IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
ISSN: 2278-1684, PP: 28-32
www.iosrjournals.org

Design and Development of Waste Heat Recovery System for Domestic Refrigerator

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ABSTRACT: *Heat is energy, so 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.*
Keywords*-Waste heat recovery, 165 liter Domestic refrigerator, Air cooled condenser, Experimental analysis, COP of refrigerator.*

1. Introduction

Waste heat is generally the energy associated with the waste streams of air, gases and liquids that leaves the boundary of the system and enter into environment. Waste heat which is rejected from a process at a temperature enough high above the ambient temperature permits the recovery of energy for some useful purposes in an economic manner. The essential quality of heat is not the amount but its value. Waste heat recovery and utilization is the process of capturing and reusing waste heat for useful purposes. Not all waste heat is practically recoverable. The strategy of how to recover this heat depends on the temperature of the waste heat sources and on the economics involves behind the technology incorporated.

By experimentation with waste heat recovery system (WHRS) in refrigeration unit, Kaushik and Singh [1] have found that 40% of condenser heat can be recovered through the Canopus heat exchanger for typical set of operating conditions. P. Sathiamurthi and PSS. Shrinivasan [2, 3] discussed in studies on WHR from an air conditioning unit that the energy can be recovered and utilized without sacrificing comfort level. They have also shown that such a system is economically viable. Energy consumption by the system and environmental pollution can still further be reduced by designing and employing energy saving equipments. F.N.Yu, K.T.Chan [4] discussed the improved condenser design for air cooled chillers.

In this paper, the authors have investigated a WHRS and experimented to recover condensation heat from domestic refrigerator of 165 liter. The refrigerating unit rejects considerable amount of heat to the atmosphere through its condensing coil unit. So, by suitably retrofitting the WHRS in the unit, waste heat is recovered. This heat is used to keep snacks and food warm, to heat the water which can be further used in health care centers, schools and industrial processes, to wash the cans in dairy by hot condensate, to dry clothes, grains etc. thereby saving significant amount of energy.

2. System Description and Design

In the proposed system, the basic requirement is to utilize more and more exergy (waste heat). For that purpose some calculations are made regarding size and length of condenser and then WHRS is designed. But after different discussions and calculations for heat transfer rates we approached to the final design of insulated cabin with compact construction and with reasonable cost. So as to extract more and more heat, we have mounted two sections of air cooled condenser one at bottom and one at top side of the insulated cabin. This whole assembly is placed on the top of the refrigerator. The main advantage of this design is that we can get maximum heat with minimum losses.

3. Fabrication and Assembly Work

3.1 Major Equipments and Parts

Since the concept gives brief idea about utilizing waste heat at domestic level, hence we have decided to use a "Voltas" second hand working domestic refrigerator of capacity 165 liters. Parts of domestic refrigerator are as follows.

Compressor, Modified Air cooled Condenser, Capillary Tube, Plate type Evaporator & Insulated Cabin.

The insulated cabin is a peripheral component which is used for utilizing the waste heat from refrigerator. This insulated cabin is fabricated by using galvanized iron sheets.

Table 1: Equipments with Specifications

Sr. No	Equipment	Type/ Material	Specification/ Capacity	Manufacturer
1.	Refrigerator a. Compressor b. Condenser c. Evaporator	Domestic Type Hermetically sealed Copper, Air cooled Plate type	165 Liters $1/8^{th}$ HP No. of Tubes – 18, Surface Area -2798cm^2	Voltas Kirloskar Kirloskar Roll bond
2.	Refrigerant	R12	80gm	Inno tech
3.	Insulated Cabin a. Outer Box b. Inner box c. Door d. Insulation	Galvanized Iron G.I G.I G.I Thermocole	 52.5cm × 50cm ×42.5cm 42.cm ×45cm ×32.5cm 52.5cm ×5cm ×42.5cm Thickness:- 3.50cm	

3.2 Fabrication of Insulated Cabin

3.2.1 Material Used: Galvanized Iron Sheet

3.2.2 Process used - Sheet metal forming.

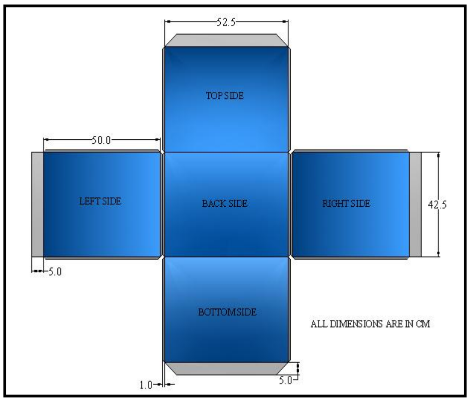


Fig.1 Outer box of cabin

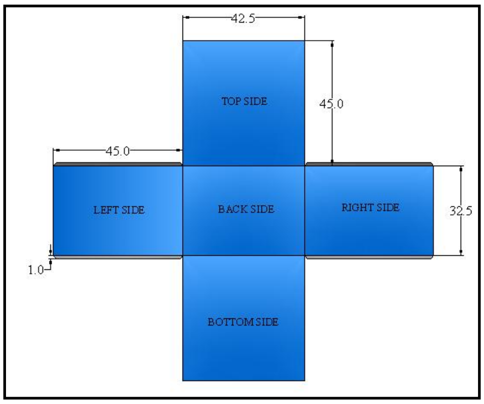


Fig. 2 Inner box of cabin

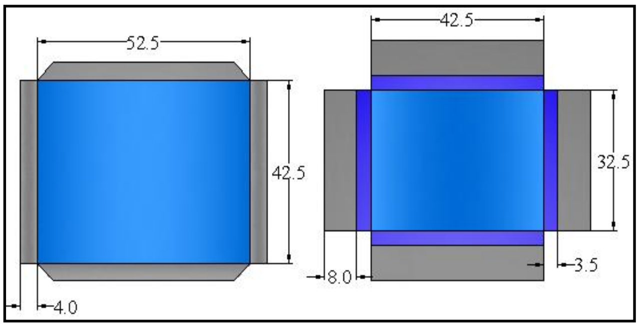


Fig.3 Door of Cabin

3.2.3 Fabrication of Cabin

The insulated cabin is made up of following parts.

- Inner box and outer box of insulated cabin are made up of Galvanized iron sheet.After defining dimensions, sheet metal working is performed. The cabin is painted by silver color.
- Insulation material-, here thermocole is used for insulation purpose and it is of 3.5cm thickness.
- After forming all parts of cabin it is assembled in well manner as shown in Fig.4.

Fig. 4 Assembly of Insulated Cabin

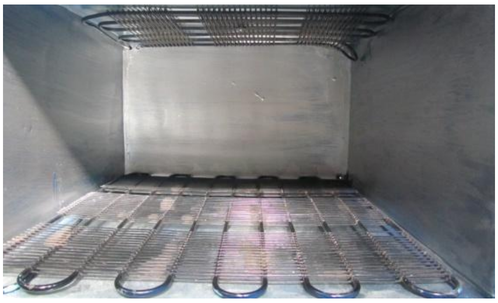


Fig. 5 Condenser mounting

3.2.4 Copper tube brazing and Condenser mounting

To utilise more and more heat, condenser is mounted inside the insulated cabin. Sol, condenser is divided in two sections such that it can fit conveniently inside the cabin as shown in Fig. 5. The copper tubes at outlet of compressor and inlet of condenser in insulated cabin are joined by brazing.

4. Result and Analysis

4.1 Actual COP of System Based On Theoretical Data

For Refrigerator of 165 liters capacity, given data from Kirloskar Ltd manual follows-

Refrigerator cooling capacity (amount of refrigeration produced or heat extracted in refrigerator) =76 kcal/hr

$$= \frac{76\times4.187\times1000}{3600}$$

= 88.392 W

Power required running the compressor (work done on refrigerant)

= 1/8 HP

= 1/8×746

= 93.25 W

The coefficient of performance (COP) is the ratio of heat extracted in refrigerator to the work done on refrigerant.

$$\text{COPactual}=\frac{\text{Heat extracted in refrigerator}}{\text{Work done by compressor}}----(1)$$

$$=\frac{88.392}{93.25}$$

$$= 0.948$$

The main aim is to increase the COP of system by utilizing energy. When the condenser heat is utilized, COP of system will boost up.

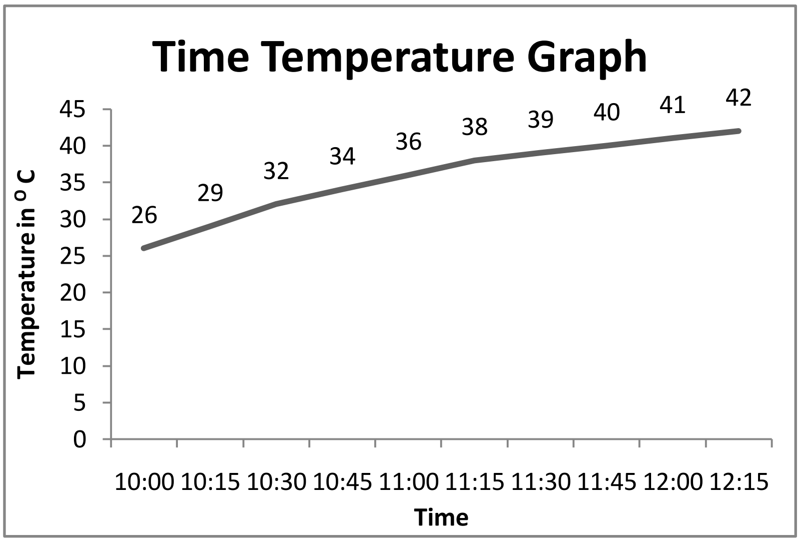
4.2 Experimentation

Experiments are conducted by taking readings as follows.

Copper pot filled with known quantity of water is put inside the cabin and temperatures are noted after specific interval of time. By following above procedure, observations are noted and time temperature graphs is plotted.

Observation Table

Time	Temperature Of Water In Pot (°C)
10:00	26
10:15	29
10:30	32
10:45	34
11:00	36
11:15	38
11:30	39
11:45	40
12:00	41
12:15	42



4.3 Calculations for Increased Rate of Waste Heat

Heat Recovery Achieved, Q = Heat Absorbed By Water

Given data-

Mass of water in the pot, m = 1200 gm =1.200 kg

Specific heat of water, Cp = 4.184 KJ/Kg K

Initial temperature of water = 26^0C

Final temperature of water = 42°C

Time required for reading Δt = 135 min

Heat Absorbed By Water,

$$Q = \frac{m \text{ x } C_p \text{ x } \Delta T}{\Delta t}$$

$$= \frac{1.200 \text{ x } 4.187 \text{ x } 16}{135 \text{ x } 60}$$

= 9.92 J/s

Heat recovery achieved Q = Heat Absorbedby Water

= 9.92 W

4.4 Improvement in COP

Condenser heat is utilized, which is the part of compressor work. The denominator in equation (1) will reduce in value. Hence COP of system will improve.

$$COP_{improved} = \frac{\text{Heat extracted in refrigeration}}{\text{Work done by compressor-Heat recovery achieved}}$$

$$= \frac{88.392}{93.25\text{-}9.92}$$

= 1.06

$$\text{Improvement in COP} = \frac{COP_{improved} \text{ - } COP_{actual}}{COP_{improved}} \times 100$$

$$= \frac{1.06 \text{ -}0.948}{0.948} \times 100$$

= 11.81 %

4.5 COP Improvement Limitations

COP improved may be more than the actual calculated because of following errors.

1. Heat outleak while opening or closing the door cannot be exactly evaluated.
2. Actual COP is different than the value taken beacause the refrigerator is old.
3. Air may leak in or out because of old gasket.

5. Conclusion

"Waste heat recovery system" is an excellent tool to conserve available energy. An attempt is made to recover the waste heat from 165 L refrigerator used for domestic purpose. As indicated in this paper, recovered heat can be utilized as food and snacks warmer, water heater, grain dryer. So one can save lot of time and energy also. The study provides the following conclusions:

1. Suitable heat recovery system can be designed and developed for every household refrigerator.
2. The experimentation has shown that such a system is practically feasible.
3. Technical analysis has shown that it is economically viable.
4. If this can be started from individual level then it can sum up and enormous effect can be obtained. Thus with small addition in cost if we recover and reuse the waste heat, then definitely we can progress towards energy conservation and simultaneously achieve our day today function.
5. In present situation where everybody in a home is moving out, this combination of refrigerator and food warmer is definitely a boom to efficient house wife.

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