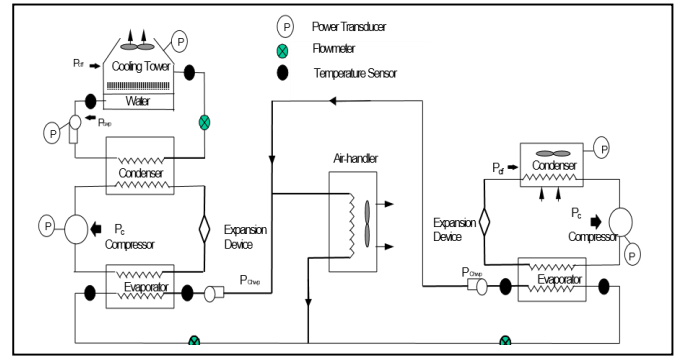


Fig.4 Schematic diagram of AC system used for performance assessment [Source: Goswami et al (1993)]

Air cooled condensers are more popular for residential or domestic usage as their cooling capacity is not dependent on water availability. In addition to this they are a more cost effective option as their installation is comparatively cheaper than water cooled condensers. Their maintenance cost is also less than that of a water cooled condenser. The air cooled condenser has some limitations. The length of the air cooled condenser is large and requires large space to fit in. They are less efficient than water cooled condensers and also tend to produce noise when operated. Efficiency and power usage is always a concern in case of air cooled condensers. This topic deals with the various modifications done in air cooled refrigeration systems to enhance efficiency and reduce power consumption. Scott (1975) has done a study on a system in which air cooled condenser coils are cooled with the help of water vapour or mist so that the temperature of the coil is lowered by evaporation. This in return increases the efficiency of an air conditioning system using air cooled condenser coils. Permetti (2005) did this invention related to a mist cooler and in particular in order for cooling the air partially or completely surrounding a conventional air cooled condenser of an air cooler or refrigeration unit. This invention can be merged as an addition to any air conditioning air cooled condenser for residential, commercial, industrial, or institutional application. Goswami et al (1993) demonstrated utilization of indirect evaporative cooling processes to boost the performance of an air-to-air vapour compression refrigeration system. They performed an experiment on an air conditioning system of 2.5 ton (8.8 kW) and concluded that 20 percent electric energy was saved. Sumeru et al (2018) investigated performance of the system of residential air conditioner using condensate as a compressor discharge cooler. They worked on a split-type air conditioner of 2.5 kW. It was found that discharge compressors caused decrease in condenser outlet temperature by 2.2°C. Cooling capacity was also found to be enhanced. Chen et al (2008) carried out an experiment which predicted the potential energy saving using water cooled air conditioners in residential buildings in Hong Kong. A split type air conditioner which had both air cooled and water cooled. The results obtained showed that the COP of the water cooled was approximately 17.4% above the air cooled and the energy savings accounted to be

around 8.7%. Baweja et al (2013) examined air-cooled condensers under various operating conditions. Drop in efficiency of air-cooled condensers and extra fouling of fins surface under high ambient temperatures and windy conditions were discovered. They concluded that hybrid dephlegmator, shading of condensers and fouling fins cleaning could be a solution to minimise the effect of weather. Sumeru et al (2018) utilised the concept of subcooling to enhance the system's performance. They concluded that subcooling had led to an increase in cooling capacity by 12.1% and the use of condensate water as a compressor discharge cooler increased the COP by 21.7%. Yeunyongkul et al (2016) in this paper made an experimental investigation for the use of a hybrid condenser as the condenser for a vapour compression refrigeration system. In this paper hybrid condensers were used instead of the conventional condenser in the split type air conditioner to decrease pressure drop and recover heat rejection from the condensing process.

The efficiency of the air-cooled condenser can be enhanced by modifications which include adding spray water above the condenser, wet pad before condenser (subcooling) water vapor nozzle in the condenser airflow.

### **B. Water cooled condenser**

A water-cooled condenser is a heat exchanger that removes heat from refrigerant vapour which carries heat and transfers it to the water. The water outside the tube gets heated and makes the refrigerant cool which flows through the expansion valve into the evaporator and the water which is hot is then transferred to the cooling tower. It is an important component on the high side of an air-conditioning system. These condensers are of three types namely shell and coil, shell and tube multi pass, and double tube. The water-cooled condensers have high heat transfer capacity due to high thermal conductivity of water i.e., 0.60 W/m K. These types of condensers are used for large capacity plants. But the limitations are that it is a bit complicated. Therefore the initial and maintenance cost is very high. And also its maintenance takes a long time compared to the air-cooled type condenser. One of the major problems with these types of condensers is disposing water. Also it has a high possibility of corrosion carrying of water. So, therefore it has a high fouling effect that reduces the rate of heat transfer. Also there can be the possibility of algae formation in the stored water. Due to scaling and algae formation heat transfer rate of condenser gets reduced to some extent. Ferry (1996) has done a study on treatment of water for controlling the growth of biological organisms specially algae. Formation of algae in stored water is a natural phenomenon which takes nutrients from water. The formed algae flow into the water jackets and water pipes of cooling systems from the tank which are the supply line for cooling water and the above components are choked with an accumulation of biological organisms. This innovative idea relates specifically to control of algae growth in stored water like in cooling systems. Apart from that, Wu (1986) had invented an improved water-cooled air conditioner

where a cooling device to be served as a conventional cooling tower is combined with the evaporator of the air conditioner to form a single unit. This model reduces the cost and also it is easy to install. Some of the work has also been done in the field of improvement of performance and consumption of energy of water-cooled condensers .

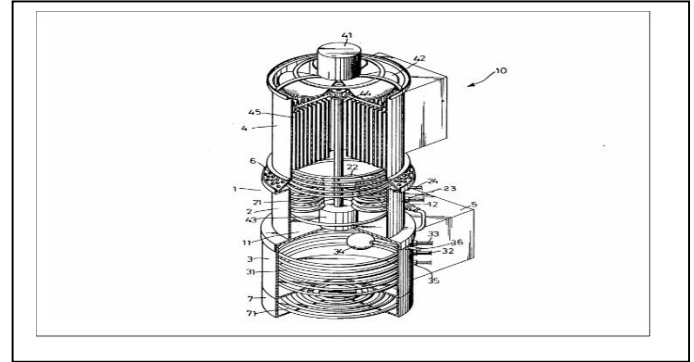


Fig.5 Shows combination of cooling tower, condenser, evaporator, heating coil unit [Source: Wu (1986)]

As Lee et al (2008) worked on water cooled air-conditioning systems and developed an empirical model for predicting the operational performance and consumption of energy for the use of water-cooled air conditioners whereas Siricharoenpanich et al (2019) tried boosting the thermal performance of an air conditioning system using a cooling water loop and found that the coefficient of performance is significantly increased. Similarly, Hu et al (2005) had also worked on the improvement of performance coefficient of water cooled air conditioner by employing residential water-cooled air conditioners with a cellulose pad as filling material for cooling tower. They observed that the coefficient of performance of this kind of air conditioner is higher than the conventional air conditioner. Some mathematical work had also been done on a water-cooled air condenser. Charun et al (2013) have examined the two refrigerants R134a and R404a in long serpentine coils. After thorough investigation he concluded that the condensation process in long coil pipes is different from that in horizontal pipes. Using this he coined a new expression for calculating the average heat transfer coefficient and flow resistance in the two-phase area which could be used for designing water cooled serpentine coil condensers. And Xu et al (2016) simulated the difference in temperature distribution between shell tube and plate fin heat exchanger, after experiments were performed on the two it was found that shell tube heat exchanger achieved better heat transfer power, especially with large input. This concludes that the major work had been done for the improvement of performance coefficient by applying several methods on water-cooled condensers. Some of the ways had also innovated to deal with the algae formation. And the mathematical work had also been done for calculating the heat transfer coefficient and flow resistance.

### C. Evaporative condenser

To increase the performance of an air conditioning system different cooling methods for condensers are disclosed by the researchers, evaporative cooling is one of the methods among them. In this method water is sprayed on the exterior surface of the condenser coil and air is sucked by the blower which increases the rate of evaporation.

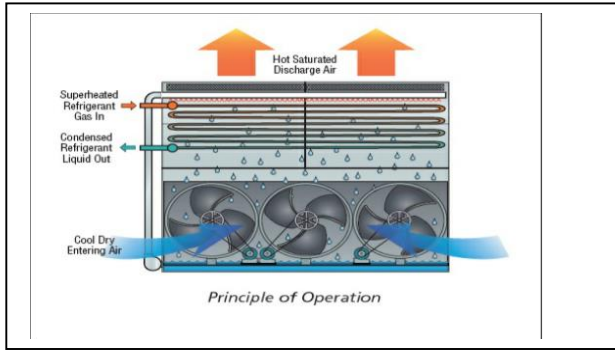


Fig.6 Arrangement of evaporative cooling of water in split type air conditioner [Source: EVAPCO]

Water absorbs heat and changes its phase from liquid to vapor, through this process we reduce the temperature of the condenser surface. Evaporative cooling is also applicable in cooling of water in water cooled systems instead of cooling towers. Water used in evaporative condensers is less than that of cooling towers. In this regard Kocher et al (1990) introduce a fogging nozzle which sprays water as a mist in the path of air which results in increased evaporation rate. Whereas Kreid et al (1978), Leidenfrost et al (1982) have done a study on finned evaporative coolers and condensers. They conclude that fins increase heat transfer rate only if water is sprayed on the whole surface. Islam et al. (2015) have done an analysis on the performance of an air condition system having evaporative condenser and compared the experimental values with the numerical ones. On the other hand Forgy (2003) has done an analysis on an air conditioner in which the compressor and accumulator dipped in water into a water tank. Water is sprayed on the exterior surface of the condenser. The temperature of the compressor is reduced by the water in the water tank which is cooled by evaporative cooling.

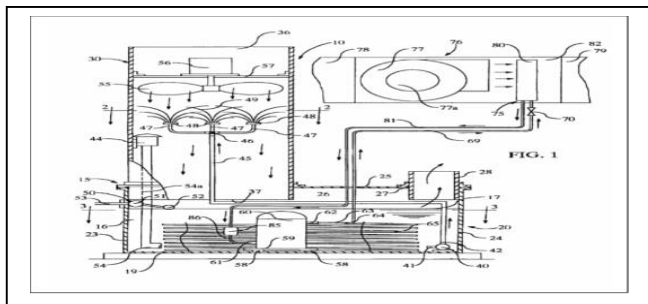


Fig. 7 Simple setup of an evaporative condenser[Source: Forgy (2003)]

Whereas Goswami et al (1993) and Hajidavalloo (2007) performed an experiment on performance enhancement of air conditioners using indirect evaporative cooling. They found a 20 percent reduction in power consumption and 55% increment in COP with the use of a media pad type evaporative cooler. Whereas Zhu et al (2020) and Liu et al (2015) studied the effects of important characteristics on the heat and mass transfer performance in evaporative condensers. In the result they found that COP increased by 13.1% with the increase in air velocity from 2.05 to 3.97 m/s whereas COP increased by 6.1% with the increase of spray rate from 0.03 to 0.05 kg m<sup>-1</sup> s. However, COP decreased with increasing inlet air dry bulb temperature and frequency of compressor. On the other hand Fiorentino et al (2018) introduced a new hybrid method which was applied on countercurrent evaporative condenser. It was found that water flow rate was increased by 50% leading to a 14% heat transfer rate. Huang et al (2017) have reviewed fractal geometries, evaporative cooling and given a design to apply biomimicry to heat exchangers. Hence we conclude that evaporative condensers have higher heat transfer coefficients per unit area and lower condensing temperatures than dry condensing units; it also reduces water consumption and pumping power associated with cooling towers. Inspired by the bio heat transfer process inventors designed a fractal heat exchangers. Many researches are being conducted in the field of evaporative cooling of fractal heat exchangers.

### D. Comparison

Every refrigeration system needs to be equipped with a condenser. Each of them has its own set of advantages and disadvantages, there are many factors that are considered for selecting the condenser, this include available space, refrigeration capacity, coefficient of performance, cooling effect, energy consumption, cost efficient and on-going maintenance. As air cooled condensers can be more cost effective in their standard smaller configurations while water cooled evaporative condensers are often applied in larger industrial installations. Therefore, comparison of different condensers helps to find an appropriate condenser for use in every aspect. Singh et al (2016) have compared the performance coefficient between air-cooled and water-cooled but with the help of using evaporative pad in vapour absorption and compression refrigeration system. Evaporative pads are made up of cellulose that improves the coefficient of performance of the system by reducing the condensing temperature to a great extent. The refrigerating effect of water-cooled condenser using evaporative pads exceeds by 2.9-14.4% and coefficient of performance is improved by 1.5-10.2% when compared with an evaporative condenser whereas Maheshwari et al (2004) have conducted an experiment in one of the major hospitals in Kuwait to investigate the performance of water cooled and air cooled systems in terms of peak power and energy consumptions. Lee et al (2008) have also done an experimental



study of air conditioners with water cooled and air cooled and compared their coefficient of performance. The results obtained were used to test the mathematical models developed for predicting the performance of water cooled air conditioner and air cooled air conditioner at different operating conditions and load characteristics and overall energy saving was also estimated. Hosoz et al (2004) have compared all the three condensers and found that the water cooled system had a greater refrigeration capacity by 14.4% and greater coefficient of performance by 10.2% as compared to evaporative condensers. On the other hand, the refrigeration capacity and performance coefficient of the refrigeration system with evaporative condenser were higher than the system with air-cooled condenser by 31.0% and 14.3% respectively. Apart from that Harby et al (2016) have worked on evaporative condensers in residential cooling systems. He focused on energy consumption and its related complications by comparing different types of condensers. This concludes that the different authors have compared all three condensers on various aspects such as performance coefficient, energy consumption, refrigeration capacity peak power, etc.

**E. Material**

In order to make a good condenser its material should be selected as a solid that allows good transfer of heat. This heat transfer should occur in such a manner that it does not react with the gaseous or liquid phase of the chemicals involved in the process. The material should be such that it does not get corroded easily on contact with fluids and so the coolant must be selected cautiously. Most common examples of materials that are selected for condensers include copper, brass, aluminum, and stainless steel. Copper is commonly used as condenser material as it possesses high thermal conductivity. But it has poor corrosion resistance so it is mostly used with standard coolants and water. Brass, an alloy of copper and zinc, has high thermal conductivity for efficient heat transfer and suffers from corrosion resistance. In order to make it more resilient it can be alloyed with zinc. Aluminum on the other hand is a lightweight metal and provides high heat transfer efficiency at low cost. It is alloyed with bronze and nickel in order to increase its corrosion resistance. Stainless steel is an alloy of steel that has excellent corrosion resistance and comparatively lower heat transfer efficiency. Thus, it is the best material to be used when required to work with corrosive refrigerants. Babu et al (2016) have done CFD analysis and heat transfer analysis of condensers because water cooled condensers occupies a smaller space than air cooled condensers. In this paper heat transfer analysis and CFD analysis is done on the condenser to find the better design and material. Furthermore, they concluded that the material taken for manufacturing the condenser tubes are made of copper and for fins the material is aluminum alloys 1100, 6063 and Magnesium alloy for different refrigerants HCFC and 404R. Sapali (2009) experimentally investigated using two phase heat

transfer coefficients and pressure drops of R-404A in a smooth (8.56 mm ID) and micro-fin tube (8.96 mm ID). Experiments were performed for different condensing temperatures, with superheating and subcooling .It was observed that both the tubes show that the average heat transfer coefficient and pressure drop increases with mass flux but decreases with the increasing condensing temperature. They concluded that average heat transfer coefficient is around 30-210% higher for micro-fin tube compared to smooth tube, for moderate increase in pressure drop lying between 10-55%. The data-analysis procedure determines the average convective heat transfer coefficient of refrigerant side, which also takes into account oil present in the refrigerant (because refrigerant carries the compressor oil in the test condenser). In addition, the data analysis determines the correlation constants required for average convective heat transfer coefficient of water. The equations to find rate of heat rejected by refrigerant and rate of heat absorbed by cooling water are as follows. The variation between the heat rejected by refrigerant and heat absorbed by water is within 5 %.

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$$Q_r = Q_{sv} + Q_c + Q_{sl} \tag{1}$$

Where,

$$Q_{sv} = m_r C_{pv} (T_{ri} - T_{hi}) \tag{2}$$

$$Q_{sl} = m_r C_{pl} (T_{ho} - T_{ro}) \tag{3}$$

$$Q_c = m_r (h_{ti} - h_{to}) \tag{4}$$

$$Q_w = m_w C_{pw} (T_{wo} - T_{wi}) \tag{5}$$

The average LMTD value is obtained by using following equations-

$$T_{wd} = T_{wi} + \frac{Q_{sw}}{m_w C_{pw}} \tag{6}$$

$$T_{wc} = T_{wd} + \frac{Q_c}{m_w C_{pw}} \tag{7}$$

$$LMTD_d = \frac{(T_{ri} - T_{wi}) - (T_{hi} - T_{wd})}{\ln \left( \frac{T_{ri} - T_{wi}}{T_{hi} - T_{wi}} \right)} \tag{8}$$



$$LMTD_c = \frac{(T_{hi}-T_{wc})-(T_{ho}-T_{wd})}{\ln\left(\frac{T_{hi}-T_{wc}}{T_{ho}-T_{wd}}\right)} \quad (9)$$

LMTD<sub>d</sub> -logarithmic mean temperature difference (°C) for desuperheating process

LMTD<sub>s</sub> -logarithmic mean temperature difference (°C) for sub cooling process

$$LMTD_s = \frac{(T_{ri}-T_{wi})-(T_{hi}-T_{wd})}{\ln\left(\frac{T_{ri}-T_{wi}}{T_{hi}-T_{wd}}\right)} \quad (10)$$

m<sub>r</sub>- mass flow rate of refrigerant (kg s-1)

m<sub>w</sub>- mass flow rate of water (kg s-1)

$$LMTD = \frac{Q_r}{\Sigma_{LMTD}} = \frac{Q_r}{\Sigma\left(\frac{Q_d}{LMTD_d} + \frac{Q_c}{LMTD_c} + \frac{Q_s}{LMTD_s}\right)} \quad (11)$$

Q<sub>c</sub> -rate of heat rejected by refrigerant during only condensation (kW)

Q<sub>r</sub> -total rate of heat rejected by refrigerant (kW)

Q<sub>sl</sub>- rate of heat rejected by refrigerant during sub cooling of refrigerant (kW)

Q<sub>sv</sub> -rate of heat rejected by refrigerant during desuperheating of refrigerant (kW)

Q<sub>w</sub>- rate of heat absorbed by cooling water (kW)

T<sub>hi</sub> -refrigerant saturation temperature at the inlet of condenser (°C)

T<sub>ho</sub> -refrigerant saturation temperature at the outlet of condenser (°C)

T<sub>ri</sub>- refrigerant temperature at the inlet of condenser (°C)

T<sub>ro</sub> -refrigerant temperature at the outlet of condenser (°C)

T<sub>wc</sub> -estimated water temperature at the end of only condensation of refrigerant (°C)

T<sub>wd</sub> -estimated water temperature at the end of desuperheating of refrigerant (°C)

T<sub>wi</sub> -cooling water temperature at the inlet of shell (°C)

T<sub>wo</sub>- cooling water temperature at the outlet of shell (°C)

U<sub>o</sub> -overall heat transfer coefficient based on outer surface area (W m-2.K-1)

Apart from that Hannemann et al (1976) worked on analysis of the effect of the condenser material and its thermal properties on the dropwise condensation heat-transfer coefficient. They concluded that combination of single-droplet constriction resistance solution with known droplet distribution leads to a simple interrelationship for the effect. Liang et al (2015) proposed shell-and-tube based phase change material thermal storage system with conventional air conditioner. They used

The average heat transfer coefficient is determined by using-

$$U_o = \frac{Q_r}{A_o LMTD} \quad (12)$$

Assuming that the resistance of the copper tube is negligible, the following formula is obtained for the average heat transfer coefficient on the inner surface of the test tube:

$$h_i = \frac{1}{\left(\frac{1}{U_o} - \frac{1}{h_o}\right)\left(\frac{A_o}{A_i}\right)} \quad (13)$$

Where,

A<sub>i</sub> -inner surface area of tube (m<sup>2</sup>) (=πd<sub>i</sub>L)

A<sub>o</sub> -outer surface area of tube (m<sup>2</sup>) (= πd<sub>o</sub>L)

C<sub>pl</sub> -specific heat of liquid refrigerant (kJ kg-1.K-1)

C<sub>pv</sub> -specific heat of vapour refrigerant (kJ kg-1.K-1)

C<sub>pw</sub> -specific heat of water (kJ kg-1.K-1)

d<sub>i</sub> -maximum inner diameter of tube (m)

d<sub>o</sub> -outer diameter of tube (m)

h<sub>i</sub> -film coefficient inner side (refrigerant) (W m-2 K-1)

h<sub>o</sub> -outside heat transfer coefficient (water side) (W m-2 K-1)

h<sub>ii</sub> -specific enthalpy at test condenser inlet (kJ kg-1)

h<sub>io</sub> -specific enthalpy at test condenser outlet (kJ kg-1)

LMTD- average weighted logarithmic mean temperature difference (°C)

LMTD<sub>c</sub> -logarithmic mean temperature difference (°C) for condensation process



two different kinds of medium like air and water for the heat transfer fluids. It was concluded that proposed phase change material thermal storage system is generally higher than 0.5 and COP increased about 25.6%

REFRIGERANTS	MATERIALS	RESULTS		
		Nodal Temperature (K)	Thermal Gradient (K/mm)	Heat flux (W/mm <sup>2</sup> )
HCFC	Aluminum 1100	313	5.52101	1.26983
	Aluminum 6063	313	5.82506	1.12424
	Magnesium	313	6.16722	0.986754
404R	Aluminum 1100	313	6.43696	1.4805
	Aluminum 6063	313	6.07077	1.28162
	Magnesium	313	6.94673	1.11148

Table: 1 [Source: Sapali [11]]

So it can be interpreted that copper is the best condenser material whereas aluminium is the best material for fin. Also use of Phase Change Material (PCM), as condenser material can increase the COP of the air conditioner.

**F. Optimization**

Optimization refers to the process of obtaining a favourable or desirable condition. In our case we have focused on the optimization of different types of condensers namely air cooled, water cooled and evaporative condensers. The focus is on reduction of power consumption, increasing the COP and utilization of waste water. Goswami et al (1993) performed an experimental investigation on an air-to-air vapour compression refrigeration system. They used a media pad type evaporative cooler, a water source and a pump instead of the traditional air conditioning system and found that using a evaporative cooler on the condenser can reduce the energy consumption whereas Hajidavalloo (2007) also employed evaporative cooling in a normal air conditioner with two cooling pads on both the sides of the air conditioner and injected water on the pads in order to cool the air before it passes over the condenser. He discovered that employing such a system decreases the power consumption and increases COP. Patel et al (2020) presented a performance analysis and optimization of the COP using evaporative cooling in condenser which is achieved by spraying water on the fins of

condensing unit at regular intervals of time. Unlike the others mentioned above, Charoenpanich et al (2019) improved the thermal performance of air conditioners using a cooling water loop. He installed a concentric helically coiled tube heat exchanger between the compressor unit and condenser unit and observed that COP increases also hot water storage was obtained. Sarnitchartsaka et al (2013) presented system analysis and optimization using R-410A as the refrigerant. He investigated numerically and experimentally the working of the entire system using evaporative cooling units. Different parameters like varying of frequency, water flow rate and spraying temperature were observed and found that such a system recorded an extended frequency range of 30-90 Hz. Park et al (2008) used the same refrigerant as Sarnitchartsaka et al (2013) but instead of evaporative condenser microchannel condenser and a round tube condenser were used in a residential air conditioner. On investigation it was observed that microchannel condenser had a higher COP and cooling capacity compared to round tube condenser air conditioner. Santa (2012) analyzed heat transfer models for condensation in horizontal smooth tubes using numerical-graphical methods. He selected an optimal model from the examined two phase condensation heat transfer models. The selection of condensing refrigerant two phase heat transfer model is based on boundary condition. Mohamed et al (2017) researched that efficiency of air cooled condenser can greatly be increased by shifting the load peak to off-peak period with thermal storage. They estimated the daily cooling load profile using a model of normal material and the other model with 5-8 cm thermal insulation and double layers glass windows. It was concluded that models with thermal storage reduced the power consumption to a great extent and also a lot was saved on electricity bills. Sharma et al (2014) not only improved the efficiency of the condenser but also utilized the waste water from the air conditioner. They proposed a combination of air conditioner and water cooler. The wastewater of the water cooler is sprayed on the condenser so that the efficiency of the air conditioner is increased. Dalai et al (2017) like Sharma et al (2014) also focused on utilizing the waste water but for a different purpose. They utilized the moisture present in air using the concept of humidification-dehumidification. The water extracted through this technique could be used for drinking and other purposes. It can be concluded from various studies that performance of a condenser for a residential air conditioner can be optimized using evaporative cooling and also by shifting the load peak to off-peak period for an air cooled condenser using thermal storage. The water being wasted can be utilized in a number of ways.

**III. CONCLUSION**

This paper reviewed publications related to the condenser design used in the vapor compression system (VCS). Three types of condensers are taken under research namely air-cooled, water-cooled, and evaporative condenser. Different methodologies of simulation, analytical, and experimental design are being used to reduce power consumption for



enhancement of COP. For improvement of heat rejection from condenser, spray techniques were used in evaporative condenser which has given considerable drop in condenser pressure. Water-cooled condenser using the concept of central air conditioning system was also studied for small units. A significant increase in coefficient of performance was observed by employing cellulose pad as filling material for cooling tower. The concept of sub cooling was implemented using concentric tube heat exchanger which led to increase in coefficient of performance. Hybrid condensers were used as an alternative to conventional condensers which resulted in decrease of pressure drop and heat rejection was recovered. The dual condenser is a combination of both air-cooled and water-cooled condensers. In such a system, heat is dissipated to the atmosphere as well as to the water condensed by the evaporator. Numerous papers have been evaluated and analyzed to make a culmination that no work is done in the field of dual condenser cooling for performance enhancement of an air conditioner. In our view, the use of dual condensers may be the primary solution to enhance efficiency and decrease power consumption.

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