WASTE HEAT RECOVERY FROM DOMESTIC REFRIGERATOR

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Abstract
Refrigeration is a process where the heat moves from low temperature reservoir to high temperature reservoir. Heat which is rejected by the condenser of a refrigerator is of low quality which means the temperature is low. So in this current project an attempt is made to utilize this waste heat from the condenser of a household refrigerator. Though it is impossible to recover the entire energy lost by the waste heat of the refrigerator, this project aims at minimizing the losses and recovery of maximum heat from the system by using water cooled condenser. To fulfill this, a heat exchanger was fabricated with tube-in-tube construction and was replaced with the original condenser. This helped in saving of energy as no electricity was used for heating water. The new system has given better performance than the existing one however with few more modifications a better efficiency from the developed system can be achieved. Also it has contributed to energy saving as well as cost saving as both the utilities (refrigeration and heating) are combined in one system. The maximum temperature of the water obtained after 2 hours of continuous operation was 44.3°C. This water obtained can be utilized for domestic applications like bathing, laundry, cleaning etc.
Keywords: Domestic refrigerator, Energy savings, Water cooled condenser, Waste heat recovery.

I. INTRODUCTION

It has been observed that due to the rising demand of energy supply of developing countries, the global economy of future is going to consume more energy. At the same time there is a huge risk on temperature change which will lead to a situation where the supply of energy will become difficult. So it is important to take necessary steps for the conservation of energy through waste heat recovery. Since the energy production is less as compared to the energy consumption it is extremely essential to minimize the usage of energy and try to conserve it in every possible way.

To calculate the feasibility of waste heat recovery it is essential to characterize the waste heat source and stream to which the heat will be transferred. The parameters of waste stream which needs to be determined are as follows:

- Quantity of heat
- Quality of heat
- Composition of the heat stream
- Operating conditions, minimum allowed temperature, availability of heat source and other logistics.

In the refrigeration cycle heat absorbed in the evaporator and the compressor work is released back in the condenser. Instead of wasting this heat quantity by dissipating it to the environment, appropriate measures can be implemented in order to put this heat flow to meaningful use for heating purposes because of its temperature level. Though it is impossible to recover the entire energy lost by the waste heat of the refrigerator, this project aims at minimizing the losses and recovery of maximum heat from the system by using water cooled condenser. High grade heat comes from 'de-superheating' the refrigerant between the compressor and the condenser. This heat can be between 60ºC and 90ºC. Low grade heat comes from the refrigerant being condensed. The above method can be implemented to recover waste heat and utilize it for domestic purpose by retrofitting the system with water cooled condenser.

The literature review for this work focuses on easy access to high quality research work which is relevant to the recovery of waste heat from refrigerators. Efforts are taken to summarize, evaluate and compare the results obtained for the specific work related to the project. The importance of this literature review is that it has provided up-to-date information about different methods for waste heat recovery and its significance. The research work has critically summarized the current knowledge in the area under investigation. It has also helped to identify the various methods adopted to recover the energy of waste heat from the condenser of domestic refrigerator. There is lot of relevance of the literature with the current work which has helped to establish the theoretical framework for the project and also focus on the methodology.

Monim have experimented to recover heat from the condenser unit of household refrigerator by thermo siphon method. The experiment was carried out on a LG refrigerator of 175 liter capacity. The refrigerant tube of 0.7cm was helically brazed in a tank which was filled with water. The maximum temperature of the water attained is 60°C. It was found that recovering heat from the condenser of the conventional refrigerator has increased its performance than the conventional refrigerator. [1]

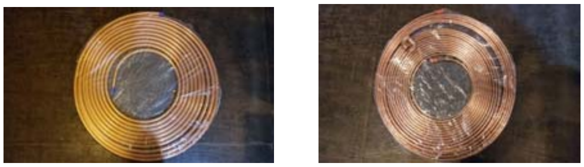
Patil and Dange worked on a domestic refrigerator of 190 liter which rejected heat to the ambient air through the condenser. This heat was recovered with the help of a water tank installed on top of the system containing the refrigerator condenser coils in it. The performance improved after the heat recovery process. Experiments showed that the maximum temperature attained for 100 liter water at full load condition was 45°C. But when the quantity of water is reduced to 50 liter it takes 5-6 hours to attain 45°C, later on the performance also decreases. This shows that the system requires regular supply of water. The system was lagging mobility and hence it could not be used for domestic purposes. [2]

Romdhane BEN SLAMA (2009) innovated coupling of refrigerator to a cumulus to heat water by yielding heat from the condenser of the refrigerator system. The original condenser of the system is replaced by spiral heat exchanger immersed in water kept in a tank. With this arrangement the quantity of energy transferred by the water-cooled condenser is sufficient enough to raise the temperature of heating water upto 60°C in approximately 5 hours. The recovery process enhances the performance of the refrigerator in terms of increased COP and power savings. [3]

Sreejith, Sushma and Vipin have done a comparative study between the air-cooled and water-cooled condenser at different load conditions. Results showed that when water-cooled condenser was used the performance of the system increased. Also when the air-cooled condenser was replaced by the water-cooled condenser the energy consumption went down at different loads. There was a reduction in the energy consumption by approximately 8% - 11%. Experimental results also proved that there was considerable enhancement in the COP of the refrigerator. The construction of the system was modified by retrofitting it, instead of air-cooled by making a bypass line. The quantity of water obtained at 58°C from this system was around 200 liter. [4]

II. EXPERIMENTAL SETUP

The important design parameter for a heat recovery device is selecting the construction type of the heat exchanger for the given application. For this project, a system is fabricated to construct a tube-in-tube type heat exchanger. Being a highly conductive metal, copper was selected as the tube material for the heat exchanger. The inner tube diameter was selected as ¼ inch (6.35mm) as per the existing system. Taking into consideration the flow of water the outer tube diameter was taken as 5/8 inch (15.87 mm). As per the space availability the length of the heat exchanger tube was taken as 10.6 m.



(a) Outer Tube-5/8”   (b) Inner Tube-1/4”

Fig. 1 Copper Tube

Several studies have indicated that the helical coiled tubes are more efficient than the straight tubes when they are used for heat transfer applications. Hence a helical coil heat exchanger was finalized and designed for implementing the project. [4]

The construction of the heat exchanger involved alignment of two coaxial tubes of different diameter. The annulus part of the tube was filled with sand to maintain smoothness on the inner surface and the ends were sealed by soldering them. Thereafter the tube was bent by rolling process and the desired construction of heat exchanger was obtained. During this process, care has been taken to preserve the circular cross section of the coil. Later on the sand was washed away with the help of compressed air. After the construction of the heat exchanger it was fitted to the refrigerator on which the experimentation was conducted. The heat exchanger acted as a condenser for the refrigerator one end of which was brazed to the discharge line of the compressor and the other end was brazed to the expansion valve.

Fig. 2 Brazing Process

Once all the components were fixed to the system, it was thoroughly checked for leaks. The leak test was done using soap solution. After fixing the leaks, the setup was prepared for experimentation.

To carry on the experiment a household second hand refrigerator of Kelvinator having capacity of 165 liters with compressor make LG model no. NR58LAJG was used. The specification of the compressor with visual inspection was 220V and 50Hz.

Fig. 3 Actual Experimental Setup

III. EXPERIMENTAL PROCEDURE

The experiment was conducted on the setup with the newly modified water cooled condenser. Previously the system would reject heat to the atmosphere but in the new condenser it is supposed to reject the heat to the water which will flow through the annulus over the refrigerant tube. Water of known quantity was circulated with the help of a pump having flow rate of 800 LPH from the outer tube of the condenser and the rise in temperature of water was noted after specific interval of time. Flexible PVC tubing was used for the circulation of water through pump. The experiment was performed under the ambient conditions. To avoid heat dissipation directly to the environment and to prevent heat loss from the tubing assembly, required insulation was done to conserve the heat and get the accurate heat transfer from the inner tube carrying refrigerant to the water flowing through the outer tube. The material used for insulation was Foam Sheets.

Fig. 4 Condenser Tube with Insulation

Total four trials were conducted on different days to check the accuracy of the system. The system was made to run for 2 hours continuously for taking the temperature reading. Temperature data was recorded during the trial after every 15 minutes.

IV. RESULTS AND DISCUSSION

The result which gives the temperature of water as well as the temperature at various points i.e. condenser inlet-outlet and evaporator inlet-outlet of the refrigerator with respect to time is represented graphically. The four trials were conducted with 5 liters of water and for duration of 2 hours. The heat recovered during each trial of the experiment was also calculated.

The specific heat of water to calculate the recovered heat was taken as 4.178 kJ/kgK .

Thus the values taken for the calculation of the amount of heat recovered in each trial is taken as,

Mass of water, m = 5 liters

Total duration of the experiment, Δt = 2 hours

Specific heat of water, Cp = 4.178 kJ/kgK

Change in temperature of water, ΔT = as per the reading obtained.

Taking the average values of the water temperature from the trial conducted, we have

Inlet Temperature of water = 31.4°C ≈ 31^0C

Outlet temperature of water = 42.1°C ≈ 42^0C

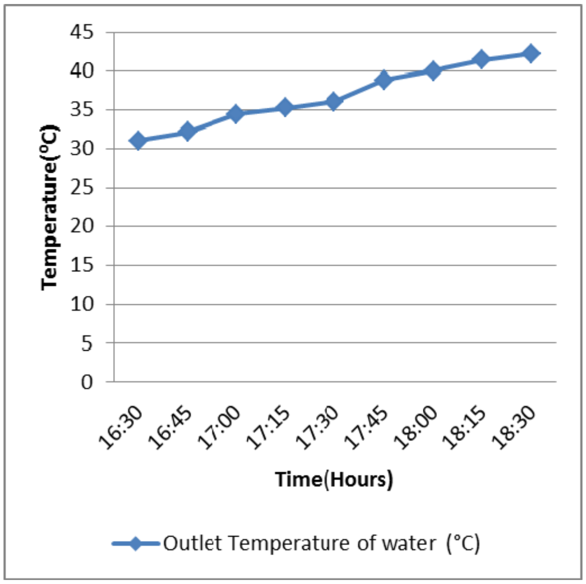


Fig. 5 Time Vs Temperature - Trial 1

Referring to the above graph the following values of water temperature were noted,

Initial temperature of water = 31^0C

Final temperature of water = 42.2^0C

Change in temperature of water, $\Delta T = 11.2^0$C

Taking these values the heat recovery obtained from the system is,

Q = (m*Cp*ΔT)/_t

Q = (5000*4.178*11.2)/(2*60*60)

Q =32.495 J/s

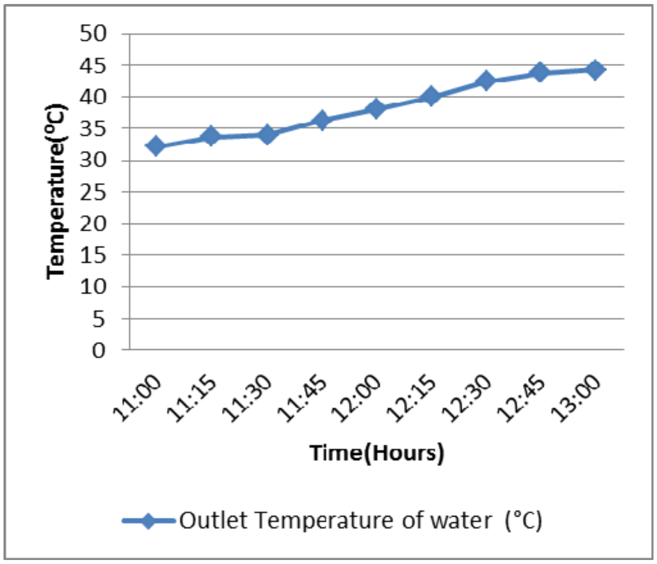


Fig. 6 Time Vs Temperature - Trial 2

Referring to the above graph the following values of water temperature were noted,

Initial temperature of water = 32.2^0C

Final temperature of water = 44.3^0C

Change in temperature of water, $\Delta T = 12.1^0$C

Taking these values the heat recovery obtained from the system is,

Q = (m*Cp*ΔT)/Δt

Q = (5000*4.178*12.1)/(2*60*60)

Q =35.106 J/s

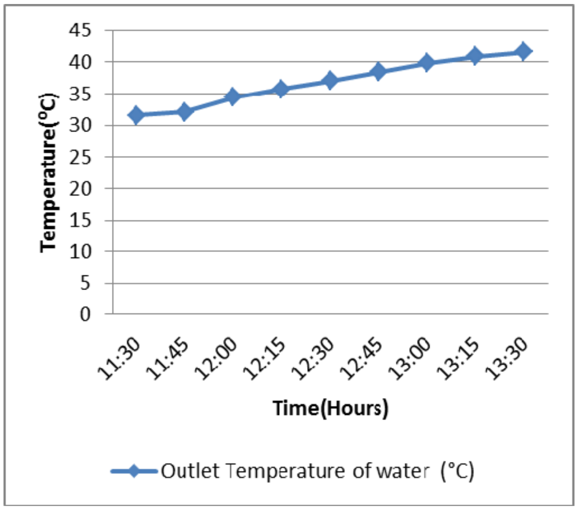


Fig. 7 Time Vs Temperature - Trial 3

Referring to the above graph the following values of water temperature were noted,
Initial temperature of water = 31.5^{0}C
Final temperature of water = 41.6^{0}C
Change in temperature of water, ΔT = 10.1^{0}C
Taking these values the heat recovery obtained from the system is,
Q = (m*Cp*ΔT)/Δt
Q = (5000*4.178*10.1)/(2*60*60)
Q =29.304 J/s

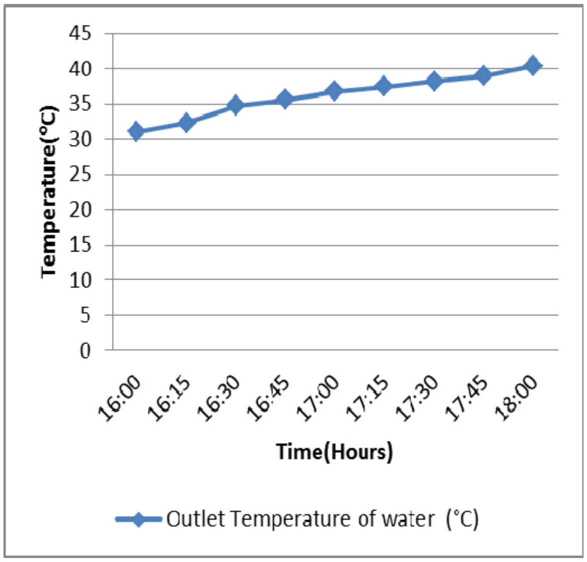


Fig. 8 Time Vs Temperature - Trial 4

Referring to the above graph the following values of water temperature were noted,
Initial temperature of water = 31^{0}C
Final temperature of water = 40.4^{0}C
Change in temperature of water, ΔT = 9.4^{0}C
Taking these values the heat recovery obtained from the system is,
Q = (m*Cp*ΔT)/Δt
Q = (5000*4.178*9.4)/(2*60*60)
Q =27.273 J/s

Calculation of actual COP of the refrigerator based on the data available:
Cooling capacity of the refrigerator (amount of heat extracted in refrigerator) = 96 kcal/hr
= 111.57 watt

Power required to run the compressor (work done on the refrigerator) = 1/8 HP
= (1/8) * 746
= 93.25 watt

The actual coefficient of performance,

$$COPactual = \frac{\text{Heat extracted in refrigerator}}{\text{Work done by the compressor}}$$

$$= \frac{111.57}{93.25}$$

=1.196

Calculation of heat recovered by the system:
Given data:-
Mass of the water circulating through the condenser, m = 5000gm = 5 kg
Specific heat of water, Cp = 4.184 kJ/kgK
Initial Temperature of water = 31°C
Final Temperature of water = 42°C
Total time taken for the reading = 120 min

$$Q = \frac{m*Cp*\Delta T}{\Delta t}$$

$$= \frac{5000*4.187*11}{120*60}$$

= 31.98 J/s

Heat recovered by the system=Heat absorbed by the water, Q = 31.98 J/s.

Enhancement in COP of the modified system:

COPimproved=

$$\frac{\text{Heat extracted in refrigerator}}{\text{Work done by the compressor} - \text{Heat recovered by the system}}$$

$$= \frac{111.57}{93.25 - 31.98}$$

= 1.8209

Enhancement in COP =

$$\frac{(COP)improved - (COP)actual}{(COP)improved}$$

$$= \frac{1.8209 - 1.196}{1.8209} * 100$$

= 0.343 * 100

= 34.3%

The COP of the modified system was found to be more than the previously existing system. It was observed that there is enhancement in the COP of the new system by 33.37%
The enhancement in COP of the modified system may be more than the calculated value because of the following reasons:

1. During the experiment water was circulated from an open bucket; due to this there is possibility of heat dissipation which is not evaluated.
2. Since the refrigerator used for the experiment was a second hand model, the actual COP may be different than the obtained value.

The payback period is the time which is required for an amount to be repaid which is invested in an asset in terms of the net cash flow which will be generated by the asset. In this project considering the amount invested for the modification of the system and the return cash flow in terms of energy savings, the payback period which is 4.6 years.

In this case since a single unit was manufactured for the experimental analysis the investment cost was more. When the system will go for mass production there will be 40-50% reduction in the investment cost which will definitely give a short payback period.

V. CONCLUSION

In this project an experimental setup to conduct trial for waste heat recovery was built up. The experiment was carried out on a second hand household refrigerator. As mentioned in this project the recovered heat can be used for domestic applications like cleaning utensils, bathing and washing.

The project provides the following conclusion.

1. This experimentation proves that such a system is practically feasible.
2. A small addition in cost helps to recover and reuse the waste heat thus contributing to energy savings.
3. The results show that enhancement in the performance is achieved by the modified system.
4. In the present situation of energy crisis the combination of both the utilities (refrigerator and water heater) can prove to be efficient which will save substantial energy.
5. Maximum temperature of 44.3^0C is obtained from the system consisting of 165L refrigerator which can be utilized for domestic applications.

In future with minor modifications in the ergonomics of the setup more efficient system can be developed. To achieve this, the construction of the heat exchanger can be modified to make it fit in a confined space. Also provision can be made for filtration of water so that the hot water obtained from the system can be utilized for drinking purpose also.

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