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A Review of Waste Heat Recovery from Air Conditioning System

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***Abstract*— Energy is a basic necessity required for the continuance and growth of human life. Primarily the popular sources of energy on Earth are fossil fuels, which provide for the energy reliability of a country. The irregular utilization of these resources has often led to its wastage. In the modern world, as people's demand for comfort cooling is increasing, the usage of air conditioners is also increasing nowadays. Air conditioning plays a tremendous role in increasing the Earth's temperature at some extent. An air conditioner is a system that treats air in a defined, usually enclosed area. In air conditioners, the heat of the indoor air is transferred to the outside air and rejected as waste heat into the environment, which can increase the overall Earth's temperature. Now, this waste heat rejected by the condenser contributes to global warming to some extent. So, to utilize this waste heat for productive purposes, Waste Heat Recovery System can be used, which can increase the efficiency of a system. In this regard, the use of waste heat recovery has been keyed as one of the major areas of research systems in industrial processes, to reduce fuel consumption, lower harmful emissions and improve production efficiency.**

Keywords—Waste Heat Recovery, Coefficient of Performance(COP), Air Conditioning, Heat Exchanger, Phase Changing Materials

I. INTRODUCTION

A. Waste Heat

Waste heat is the unused heat dissipated or given out to the surrounding environment(in the form of thermal energy) during or after the thermodynamic process. It is dissipated, as a result of a by-product in between, or at end of such a process[20]. As waste heat is low-grade energy, waste heat has lower utility than the original energy source. All such processes give off some waste heat as a fundamental result of the laws of thermodynamics[53]. The sources of waste heat include hot combustion gases discharged into the atmosphere, heated products exiting the industrial process, an air conditioner conditioning the room space and rejecting the heat to the environment, and heat transfer from hot equipment surfaces[59].

B. Working of Air Conditioner

Today, an air conditioning system is a staple of everyday life. Whether in homes, offices, or vehicles, the main purpose of this system is to provide comfort by altering the properties of the air, usually by cooling the air inside. This system is so common that one can experience its effect anywhere we enter. The main function of an air conditioner is to change adverse temperatures. Air Conditioner follows the principle of Vapor Compression Refrigeration system Generally, there are four main components of an air conditioning system: compressor, condenser coil, expansion valve, and evaporator coil.

The compressor lies at the heart of any air conditioner. The compressor takes in the warm refrigerant vapor and compresses it into a denser form. This process also causes an increase in temperature and pressure, making the refrigerant hotter than before. The pressurized refrigerant is eventually pushed through the condenser coil. After that, the high temperature, high-pressure refrigerant vapor enters into the condenser. A condenser fan built into the outdoor cabinet directs ambient air through the condenser coil. This process, which is a constant pressure, changes the refrigerant from hot, high-pressure vapor into a hot liquid. The condenser coil uses the airflow to expel heat from the refrigerant and its job is to release heat from the refrigerant.

After then, the refrigerant moves the expansion valve. Before the refrigerant passes to the evaporator coils, it must be cooled down. This is where the expansion valve (also known as a metering device) comes in, normally a thermostatic expansion valve, operating at constant enthalpy. In this process, the refrigerant passes through the expansion valve, which converts hot refrigerant at high pressure into cool refrigerant at low pressure, thereby reducing its pressure and temperature. Then this refrigerant now passes through the evaporator coils. The evaporator coil plays a starring role in keeping the room cool and comfortable, which sucks the heat from the room, which is absorbed by the refrigerant, thereby reducing the room temperature, making it cool, and increasing the refrigerant temperature.

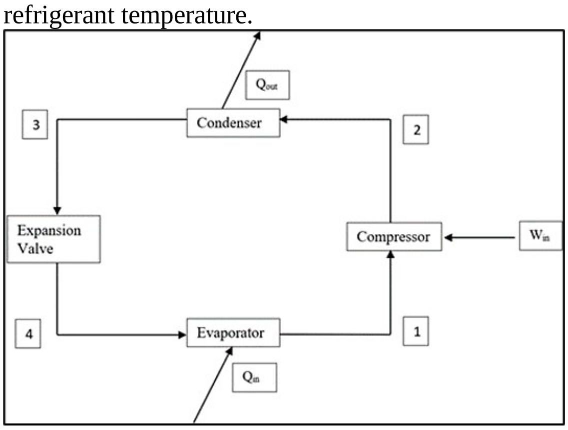

Figure 1: Block Diagram of Vapor Compression Refrigeration System

C. Phase Changing Materials(PCMs)

Phase Change Materials(PCMs) is defined as a material that releases/absorbs energy at phase transition temperature to provide useful heat/cooling. These are substances that

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can absorb or release large amounts of energy, i.e., so-called latent heat when they experience phase transitions among solid, liquid, and gas states. PCM acts like a battery for heat energy because they absorb heat energy as they melt and can be "recharged" by cooling them until they crystallize and give the stored energy back to the environment. Phase change materials (PCMs) are ideal for use in any application where storage and release of thermal energy are desired. They can store and release heat energy thousands of times without a change in thermal properties[73].PCMs are currently attracting a lot of attention for this application due to the progressive reduction in the cost of renewable electricity, coupled with limited hours of availability, resulting in a misfit between peak demand and availability of supply[72].

Property or Characteristic	Paraffin Wax	Non-Paraffin Organics	Hydrated Salts	Metallics
Heat of Fusion	High	High	High	Med.
Thermal Conductivity	Very Low	Low	High	Very High
Melt Temperature (°C)	-20 to 100+	5 to 120+	0 to 100+	150 to 800+
Latent Heat (kJ/kg)	200 to 280	90 to 250	60 to 300	25 to 100
Corrosive	Non-Corrosive	Mildly Corrosive	Corrosive	Varies
Economics	$$	$$$ to $$$$	$	$$ to $$$
Thermal Cycling	Stable	Elevated Temperature Can Cause Decomposition	Unstable over Repeated Cycles	Stable
Weight	Medium	Medium	Light	Heavy

Figure 3: Comparison of the properties of different Phase Changing Materials[73]

Paraffin waxes are the most common PCM for electronics thermal management because they have a high heat of fusion per unit weight, have a large melting point selection, provide dependable cycling, are non-corrosive, and are chemically inert. Paraffin PCMs also have a low thermal conductivity, so designing sufficient conduction paths is another key design consideration[64].

D. *Requirement of Waste Heat recovery System*

One of the great ironies of climate change is that as the planet warms, the air conditioning technology, which people need nowadays to stay cool, will only make the climate hotter. According to the International Energy Agency, there are about 1.6 billion heating, ventilation, and air conditioning units in the world. By 2050, researchers expect the number of room air conditioners on Earth to quadruple to 4.5 billion, becoming at least as ubiquitous as cell phones are today[50]. By the end of the century, greenhouse gas emissions from air conditioning will account for as much as a 0.5○C rise in global temperatures, according to the World Economic Forum[56]. So to reduce the amount of waste heat rejected by the condenser of the Air Conditioning System, and to increase its C.O.P, a waste heat recovery system is required which can utilize the amount of waste heat coming out from condenser of Air Conditioning System in some useful and productive purposes.

II. LITERATURE REVIEW

There are many different heat recovery technologies available which are used for capturing and recovering the waste heat in the form of a waste heat recovery unit under different methodologies. This section presents the literature review of various authors in the field of the Waste Heat Recovery.

M. Joseph Stalin et.al.2012[1] devised a methodology where the authors experimented to recover the waste heat rejected by 1TR air conditioning system. Their main aim was to utilize the waste heat discharged at the outlet for some productive purpose. In their experiment, the heat rejected by the condenser is used for heating the water into the circulating tank, which increases the temperature of the water. Then, the hot water was stored in an insulating tank, which can be used for domestic purposes. They had shown that by replacing water-cooled condenser in AC rescue 4 LPG gas Cylinders/ year.

R.B. Lokapure and J.D.Joshi [2] devised a methodology and emphasized energy conservation by using the technique of waste heat by utilizing waste heat from the Window Air-conditioning system and increasing C.O.P simultaneously. The purpose of this experimental apparatus is to develop a multi-utility air conditioning system to produce simultaneously both the air conditioning effect and the generation of hot water, which can be used for domestic purposes. Their experimental setup was set on the Window AC, where they connected the waste heat recovery system, with a designed heat exchanger attached to it. They had set the target of improving the C.O.P of the system up to 20 %, but in this case, they were able to achieve their goal by recovering energy and improving C.O.P up to 13.66% only.

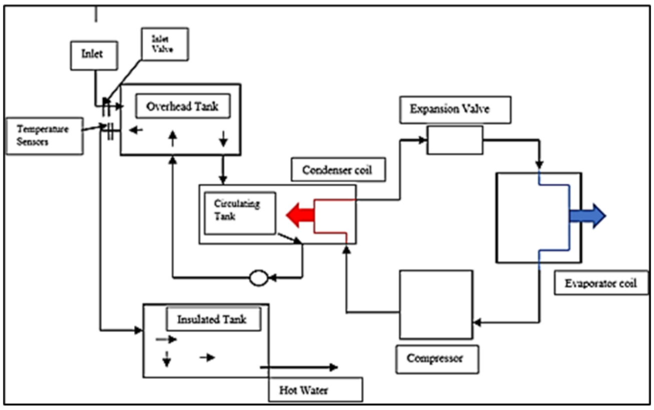

Figure 4: Sketch of Hot Water System integrated with Air Conditioning System[1]

Naser Rezaei et.al[3] devised a unique and innovative methodology of waste heat recovery which can simultaneously reduce the chances of spreading SARS-CoV-2 from heating, ventilation, and air conditioning(HVAC) systems. They have devised a Waste heat recovery system that can reduce the chances of spreading SARS-CoV-2 from hospitals, by using the waste heat to heat the exhaust air. These authors have done their best efforts for controlling the outbreak of SARS-CoV-2 with their proposed heat recovery system. Their system produces exhaust air with a temperature range of 50 °C –80 °C and a relative humidity range of 40%–50%, conditions under which SARS-CoV-2 was observed to disappear.

Ramyashree A. P et.al. [23]. worked on a window-type air conditioning system consisting of an air-cooled condenser that was taken for experimentation. Behind the condenser, a rectangular duct is created with a hole at the center which bypasses the hot air. This heating of water is done by extracting the waste heat coming out of the condenser. With this system, they were able to increase the COP of the system by 6% by incorporating a heat exchanger with AC.

Xuelai Zhang et.al[4] have devised an experimental investigation on a condensing heat recovery system by using paraffin wax as the PCM(Phase Changing Material), which is designed for daily hot water preparation. They have followed the methodology of doing the experimental analysis of the waste heat recovery system using paraffin wax as PCM. They have designed the waste heat recovery system for the air conditioner with a thermal storage container, thermally insulated with polyurethane, and having paraffin wax as the Phase Changing Material. With their experiments and analysis, they concluded that sensible condensing heat could be recovered effectively by a thermal storage container added and an air conditioning system kept in order with condensing heat recovery.

Rohit Prabhakar Rao Sarode et.al 2020 [7] laid emphasis and reviewed the approach of a waste heat recovery system using the heat exchanger. In their review, they concentrated on an approach towards the most dominant passive technology of waste heat recovery i.e. Plate Heat exchanger. A plate heat exchanger is one type of heat exchanger that uses metal plates to transfer heat from one fluid to another. This type of heat exchanger has major advantages over a traditional heat exchanger. The fluids spread over a very large surface, which means a much more heat transfer area is provided. In this type of heat exchanger, hot fluid flows in alternating chambers in one direction and cold fluid flows in other alternate chambers but flowing opposite to the hot fluid direction. In their review analysis, they presented that the plate heat exchanger using for waste heat recovery can be a major investment. Plate heat exchanger offers a cost- effective way to capture heat from industrial processes and heat can be utilized in diverse industrial processes. The plate heat exchanger offers high temperature and pressure limits and is used to heat transfer from one fluid to another with a high heat transfer area

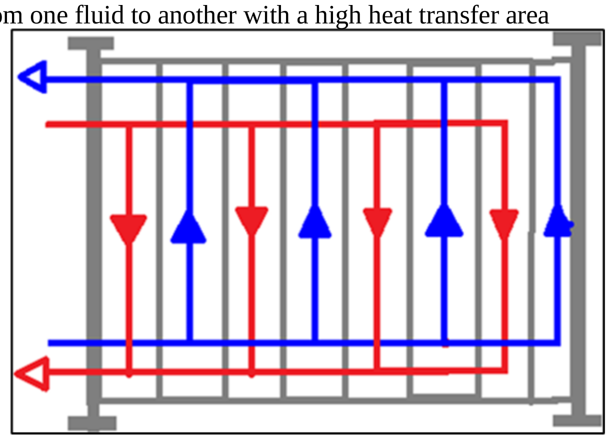

Figure 5: Schematic Diagram on Plate Heat Exchanger in 2D (Red: Steam converting to condensate, Blue: Product flowing from one end to another end) [7]

Zhaolin Gu et.al[16] have developed a heat recovery system using phase change materials (PCMs), which is used to store the rejected (sensible and condensation) heat from the air conditioning system. The thermal properties of the technical grade paraffin wax and the mixtures of paraffin wax with lauric acid(LA) and with liquid paraffin(LA) (paraffin oil) were investigated and discussed by them. Calculations were performed at different condensing temperatures i.e. at temperatures 40, 45, 50, 55, and 60 ○C, and according to their analysis, the amount of compressor power input is increased with the condensing temperature increase, whereas the refrigeration capacity and heat recovery capacity are decreased with the increasing condensing temperature. According to their research, analysis, the technical grade paraffin wax and the mixtures with LP and LA are proper PCMs for heat thermal energy storage.

Mahbubur Rahman et.al[43] gave a thorough review on Phase Changing Materials, and its classification in detail. According to the authors, they have defined PCMs as the latent heat thermal energy storage materials which use their chemical bonds for the storage and releasing of energy. When these materials reach the temperature at which they melt, they absorb large amount of energy without getting heated. PCMs solidify and releases energy when the surrounding temperature drops. They haves stressed on utilising such type of materials in different types of industries other than solar energy, which can help in doing the energy conservation.

III. METHODOLOGY

Many authors have adopted different methodologies or approaches in their experimental analysis towards the waste heat recovery from the air conditioning systems. One of the most common approaches adopted was making the Waste Heat Recovery system with the help of Heat Exchangers. Many authors designed their recovery systems with the help of different types of heat exchangers like Shell and Tube Heat Exchangers, Plate Heat Exchangers, etc. Then, by using their system, they performed the experiments based on different conditions, calculated the C.O.P of the Air Conditioner, and compared the values between them. The other approach adopted by some authors was using Phase Changing Materials (PCMs) in the Waste Heat Recovery. Some of the authors were able to utilize the benefits of Phase Changing Materials in their Waste Heat Recovery analysis. Although PCMs are a recent discovery, many authors researched them and found them more beneficial for waste heat recovery systems.

The Paraffin Wax was selected as the Phase Change Material for our Waste Heat Recovery System. The main motive for using the Phase Changing Material as the main material for our Waste Heat recovery System is to utilize most of the waste heat from the air conditioner. Paraffin is a high-molecular-mass hydrocarbon with a waxy consistency at room temperature. Kinds of paraffin are made of straight-chain hydrocarbons. The melting point of paraffin is directly related to the number of carbon atoms within the material structure with alkanes containing 12-40 C-atoms possessing melting points between 6°C and 80 °C. So, after selecting the wax, we experimented to find out its melting point. We found that the melting point of Paraffin Wax is 39.2°C. And for preparing the composite Phase Changing Material, we have used Carbon in the form of Charcoal Powder. Well, as per Guijun Yang et. al[47], experimental results proved that Carbon can effectively improve the thermal conductivity of PCM, and it is well suited. In this waste heat recovery system, we have mixed the Carbon and Wax in a solid-state only to form composite PCM.

Initially, the Aluminum pipes were cleaned so that no foreign particle is present there inside the pipe. Then Paraffin Wax as per the calculations was measured in total, and then we split the total weight of the wax as per the number of pipes in the experimental analysis. We performed the Waste Heat Recovery analysis by using the combined mixture of PCM(Wax) and Carbon in the form of Charcoal Powder. We added the Charcoal powder to the total weight of Wax, and made the batches out of it, as per the proportions. Then, by permanently sealing one end of the hollow Aluminum pipe, we added the mixture to each of the pipes carefully.

Figure 6: Waste Heat Recovery System with Composite PCM inside Aluminum Tubes

After filling them, we stacked all the pipes with rope, sealed the remaining end with the thermocol cork, and then we hanged it vertically in the plywood box chamber, in front of the condenser. Then we attached this box in front of the condenser. We started the air conditioner after attaching it, performing each of the experimental analyses for 30 min, noted down the temperature of the air inside the box at regular intervals. After experimenting for 30 minutes, we opened the door of the box, took out the aluminum pipes stack, and then quickly immersed the whole into the bucket of water.

TABLE I. PROPERTIES OF PHASE CHANGING MATERIAL(PARAFFIN WAX)[74]

Sr No	Details	
	Topic	***Values***
1.	Latent Heat of Fusion	190 KJ/kg
2.	Solid Density	930 kg/m^3
3.	Liquid Density	830 kg/m^3
4.	Thermal Conductivity	0.21 W/m °C
5.	Solid Specific Heat	2.1 KJ/kg °C
6.	Liquid Specific Heat	1.98 KJ/kg °C

IV. APPLICATIONS

A waste heat recovery unit/heat exchanger recovers heat from hot streams, water or gasses that still have a relatively high energy content which would otherwise go unused into the atmosphere. The most common examples are from steam from cooling towers or flue gases from a heat source such as a diesel generator. Even such type of waste heat recovery systems if planted in different condensers of the air conditioners, then by absorbing such type of waste heat can reduce global warming to some extent. It can be mainly used in heating up of the water, without using the fuel. And in some cases, waste heat recovered from commercial processes in industries can be utilized properly, depending upon the process.

V. CONCLUSION AND FUTURE SCOPE

The area of Waste Heat Recovery, in general, is necessary for those countries, which are deficient in energy consumption. More strict environmental legislation can be considered as a driving force, leading to the development of novel types of technologies and equipment. It is necessary to reach a balance between economically, technically, and environmentally appropriate ways of recovering waste heat not only from Air Conditioners but also from other processes too. Technologies need rapid development for recovering the waste heat from different processes.

As the Earth's global temperature is increasing day by day, human life on Earth will exhaust in the future. And many of the people are using Air Conditioners, which rejects lavish amount of heat into the environment, which goes waste and contributes to the global warming. As in the coming future, fossil fuels are going to be replenished, so engineers have to devise such systems in the upcoming future so to devise this precious waste heat for different purposes in the useful manner.

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