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Waste heat recovery: A review of vapour compression refrigeration system

Abadh Bihari Mandal and Pankaj Kumar

Department of Mechanical Engineering, Birsa Institute of Technology Sindri, Dhanbad, India.

Abstract: Global warming and energy demand is the present scenario before us. Increasing demand of energy compelled us to take necessary steps to recover waste heat from several sources. To fulfil the energy crisis and global environment protection utilization of waste heat should be the prime focus. The main aim of this paper is to find the best possible way to recover the waste heat from condenser of a domestic refrigerator. We know that the condenser of refrigerators reject large heat inside room which make us uncomfortable in summer due to temperature rise. This waste heat can be utilized for number of household purposes such as keeping food hot, heating water, cloths and grain drying. This seems to be a most valuable optional approach to improve overall efficiency of refrigerator and utilize the waste heat. This research shows that such a system is possibly feasible and economically suitable.

Keywords: VCR System, domestic refrigerator, Waste heat recovery, energy saving

1. Introduction: Energy transfer takes place if a temperature gradient exists in a system, or when two systems are at different temperatures limit are come into contact. Such process due to which the energy transfer takes place is called as heat transfer. The transfer of heat involves the exchange and/or conversion of energy. They must, therefore, follow the first as well as the second law of thermodynamics. Heat transfer is a basic and an essential topic that deals with the energy and has long been an essential part of mechanical engineering courses all over the world. Heat transfer processes are used in a vast number of engineering utilities such as heat retrieval systems. It is important for mechanical engineers to understand the principles of thermodynamics and heat transfer and be able to use correct equation that decides the quantity of energy being transferred. By retro fitting the waste heat recovery unit this waste heat can be recovered and can be utilized for water and air heating requirements. Hot water and dry air produced by this process can be used for several household utilities. The hot water can store in an insulated tank for further use. The proposed system results in saving of energy due to non-usage of electricity for water and air heating thus cost effective with combination of both this utilities (refrigeration and heating) in one system.

A refrigerator is a basic domestic appliance that comprises of an insulated chamber known as an evaporator and when it works, transfers heat from the inside of the chamber to its external environment so that the inside of the thermally insulated chamber is cooled to a temperature below the temperature of the room environment. In general, domestic refrigerator works with air-cooled condenser. Tetrafluoroethane (R-134a) refrigerant is now widely used in almost of the household refrigerators and air- conditioners with utilizing POE oil as a most desirable lubricant. Generally, heat from the condenser is dissipated to the room environment. Without utilizing this heat, it would be simply wasted. Refrigerator has become an important appliance rather than need. Very few of us are aware about the fact that lot of heat is wasted to ambient by the condenser of refrigerator. If this energy can be utilized effectively then it will be an added advantage of commodity our project aims towards the same goal. Refrigeration in simple language is removal of heat from the place where it is objectionable and dissipation of heat to the place where it is not objectionable **[1 - 23]**.

The objective of this study is to design, construct and evaluate dual refrigeration system by manufacturing an experimental setup of heat retrieval system from the condenser and evaporator. Although studies have been done before on dual refrigeration systems, more research could be done to further enhance the results obtained by experimenting using different sets of working pair's material and testing them in different conditions and shape and sizes. For example, in experimental investigation with waste heat recovery system in refrigeration unit, Kaushik and Singh in 2012 have found that 40 % of the condenser heat can be retrieve from the Canopus heat exchanger for typical set of operating conditions in a dual refrigeration system **[3]**. To generate ice, the evaporator temperature must be less than 0 ^{o}C. The above system could generate a COP of about 1.2 to 1.4 and in this study the aim of maintaining the COP more than or equal to 1. The main objective is to increase the COP of system by recovery of waste energy. When the heat of condenser is utilized, COP of system will increase.

There is a need for hot dish and cold water simultaneously during office hours. To fulfill this requirement it would be better to achieve this is a single setup by utilizing the waste heat. A combined setup purposing a refrigerator and a microwave oven serves the need. As microwave oven and refrigerator separately consumes more electricity and left impact on surrounding. We need to find what temperature can be generating in the condenser and evaporator so that which foods can be warmed or cooled in the system. This study proves to utilize a combined system rather than a single system, where cooling and heating could be produced continuously in places far away from conventional grid. Most rural and urban area may benefit from this system in years to come.

2. Parts of the Refrigeration Cycle

The systematic diagram of the refrigerator and its various parts is as shown below:-

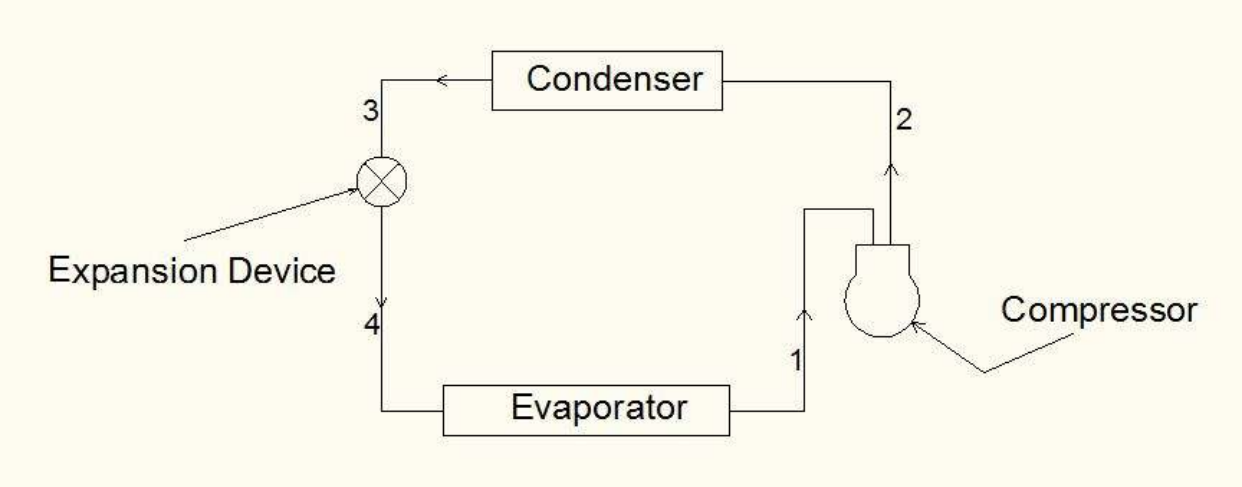

Figure (1): Flow diagram of refrigeration cycle.

2.1 Evaporator: Liquid Refrigerant absorbs heat from the cold chamber and gets evaporated. When a refrigerant is permitted to pass through expansion device, its pressure decreases and evaporation of the refrigerant will certainly happen. The evaporator offers a heat transfer surface area through which heat may move from refrigerant space in to the vaporizing refrigerant.

2.2 Compressor: To boost the pressure of the refrigerant streaming from the evaporator i.e. pulling in low-pressure, low temp saturated vapor and supplying highly pressured and high temperatures towards the condenser, compressor plays this role. Due to compression put in, vapor leaves the compressor at a varied pressure as well as the excessive function used leads to superheating of the vapor. The objective of the compressor is normally to recover the vapor from the evaporator, and to increase the heat range and pressure to a stage so that it could become condensed with the obtainable condensing part.

2.3 Condenser: High pressure and high-temperature vapor which goes to the condenser has heat taken out of it and consequently it is condensed back again into a liquid state. The heat transmission channel can become air or water, the necessity is that, the temp is usually lesser when compared to whatever compares to the condensing pressure. The process of condenser is same as evaporator except opposite work.

2.4 Expansion Device: Expansion device is the refrigerant flow control device. To lower pressure to equal level to that of the evaporator pressure, a device has to be placed to undertake this procedure, referred to as throttling device or an expansion device.

3. Literature Review

Many authors have presented their studies on refrigeration systems meant for heat recovery, which have been analyzed in greater detail. Slama et al. [2] have proposed about the combination of the refrigerator to a cumulus to heat up water that leads the heat yield towards standard of the condenser of the refrigeration system. The standard water heating was performed consequently without the energy consumption. The amount of heat carried by the water-cooled coil condenser is enough to improve the temperature of the latter with 60 ˚C by the end of 5 hrs. This process could fulfil entirely or partly certain requirements out of hot water of the family almost all day over and the week. The amount of heat recovered by water increases by four multiples the power usage by compressor. Kaushik et al. [3] have incorporated with the waste heat recovery from the commercial system of refrigeration by featuring Canopus heat exchanger. That shows there is a significant amount of low-grade energy obtainable in vast-capacity systems. To recuperate this sub- standard heat, a Canopus heat exchanger is installed in between condenser and compressor elements. The device actual usability is studied with several working ranges and the influence on heat retrieval aspects and General COP of the machine. The parametric outcomes obtained for different environment-friendly functioning liquids have been provided. He found that, usually, overall COP of the operational system is normally increased without affecting the actual performance of the device. The overall potential of low-grade heat availability is elevated with increasing cooling performance.

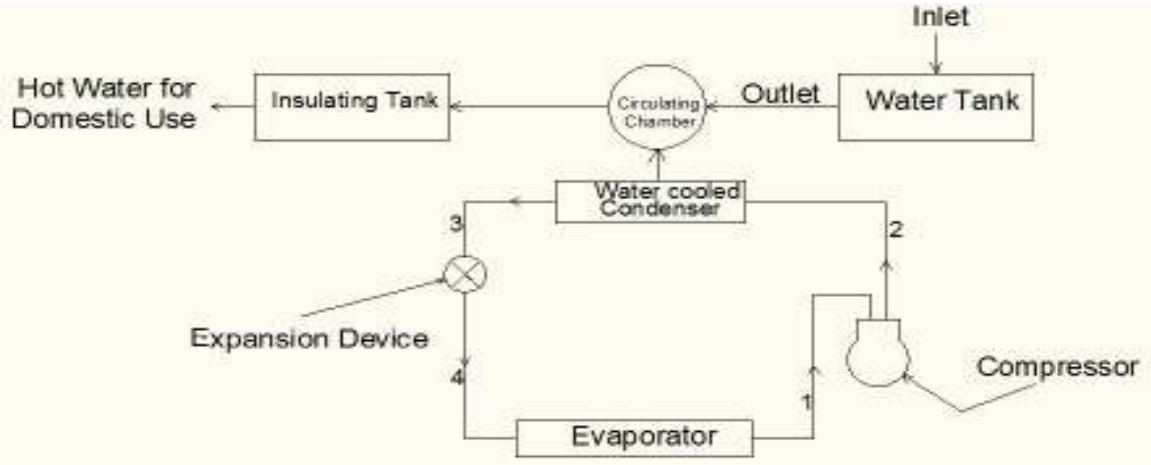

Figure (2): Waste heat utilized as water heating.

Varghese et al. [7] have mentioned the practical feasibility of the waste heat recovery unit to extract heat from the condenser exit of the refrigerator and use it for heating. The proposed work, attempted to recover the waste heat out of a 210 L refrigerator, intended for household requirements. The upper most chamber of the refrigerator was made as a hot chamber, by extending of the condenser coils, and the connection of the top section, towards top surface of the lower chamber of the refrigerator. Cold chamber and the hot chamber had temperature difference inside hence, was analyzed considering the different parameters considering the aspects of time, capacity of chamber and load.

From the results, it had been founded that the proposed technique of heat recovery could be engineered and developed for each and every household refrigerator with the nominal cost. Thus the reuse of waste heat illustrated method for optimum energy conservation. The performance could be improved by providing better insulation which in turn reduces the heat loss and increases the overall efficiency of the system.

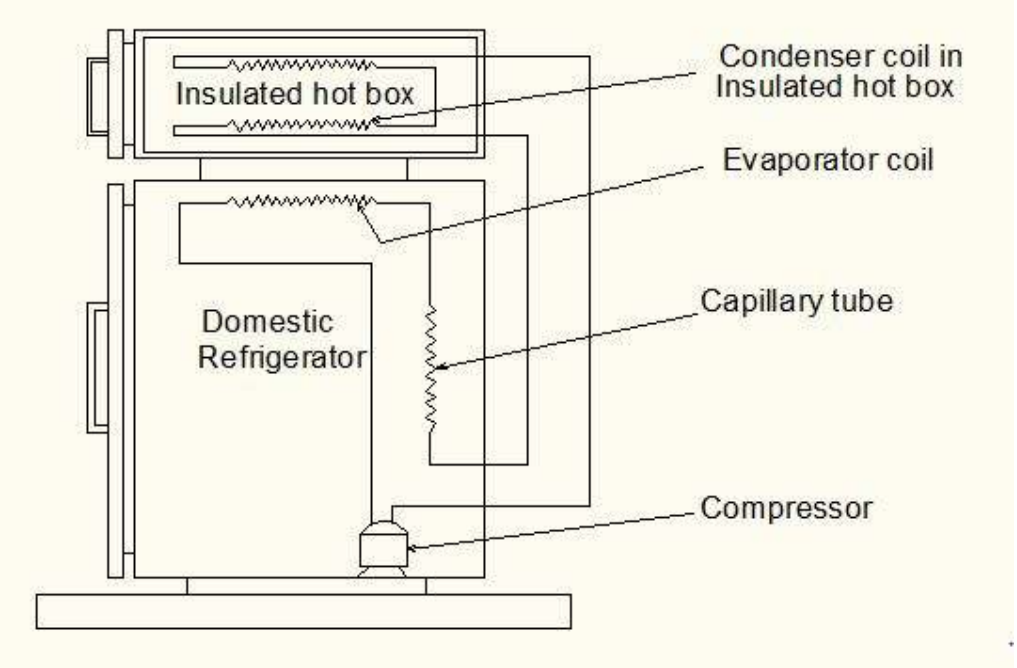

Figure (3): Schematic of waste heat utilization.

Yashwanth M. [8] has illustrated waste heat retrieval in R & AC system. With the help of one source from compressor we acquire 3 effective results i.e. warm water, cold water as well as conditioning of air. Refrigerant used for this component is usually R-290 combined with R-134a which is usually comparative to R-22. Evaporative cooler gives good cooling medium by merging normal procedure water evaporation with a basic, dependable air shifting system. Evaporative cooling is desirable for the most cost-effective and powerful method of refrigeration and air conditioning, as it releases especially in the locations where intense weather circumstances are warm and dried out. The energy conserving by doing so is usually preserved even more than 30 watts. Ti is generally known as a little size dessert cooler. Elumalai et al. [10] have studied about heat removal from the condenser coil in the Vapour Compression Refrigeration system (VCRS) by using oven heater and heating unit that could be installed between condenser and compressor parts. This existence of an heater enables us to retrieve the superheated from the discarded vapour and utilized it for raising the temperature of air inside the hot oven and raise the temperature of the fluid in the oven. With the chillers effectiveness with fluctuating operating time has been studied and results of operating temperature inside the oven and heating unit for changing working time of a refrigeration device have been analyzed and possible recovery of heat had been obtained. Maurya & Awasthi [11] have studied theoretical approach towards usage of heat waster by vapour compression refrigeration system (VCRS). The discarded energy could possibly be reutilized to perform any other low-grade energy needed refrigeration system for as simple ejector refrigeration device. Based on a few analytical samples they illustrated a combined cycle here. This is an appropriate method of usage of such a waste heat thus enhances the COP of the vapor compression refrigeration system (VCRS). Walawade et al. [12] have studied 'Waste heat recuperation framework for residential refrigerator'. For economic price range, this framework is much valuable for residential reason. An endeavor has been finalized from condenser of refrigerator to retrieve the heat. That heat could be used for number of household and industry utilities. It is an important option way to deal with enhances general effectiveness and reutilized the waste heat. The review has demonstrated that such a framework is in fact technically and economically viable.

Sreejith K. et al. [13] have studied in detail with experimental analysis of the effects of water-cooled condenser in a house-hold refrigerator. Research was carried out with R-134a as the refrigerant and Polyester oil is the lubricant. The functionality from the domestic refrigerator with air-cooled and water-cooled condenser was examined for more load conditions. This solution reveals that the refrigerator general functionality got elevated when water-cooled condenser was employed rather than air-cooled condenser for all load situations. Water-cooled condenser substantially decreased the energy usage in assessment with the air-cooled condenser meant for different load situations. That shows also an improvement in coefficient of performance (COP), when water-cooled condenser was applied rather than air-cooled condenser. Due to water- cooled heat exchanger was used and the system was revised using retrofitting it, rather than the regular air-cooled condenser by producing a bypass range and therefore the gadget can be employed as waste heat retrieval. The warm drinking water acquired can be used for household uses like cleaning, dish washing, showering and so on. Experimental result signifies that on the subject of 200 L of warm water at a temperature around 58 Celsius more than a day could possibly be generated and then the system proposed the cost-effective importance from the energy conservation perspective. Shinde et al. [14] have obtained the energy savings concerning better usage of waste heat from a household refrigerator. Household refrigerators potentially perform constantly to fix appropriate storage condition. The uniform operation of the equipment accounts considerably more electricity consumption. Further, a substantial amount of waste heat is discharged by the condensers coil of refrigerator. Heat discarded by condenser coil is of low grade energy, so this means temperature is low. Therefore, main applications of waste heat from the residential refrigerators are generally restricted to air heating and water heating system. In order to increase efficiently utilizing the waste heat, temperature of the wasted heat can be raised, to a limited degree, by increasing the condensing pressure of the refrigeration device. Even so, analyses have demonstrated the fact that increasing the pressure of condenser to attain high quality of waste heat leads to even more than it saves.

Ambarita et al. [15] have proposed on the general performance of clothes drying compartment with the use of waste heat out of a split-type residential air-conditioner (RAC) have been performed. A cloth drying chamber having a volume of 1m3 had been built and fabricated. Waste heat discarded from the condenser of the air conditioner with power of 800W was used as a heat source. Momin et al. [16] have recovered waste heat coming from condenser unit of the home refrigerator to enhance the overall performance of the system unit. Retrieval of heat from the household refrigerator is by thermos siphon. From the experiment, it had been found that after heat retrieving process from the condenser of the domestic refrigerator its overall COP got increased when compared to convention refrigerator. Stalin et al. [17] have discussed on the hypothetical evaluation of fabrication of domestic hot water and decline of LPG gas by employing air conditioner waste heat. An effort had been taken to recover waste heat discarded by 1 TR air conditioning units. With this water-cooled condenser is applied as well as water is enhanced by pumping till required temperature is attained. Then hot water was collected in well insulated container for domestic use. The end result of the paper illustrated that the temperature of hot water, time required for obtaining that temperature for the specified volume of water and the lowering of LPG gas by utilizing hot water is additionally discussed. Important factors like supply and demand, condenser coil design are considered and hypothetically determined. At last this may be the replacement for hot water heater and so it fulfils most of the applications of hot water. Likewise, it could possibly reduce the requirement of LPG gas. Soni [18] have developed ways to use waste energy releasing from condenser of the domestic refrigerator. Such kind of energy will be employed as a number of household and commercial reasons. At minimal setup construction and service cost such method is considerably very helpful for residential motive. It could be beneficial optional solution to increase functionality and reuse of wasted product which is in heat form. The study has revealed that such process is practically possible and financially acceptable. This unit released less energy to the ambient air therefore it is safer for environmental attributes. Prasad [19] have mentioned heat transfer by convection in AC by changing the refrigerants are in accordance with CFD and thermal simulation. The solution is out on an air-cooled tube condenser of the VCRS (vapor compression refrigeration system). The components are taken into consideration intended for tubes are copper mineral and Aluminum alloys 6061 and 7075. The checking is out on an air-cooled

tube around the condenser of the VCR system. The refrigerants variable can be R22, R134 and R407C. CFD simulation is performed to ascertain temperature distribution and heat transfer rates by varying the refrigerants. Heat transfer simulation is carried out on the condenser to find the desirable materials. 3-dimentional modelling is performed out in CREO and evaluation is performed in ANSYS.

Sreejith K. et al. **[20]** have designed, constructed and experimentally analyzed a waste heat recovery model for residential refrigerator. They'd analyzed the system at several load conditions (No load, 40W load and 100Wload). They even evaluated the economic aspect by comparing the waste heat recovery unit along with the standard geyser. From gathered testing outcomes, they determined that waste heat recovery system works very well with the domestic refrigerator. The hot water of moderate temperature can be achieved from it. This kind of changes made domestic refrigerator to get work as simultaneously refrigerator and water heater. With considerable amount of hot water during an appreciable temperature could be achieved from the waste heat recovery unit. Agarwal, et al. **[21]** have given economical approach for increasing the C.O.P and utility of the residential refrigerator working with R134a as refrigerant. A compartment was installed on the upper most part of a residential refrigerator with coils of the condenser of refrigerator providing as heating coils inside compartment. Known amount of water was heated by condenser coils (as a result of convection currents) thus increasing the overall COP of the refrigerator. Additionally, the utility was improved as it can certainly fulfil the other objective of geysers, cooking (oven) and so on. Besides, refrigerator can be utilized as standard refrigerator keeping the compartment door open in the instance of absence of heat sink. It was determined that it is possible to increase the COP up to 11 % simply by utilizing a compartment on the top of the refrigerator system. Additional increase in COP is achievable; even so improvements will involve excessive costs. Vedil et al. **[22]** have illustrated hypothetical method to retrieve the waste heat liberated out of vapour compression cycle that is used to operate vapour absorption cycle. This required heat has been supplied by solar powered energy. The work examined the effectiveness of the joined cooling cycle. Krishna, et al. **[23]** have analyzed condenser of the air conditioning unit which is attached with a co-axial copper pipe by means of a spiral coil and is linked to water tank via the pipes to heat up the water to be employed for domestic purposes. The outcomes demonstrated for AC (air conditioner) of 1.5TR are; water temperature in the heating tank could be improved via preliminary temperature of the water 28 ˚C to 57 ˚C within 15 to 16 minutes, the temperature from the evaporator could be decreased below within short while. By using this kind of heat recovery units, compressor performance could be improved and also, hot water intended for residential purposes could be constantly achieved. The outcome is quicker cooling and long-term compressor life as well as the AC system was determined to be higher COP when compared to conventional Air Conditioner. This system is quite simple and cost effective and capable to save the water heating cost and also, safe in environmental concerns.

4. Conclusions: This review paper shows that there are many ways to recover the 40 % of the heat from the condenser of a domestic refrigerator i.e. by water cooled condenser or by air cooled condenser. We have seen that after reading literature review, the COP of the refrigerator will also increase by heat recovery system and efficiency of the system also improves. It will also reduce the consumption of electricity by providing same power of electricity to compressor to run evaporator and condenser. We have assumed that the condenser of the refrigerator can be work as an oven by storing the escaping heat from the condenser to the environment and reduce the rise in temperature of environment to stop the effect of global warming. This can be done by forming an insulated cabinet to store the condenser coil. The heat retrieval cabinet can thus be utilized in various refrigeration utilities as well as in air conditioning. Finally, this could be surrogate for water and air heater and fulfils all of the applications of hot water and dry air, which furthermore, could tackle the requirement of LPG gas and thus, safer in environmental aspects.

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