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Coefficient of Performance increment in Domestic Refrigerator: A Literature Review

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***Abstract*—the energy performance of Refrigeration systemsare usually evaluated based on the laws of thermodynamics. However, compared to energy analysis, exergy analysis shows better and accurate location of inefficiencies. Exergy analysis locates inefficient areas having greater potential for improvement. Exergy analysis helps to understand and quantify system irreversibility's, to measure to reduce these irreversibility's to minimum level, and to optimize Refrigeration systems. This paper describes the construction and testing of an integrated heat recovery system which has been designed both to enhance the performance of a domestic refrigerator and simultaneously to heat recovery from water heat exchanger. This condenser operates in parallel with the air-cooled condenser tubing of the refrigerator so that either one or the other is active when the refrigerator is running. The refrigerator was housed in a controlled-environment chamber, and it was instrumented so that its performance could be monitored carefully. The system has been fabricated according to literature study which is different from the one which is not reported issues associated with commercial implementation of the concept; a review paper has been prepared.**

Keywords—COP; refrigeration system; water cooled heat exchanger;heat recovery system

I. INTRODUCTION

It is very much essential to put more efforts for improving the efficiency of thermal systems because of increasing energy prices and increasing concern of global warming. One of the methods of increasing efficiency is to recover and utilize waste heat from thermal systems for various applications like water heating. Hot water is required for various applications like bathing, processing, cooking, dish washing, sterilization, and utensils cleaning in dairy. In such applications, water is heated by electrical heating or burning the fossil fuels which is costly and also increases global warming.

Use of waste heat recovery is an important technique of reducing total energy costs in energy system design. Attachments need to be developed to recover waste heat energy and coefficient of performance increment in refrigeration systems by sub cooling technique in domestic refrigerator. If the heat recovery system is designed optimally and implemented in residential and small-scale commercial systems, the cumulative benefits would be significant. At many places, heating and cooling systems are simultaneously used. Air conditioning and refrigeration systems are designed to remove the heat from interior spaces and reject it to the ambient air. Heat rejection may occur directly to the ambient, as in the case of most conventional air- cooled condenser, or to water, circulating from a cooling tower. The circulating water eventually rejects the heat to the ambient air, in the cooling tower. While this heat is of a "low grade variety," it still represents wasted energy. From an energy conservation standpoint, it would be desirable to reclaim this heat in a usable form. The best and most obvious form of heat recovery is for heating water. This waste energy can be recovered and utilized for various applications, which not only saves the energy but also enhances the performance of system. Heat recovery system will not change the basic refrigeration cycle. It will simply change the type of combination of condensers used to remove the heat from the refrigerant.

II. LITERATURE REVIEW

Use of waste heat recovery from thermal system is not a new technique altogether. The focus is placed on a need to develop effective, less costly and maintenance-free auxiliary integrated with main system to achieve waste heat recovery along with COP increment by varying expansion valves. If this idea is implemented at system design level, then there would be considerable saving of energy. Following researchers contributed to the area of COP increment & waste heat recovery significantly.

Clark et al. [1] carried out experimentation on 18 ft3domestic refrigerator. They used water cooled condenser and regular air cooled condenser in parallel. Following are the findings of this research: (i) rise in temperature of cooling water is 350C in 100 hours of continuing operation, (ii) 18% - 20% energy savings for hot water, and (iii) no deterioration of the refrigerant performance.

Yilmaz [2] carried out experimentation on air condition unit. He used concentric tube type heat exchanger for heat recovery. He found that, when entering water temperature is less than ambient air temperature, efficiency of air conditioning unit is improved.

Stinson et al. [3] conducted research in dairy refrigeration by recovering the heat from condenser. They found out that by using the water cooled condenser COP of the system is enhanced by 10% to 18%. They also found that increase in condenser pressure reduces COP, and inclusion of heat recovery heat exchanger reduces head loss.

Alex et al. [4] prepared an analytical model of a residential desuperheater. They found that the results of mathematical model and results of experimental setup vary within 12%.

Rane et al. [5] developed sensible heat recovery unit and carried out experiments. Waste heat recovered is utilized for water heating. Their findings are: (i) chiller cooling capacity enhanced by 30% and COP by 20%, (ii) fuel saving reported 81liters HSD/day, annual savings of Rs. 10 Lakh/year, (iii) Reduction in CO2 Emissions 450 ton in 4 years, and (iv) simple payback of 3 to 6 months.

J. Khedari et al. [6] investigates the performance of a new hybrid domestic hot water system that combines solar energy with waste heat from a thermoelectric (TE) air-conditioner. To this end, 30 TE modules model no. TEC1-12704 (module specifications: 40 × 40 mm, maximum operating voltage and current: 13.5 VDC and 4.4 Amp) were used. The collector/storage tank capacity was 120 liters. The volume of the testing room for cooling was 2.5 m3. Investigations were undertaken by varying the voltage to the thermoelectric module (50, 100, 150 VDC), water mass flow rate and air velocity passing through the TE heat exchangers: 10, 15 l/min and 2.5, 5 m/s, respectively. It was found that this system can heat up the 120 litres to 50°C within 2 hours. The cooling capacity was 176 W. After that, the cooling capacity decreased as a result of the increase of water temperature returned from the tank and circulated through TE water/solid heat exchanger. Finally, under design consideration used in this study, the optimum conditions for operating the hot water production and cooling as well are: 100 VDC, water flow rate of 15 l/min and air velocity at 2.5 m/s. The corresponding highest coefficient of performance of the hybrid system is about 3.12.

Jie Ji et al.[7] The technology of using a heat pump for space conditioning and domestic hot water heating in residences has been developed for half a century. The earlier air-to-water heat pumps and water-heating heat pumps suffered from drawbacks like high costs, unreliable operation, and inflexible applications. They were not well positioned in the market to attract customers. This paper introduces a novel air-conditioning product that can achieve the multi-functions with improved energy performance. The basic design principles and the laboratory test results are presented. The results showed that by incorporating a water heater in the outdoor unit of a split-type air-conditioner so that space cooling and water heating can take place simultaneously, the energy performance can be raised considerably.

S. C. Walawade [8] energy saving is one of the key matters from view point of fuel consumption and for the protection of global environment. So it is necessary that a significant and concrete effort should be made for conserving energy through waste heat recovery too. The main objective of this paper is to study “Waste Heat recovery system for domestic refrigerator”. An attempt has been made to utilize waste heat from condenser of refrigerator. This heat can be used for number of domestic and industrial purposes. In minimum constructional, maintenance and running cost, this system is much useful for domestic purpose. It is valuable alternative approach to improve overall efficiency and reuse the waste heat. The study has shown that such a system is technically feasible and economically viable.

Y. A Patil & H .M. Dange [9] refrigerator has become an essential commodity rather than luxury item. The heat absorbed in refrigerated space and the compressor work added to refrigerant is too rejected to ambient through a condenser. Our aim is to recover waste heat from condenser unit of a household refrigerator to improve the performance of the system. The heat recovery from the household refrigerator is by thermo siphon. From the experimentation it was found that after recovering heat from the condenser of the conventional refrigerator its performance get improved than conventional refrigerator. The maximum temperature achieved in water tank with 100 liter of water is 45ºC at the full load condition. If the water tank contains 50 liter water then it gets heated to 45 ºC in just 5 to 6 hrs. After that performance of the system gets decreased. So it needs regular use of that hot water.

Thakre S. H. [10] Waste heat recovery is the process of capturing waste heat (thermal) energy for beneficial purposes. Energy savings and efficiency improvements of energy systems are important tasks on the path towards a more sustainable future. Conventional power stations convert only about 33% of their input heat to electricity. The remaining 67% emerges from the turbines as low-grade waste heat with no significant local uses so it is usually rejected to the environment. The present work is based on these low conversion efficiencies, strongly suggesting to find productive uses for this waste heat.

It is found from the literature review that most of the research carried out is for recovery and utilization of partial superheat from condenser, which is further used for various applications. Studies aimed at recovery of total heat of condensation and COP increment by using different expansion valves are not reported in the available literature. In this context, it is essential to carry out the research for recovery of superheat and latent heat of condensation

III. CYCLE ANALYSIS

Fig. 1 illustrates a schematic of a water-cooled tube-in-tube condenser with and without subcooling and Fig. 2 outlines the respective cycles on a T-h diagram. A prime (‘) denotes the cycle with subcooling. Due to the presence of subcooled liquid (Fig 1b), the two-phase heat transfer area would be reduced relative to a condition without subcooling (Fig 1a). As a result, the saturation temperature would rise in the condenser ($\Delta T_{c,sat}$, Fig. 2) which would subsequently increase the specific compression work (Δw, Fig. 2). On the other hand, the refrigerant temperature at the condenser outlet would decrease (ΔTc, out, Fig. 2), increasing subsequently the refrigerant enthalpy difference through the evaporator (Δq, Fig. 2). This logic can be expressed by Eq. (1) and suggests that COP may undergo a maximum, resulting from a trade-off between increasing specific refrigerating effect (by Δq) and compression work (by Δw). As illustrated in Fig. 2, strictly speaking, the subcooling ($\Delta T_{c,sub}$) can be a result of both a decrease in refrigerant condenser exit and an increase in condensing temperature.

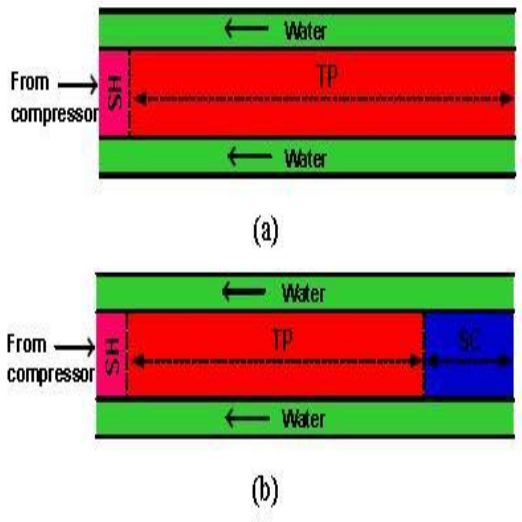

Fig.1. Schematic of water- cooled with (a) and without (b) subcooling [11]

The relative increase in refrigerating effect ($\Delta q/q$) can be approximated by Eq. (3) which shows that the relative change in refrigerating effect due to the variation of the refrigerant outlet temperature to the condenser depends on the ratio of liquid specific heat to latent heat of vaporization and on the temperature lift, $(Tc - Te)sat$. It suggests that reducing the temperature of the refrigerant at the condenser exit would be more welcome for refrigerants with large liquid specific heat and smaller latent heat of vaporization and for operating conditions with high temperature lifts. A similar approach is taken for the relative increase in specific isentropic compression work ($\Delta w/w$), given by Eq. (4).

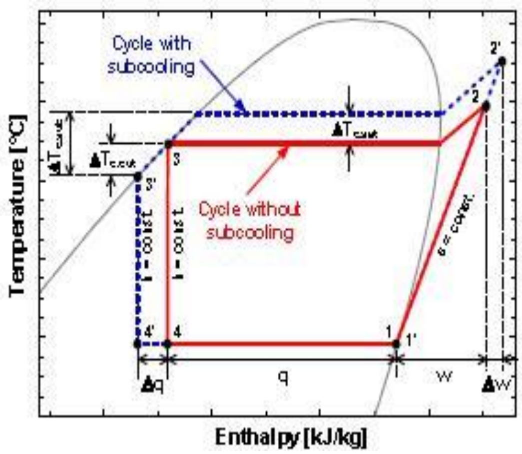

Fig.2. Schematic of cycles with and without sub cooling in a T-h diagram[11]

$$COP' = COP\left(1 + \frac{\Delta q}{q} - \frac{\Delta w}{w}\right) \quad (1)$$

$$COP = \frac{q}{w} \quad (2)$$

$$\frac{\Delta q}{q} = \frac{\Delta T_{c,out}}{\frac{h_{fg,e}}{c_{pl}} + (T_c - T_e)_{sat}} \quad (3)$$

$$\frac{\Delta w}{w} = \left(\frac{h_{2'} - h_1}{h_2 - h_1}\right) \quad (4)$$

IV. PROBLEM STATEMENT

In refrigeration and air conditioning systems, heat removed from the controlled space and heat added in the compressor during compression is rejected in the condenser to the ambient; Also COP increases by involvement of another condenser or heat exchanger for subcooling process (before throttling). To recover this waste heat and to increase COP, an experimental setup is developed by fitting water cooled heat exchange to an existing refrigeration application. Waste heat recovered will be used for water heating, which will be stored in an insulated tank, and can be used for various applications.

V. METHODOLOGY

In the proposed work, heat lost in heat exchanger will be recovered by using water cooled heat exchanger unit, and the recovered heat will be utilized for water heating. Effect of heat recovery on total system will be analysed. For this investigation, an experimental setup is developed. As per the energy balance equation, total heat added in the system is equal to total heat rejected in the water cooled heat exchanger (waste energy). In the experimental setup for removal of the waste heat, heat exchanger is used, which is fitted between compressor and condenser in parallel. Valves are used to bypass the heat recovery unit so that the system will work without the heat recovery unit.

VI. EXPERIMENTAL SET-UP

Figure-3 shows the experimental setup. It shows the spiral tube heat exchanger unit installed in parallel to air cooled condenser with conventional refrigeration or air-conditioning system. Spiral tube type heat exchanger is designed and installed in the cycle for heat recovery as shown in the figure. Figure-4 shows the theoretical amount of waste heat available for recovery on p-h diagram. Experiments are carried out on the setup as per the methodology, and results are recorded and analyzed.

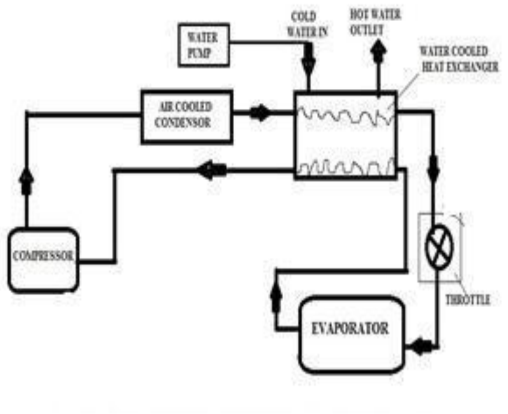

Fig.3. Experimental set up

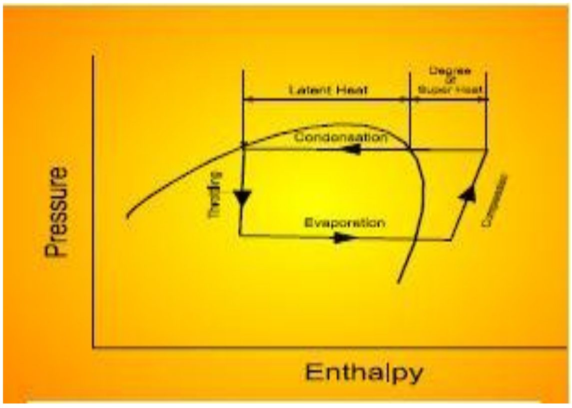

Fig.4. Waste heat available for recovery

VII. RESULT

Experiments are carried out with heat exchanger and bypassing the heat exchanger. Mass flow rate of water circulation is changed and its effect on system performance is studied. It is found out that by using water cooled heat exchanger in the cycle (Table. 1.1), discharge pressure is reduced and work required to drive the compressor is reduced. For the analysis of cycle Table-1 show outcomes of system with heat recovery unit respectively. Table-1 shows the refrigerating effect QE, condenser heat rejection QC, power consumed in kW, actual COP, and theoretical COP* water cooled heat exchanger.

In this section, the effect of the condenser subcooling on the performance of the domestic refrigerator system operating with R134a is experimentally investigated. Since the R134a as a drop in substance in domestic refrigerator systems, refrigerants were conveniently tested in the system and operating conditions. During the experiments, the air temperature and face velocity at the evaporator inlet were maintained at 30°C and 2.6 m/s, respectively. At the condenser inlet, the air face velocity was kept at 1.5 m/s and the air temperature, at 35°C. In order to vary the condenser subcooling, refrigerant mass was added in increments after the liquid receiver was completely filled with liquid so that subcooled liquid would accumulate towards the condenser exit. For each value of subcooling, data was taken during 15 minutes in steady-state. The evaporator exit superheat was maintained at 10±1°C by varying the opening of the electronic expansion valve accordingly.

In order for COP to be the only measure of improvement as condenser subcooling was varied, the cooling capacity obtained from the air side was maintained at an average of 4.1 kW, with deviations of ±0.3% show the results for several system performance variables as a function of the condenser subcooling for R134a. As mass of refrigerant accumulates in the form of subcooled liquid at condenser exit, the two-phase region is reduced. This yields an increase in saturation temperature while the liquid refrigerant exiting the condenser is cooled below saturation temperature. The increase in subcooling is a result of both reduction of condenser exit temperature and increase of saturation temperature.

Table. 1.1 Result with water cooled heat exchanger

TIME	QE	Qc	QS	kW	COP	COP*
10.59	9.33	13.42	14.86	2.86	3.442	3.043
12.03	4.79	5.69	1.98	2.99	1.647	1.892
11.75	7.01	8.69	1.49	3.01	2.511	2.863
11.88	4.56	5.89	2.2	2.96	1.625	1.911
12.33	3.63	4.33	2.3	3.06	1.688	1.662
12.48	4.98	5.988	2.3	3.06	1.688	1.662

Since the capacity was kept constant for each subcooling and the enthalpy difference across the evaporator increases with subcooling. In the water cooled heat exchanger, the growth of the subcooled region also contributes to the decrease in pressure drop, as previously discussed. In the evaporator, an additional contribution to the pressure drop reduction is given by lower inlet qualities to the coil. The performance of the water cooled heat exchanger in terms of saturation temperature is dramatically worsened with the increase in subcooling because the subcooled region introduces an area with lower temperature difference and heat transfer coefficient.

Results with the R134a respond differently to variations in water cooled heat exchanger subcooling. The COP of the R134a system was improved by 9%. Additional differences in COP improvement in the refrigerants are related to specific isentropic compression work, which increase by 1.5% for R134a, between zero and COP maximizing subcooling. Since the sensitivity of isentropic compression work to increments in condensing temperature is very similar between the refrigerant and showed similar increases in saturation temperature, this difference is probably associated with relative increase in compressor inlet pressure with subcooling, which is more substantial R134a.

VIII. CONCLUSION

A theoretical and experimental study about the effect of condenser subcooling on the performance of vapour compression systems has been presented probably for the first time in the open literature, to the best of the authors' knowledge. This study showed that, as condenser subcooling increases, the COP undergoes a maximum as a result of a trade-off between increasing refrigerating effect, due to the reduction of the condenser exit temperature, and increasing specific compression work, due to the increase in the condensing pressure. The increase in condensing pressure was associated with the reduction of the air-refrigerant temperature difference and the refrigerant-side heat transfer coefficient once the two-phase region in the condenser is shrunken to accommodate the subcooled liquid region. This paper also showed that the thermodynamic properties associated with the relative increase in refrigerating effect, i.e. liquid specific heat and latent heat of vaporization, are dominant to determine the maximum COP improvement with water cooled heat exchanger subcooling. Refrigerants with large latent heat of vaporization, In addition it has been concluded that the COP maximizing subcooling does not seem to be strong function of the thermodynamic properties for the same system under identical operating conditions. An experimental study based on R134a in a domestic refrigerator system by installing water cooled heat exchanger in the refrigerant cycle COP of the cycle is enhanced. For refrigerant, it was experimentally demonstrated that the COP in fact undergoes a maximum as heat exchanger subcooling is varied. It has also been confirmed that the COP of the system operating with R134a due difference in thermodynamic properties (latent heat of vaporization). This all happen due to heat recover by the cooled water. Experimentally measured COP improvements due to heat exchanger subcooling

IX. ACKNOWLDEMENT

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