International Journal of Control, Energy and Electrical Engineering (CEEE)
Vol.8 pp.36-41

Experimental investigation of waste heat recovery using Refrigerator System

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***Abstract*— This paper presents the experimental investigation of waste heat recovery using refrigerator system. The experimental study is used to recovery the waste heat from the condenser of domestic refrigerator for water heating. It is shown that the water temperature in the tank reached 50°C, and with a continuous use of the domestic refrigerator to maintain proper food storage condition, the temperature will be better. With the utilization of waste heat recovery for water heating then we get cooling at low energy cost, no harmful effect also this system will reduce the electricity consumption and rejected less heat to the environment so it is safer in environmental aspects. When we use the water cooled condenser in the refrigeration system we save more energy as well as more GHG emissions are reduced.**

***Keywords*— Waste heat recovery, Domestic Refrigerator, Energetic and Environmental Interest, Experimental analysis.**

I. INTRODUCTION

Throughout the world, a large amount of hot water is required for many purposes like cleaning, bathing, washing etc [1]. With this demand of hot water in residential and commercial facilities, the most common methods to heat water is the fossil fuels, the natural gas or electricity. These conventional methods for water heating are leading to global warming and ozone layer depletion [2]. With the demand of emission reduction and energy conservation, the domestic refrigerator technology for water heating should be a feasible system to save energy consumption and reduce the greenhouse gases [3]. Therefore, in comparison with traditional water heater, the condenser of domestic refrigerator immersed in water makes a better use of energy. Then, why not recover waste heat from condenser unit of a domestic refrigerator for the purposes of heating water and improving the performance of the system. [4]

II. LITERATURE REVIEW

A Survey of the literature regarding the waste heat recovery from the condenser of refrigerating machines and the use of spiral exchanger in the domestic refrigerator and air-conditioners immersed in water to heat.

Prashant.S.Pathak et al [5] Review Study of Waste Heat Recovery using Refrigeration System. They observed that, during summer, domestic refrigerators reject large heat waves inside the house which makes residents uncomfortable and ultimately increases temperature inside. They utilized a cabinet to recover waste heat from the condenser of the refrigeration system by storing heat in an isolated cabinet. They observed that the quantity of heat recovered can be used for number of domestic and industrial purposes. Stored heat is used for keeping food hot or heating water. This system will also reduce the consumption of electricity and reduce the rise of global temperature on Earth in order to stop the effect of global warming.

Soma A. Biswas et al [6] Waste Heat Recovery from Domestic Refrigerator. The aim of this study is to minimize the losses and recovery of maximum heat from the system by using water cooled condenser. They observed that the maximum temperature of the water obtained after 2 hours of continuous operation was 44.3°C. The quantity of hot water obtained from the condenser can be utilized for domestic applications like bathing, laundry, cleaning. Also, they concluded that this system can help in saving energy as no electricity was used for heating water.

Tanmay Patil et al [7] A Review of Recovering Waste Heat from Condenser of Domestic Refrigerator. They observed that the domestic refrigerator is operating continuously to maintain proper food storage condition, which contradicts the urgency to control electrical energy consumption. For this reason, they attempted at conserving this energy through waste heat recovery from the condenser of domestic refrigerator. They concluded that the waste heat recovered from the condenser of domestic refrigerator contributes to get cooling at low energy cost without any harmful effect to environment and also with a low initial cost.

P.Elumalai et al [8] They recovered the waste heat from the condenser unit of a household refrigerator to improve the performance of the system by using a thermo siphon. They

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found that after recovering heat from the condenser of the domestic refrigerator, there was an improvement in its performance comparing to a regular refrigerator.

O'Brien.M.J, et al [9] They designed a prototype of refrigerator with water heating system for domestic use. The system proposed uses heat energy rejected from the compressor and condenser by storing it in a heat sink. They concluded that the performance of the system improves and the recovered heat can be utilized for domestic purposes.

Kanshik.S.C et al [10] They studied the feasibility of heat recovery from the condenser of a vapor compression refrigeration system through a Canopus heat exchanger. The result shows that it is possible to recover the superheat of the discharged vapor and utilize it for increasing the temperature of the second fluid (water) dripping off the condenser.

Patil .Y.A et al. [11] They modified a domestic Refrigerator with the capacity of 190 liters to recover the waste heat by installing a water tank containing the condenser coils of a refrigerator. There Experiment showed that the maximum temperature increment was up to 40°C.

P.Sathiamurthi et al. [12] they presented in a series of studies on WHR from an air conditioning unit that the energy can be recovered and utilized without undermining comfort. They have also shown that such a system is economically viable. Energy consumption in the system and environmental pollution can still further be reduced by designing and employing energy saving equipment.

Clark et al. [13] they studied the waste heat recovery from household refrigerator after modifying it to meet the requirements of two conditions. It was concluded that to achieve higher efficiency, these modification should be installed in large refrigerating units.

Momin. G.G et al [14] Cop Enhancement of Domestic Refrigerator by Recovering Heat from the Condenser. They recovered the waste heat from the condenser of a household refrigerator. These experimentations revealed that after recovering heat from the condenser of a refrigerator, there is an improvement in its performance comparing to a regular refrigerator.

Lakshya Soni et al [15] Waste heat recovery system from domestic refrigerator for water and air heating. They concluded that when utilizing waste heat from the condenser of household refrigerator for water and/or air heating, the quantity of heat rejected in atmosphere is less, which makes it safer for the environment from the greenhouse gases. The use of heat recovery system illustrates the improvement in COP of full setup up-to 2 and also the reduction in power consumption. They also observed that this system is technically feasible and economically viable and it can be used for many purposes: cooking food and heating water.

Soma A. Biswas et al [16] Waste Heat Recovery from Domestic Refrigerator. The aim of this study is to minimize the losses and recovery of maximum heat from the system by using water cooled condenser. They observed that, the maximum temperature of the water obtained after 2 hours of continuous operation was 44.3°C. The quantity of hot water obtained from the condenser can be utilized for domestic applications like bathing, laundry, cleaning. Also, they concluded that this system can help in saving energy as no electricity was used for heating water.

N.B.chaudhari et al. [17] Heat Recovery system from the condenser of a Refrigerator-an Experimental analysis. They concluded that the theoretical COP without heat recovery is about 1.88 and with heat recovery system is 2.53. The actual COP of air cooled condenser system is 1.078 and for water cooled with heat recovery system the COP is practically 3.79.

P.Sarat Badu et al. [18] Experimental study of domestic refrigerator/freezer using variable condenser length. In this experimental work, they proposed to optimize condenser length for domestic refrigerator of 165 liters capacity. The result was that it may allow to find a different length other than existing length which will give better performance.

S.C.Walawade et al. [19] They designed and developed the WHR system for domestic refrigerator. They concluded that this system is much useful for domestic purpose. They also found that the recovered heat can be utilized as food and snacks warmer, water heater. In addition, the technical analysis has shown that it is economically viable.

III. System Description

The household refrigerator with a water heater tank is based on the same principle of vapor compression cycle but with few modifications. The condenser cooled by the ambient air is change by another one immersed in water to recover the quantity of heat rejected in atmosphere (waste heat). The main objective of this experiment is to utilize these different heat discharges provided by the condenser to heating water (as shown in figure 1).

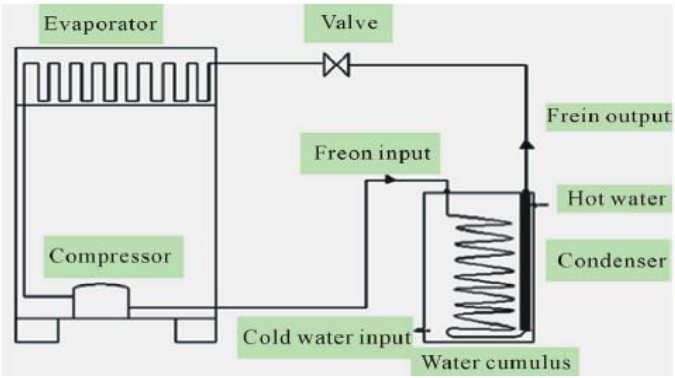

Fig.1: Domestic Refrigerator with Water Heater Tank [3]

IV. Experimentation and Measurement

Experimental Setup

As shown in Fig.2, an experimental test has been purposely designed to investigate the different temperature and pressure of household refrigerator with water heating system.

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Fig.2: Domestic Refrigerator with Water Heater Tank photograph.

TABLE.1: SPECIFICATIONS OF THE REFRIGERATOR (NEWSTAR, MODEL MP0500).

Refrigerator model : (NewStar MP0500)	***Compressor model :AES30DS***
climate class: ST	***Power supply(V/Hz):220-240 /50***
Rated current: 1.2A	***Displacement: 3.88 cm^3***
Refrigerant gas : R134a	***Motor type: RSIR***
Volume: 46 L	***Cooling capacity: 88w***
Energy consumption:0.52 KWh/24h	***COP:0.98***
Type of water tank: FRIGOBAMBO cooler with a capacity of 30 liters	

V. RESULT AND DISCUSSION

Figure 3 shows the variation of temperature with time. According to this Fig., The water temperature in the tank is increased significantly (26 to 33°C) with a volume of water is $0{,}024m^3$. This increase is due to the waste heat recovery from the condenser of a domestic refrigerator. With increasing of water temperature, the temperature of evaporator is change (not stable) but not influenced by the rise of water temperature.

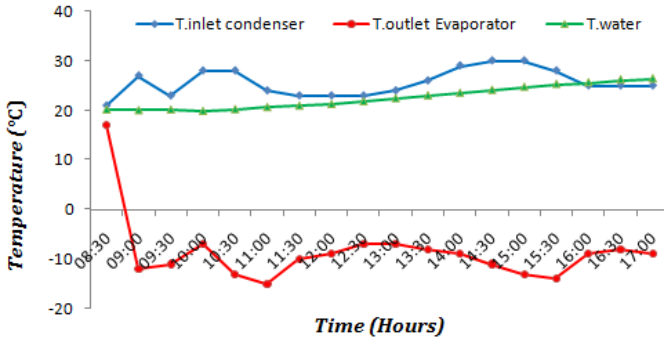

Figure.3.Variation of temperature with time

Figure 4 illustrates the experimental results of temperature with time. In the experimental study, the total amount of hot water in the tank is conserved as no water consumption during heating process. The results obtained after one day of operation shows that the value of water temperature reached is of 50°C with a volume of heated water is $[0{,}024m^3]$, with a continuously use the domestic refrigerator this value may be will be better.

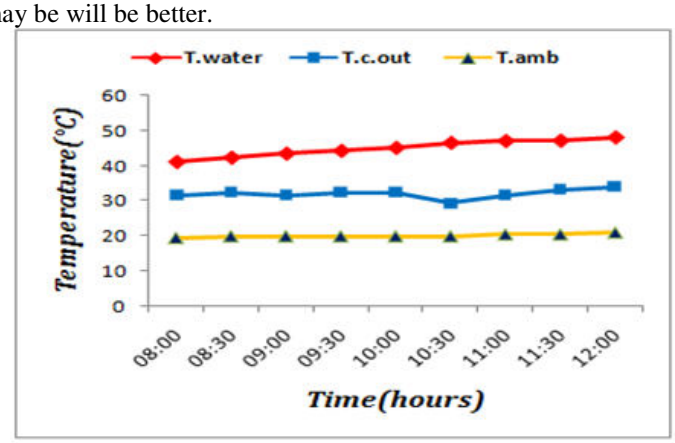

Fig.4.Experimental results of the temperature with time

Figure 5 shows the variation of water temperature and heat gained by the water with time. According to this Fig., the water temperature in the tank increases with time. The heat gained by the water curve is change (variable) with time (with the increase of water temperature in the tank). It can be seen that the temperature inside the water tank increases, the heating capacity of the domestic refrigerator is reduced. This result is in accordance with the literature (Xinhui Zhao et al.)[20]

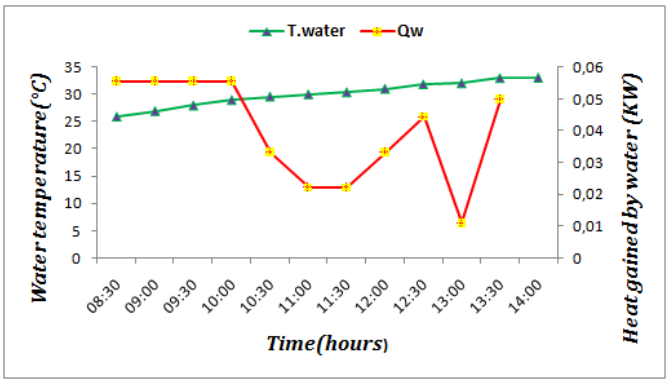

Fig.5. Variation of water temperature and heat gained by the water with time

Figure 6 shows the variation of pressure and mass flow rate of Refrigerant R134a with water temperature. We observe that the mass flow rate changes as a result of pressure at the inlet of the compressor. At the beginning of the test, the water temperature is 26°C and the absolute pressures at the compressor inlet and outlet are respectively P1=1.7bar and P2=8.5bar and the mass flow rate is 0.001152 Kg/s

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(ṁR134a=0.001152Kg/s). When the water temperature is 28.5°C, the mass flow rate takes a maximum value equal to 0.102469 Kg/s as well as the pressure at the compressor inlet (P1max =3.5 bar) but the pressure at the outlet of the compressor takes a minimum value equal to 4.5 bar (P2min = 4.5 bar). When the pressure at the compressor outlet increases (P2=8.7bar), the inlet pressure is reduced (P1=1.2bar) as well as the mass flow rate of R134a (ṁR134a = 0.000867 Kg/s). Then, when the pressure at the compressor outlet increases, the mass flow rate of refrigerant R134a at the compressor (compressor output) decreases. This decrease of mass flow rate of refrigerant contributes to the decrease of compressor efficiency and the risk of heating and also leads to more consumption of electrical energy.

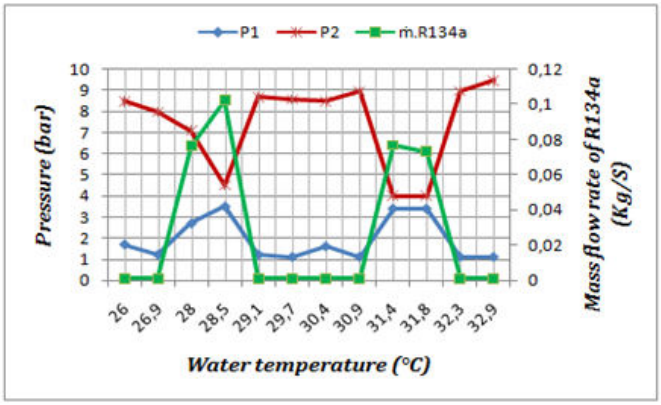

Fig.6: Variation of Pressure and Mass flow rate of Freon R134a vs. Water temperature

Sample calculation:

The work done by the compressor is given by;

$$W = h_2 - h_1 \quad (1)$$

The refrigerating effect is given by;

$$Re = h_1 - h_4 \quad (2)$$

The cooling capacity of domestic refrigerator in KW is given by;

$$Q_{cooling\ capacity} = \dot{m}_{water} \cdot Cp_{water} \cdot \Delta T \quad (3)$$

The mass flow rate of refrigerant is given by;

$$\dot{m}_{ref} = {}^{Q_{cooling\ capacity}}/_{Re} \quad (4)$$

Coefficient of performance:

The coefficient of performance (COP) of a domestic refrigerator it can be expressed by the following equation:

$$COP = \frac{Refrigeration\ capacity}{Compressor\ work} \quad (5)$$

Where

$$Refrigeration\ capacity = \dot{m}_{ref}(h_1 - h_4) \quad (6)$$

$$Compressor\ work = \dot{m}_{ref}(h_2 - h_1) \quad (7)$$

$$COP = \frac{h_4 - h_1}{h_2 - h_1} = \frac{279{,}641 - 266{,}511}{271{,}391 - 266{,}511} = 2{,}69 \quad (8)$$

The values of different thermo-physical properties was determined by using P-h diagram based on relationship between pressure and temperature obtained from experiment that has been conducted.

- Energetic Interest

Refrigerating machines have an energy interest during the valorization of thermal discharges for water heating. For an electrical energy consumption of 1 KWh, refrigerating machines for example a domestic refrigerator provides 3 to 4 KWh of heating energy at their condenser.

With the use of refrigeration machines to heating water, a low power consumption is achieved. So, this valorization technique allows us to reduce the heating bill.

- Energy Savings (in KWh)

To calculate the Energy Savings, we are not interested in the price of electric energy but we will evaluate the amount of electrical energy that will be saved from the free energy produced by the condensers of the refrigerating machines that will have been supplied in the atmosphere without used.

To determine it, we have to calculate the coefficient of performance (COP) of our refrigerating machine.

Then, the COP of the domestic refrigerator is defined by the following relation:

$$COP = \frac{\text{Energy produced by the condenser in the form of heat}}{\text{Electric energy consumed by the compressor}}$$

When a refrigerating machine had a coefficient of performance (COP) is 4 (Ben Slama.R [3]), this means that for 1 KWh of electricity consumed, our domestic machine will produce 4 KWh of heating energy.

In terms of electrical energy savings, if the refrigerating machine produces 4 kWh of heating energy during a 1 KWh of electricity consumed by the compressor, the output is 3 KWh of electric energy saved over a total of 4 KWh. Then the energy savings is about 75%.

- Environmental Interest

Nowadays, hot water production in residential sectors contributes to the environmental pollution and global warming. The use of the classical method; natural gas, wood and other combustible sources; for heating sanitary water, the planet will be degraded and the sea level will increase due to a decrease in the volume of ice in the sea, and the ozone layer may also be damaged.

All around the world, large emitters of greenhouse gases are the machines that consume electrical energy. Once greenhouse gas emissions begin to increase, the problem of environmental degradation begins to increase. Therefore, with the valorization of the thermal emissions from the refrigerating machines used in heating water, we have guaranteed a zero percentage of fumes released into the atmosphere during the period of heating sanitary water. That

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means a protection of the layer ozone and a low GWP (Global Warming Potential).

VI. Conclusion

This paper demonstrates the feasibility of waste heat recovery from the condenser of household refrigerator for the purpose of heating the sanitary water. It concludes that:

- The results show that the water in the tank at a temperature of 50°C was produced by the system.
- This modification made the domestic refrigeration to operate on both modes: cooling and heating – the machine is multipurpose.
- With this system, the power consumption for water heating can be reduced.
- The waste energy rejected to the environment is utilized for many purposes and the demand for power is reduced.
- This system has proved to be technically feasible and economically viable.
- Stored heat is used for heating water which may be used for different purposes.
- Power consumption is reduced by using water cooled condenser instead of air cooled condenser.
- This domestic refrigerator has good utilization in hotels and domestic purpose.
- This system rejects less heat to the atmosphere so it is safer for the environment.
- With the valorisation of waste heat for water heating, we get cooling at low energy cost, no harmful effect to the environment and at a low initial cost.
- With this system, the cost of fuel and energy consumption will decrease.
- The efficiency of the refrigeration system also increases.
- The results show that the use the water cooled condenser saves more energy and reduces the GHG emissions.

The residential and commercial water heating technique requires high energy consumption; therefore they have a great influence on the environment. The advantage of the valorization of the heat rejection rate from the condenser has economic (reduce the cost of energy) and the environmental (reduction of the emissions of greenhouse gases) effects. Currently, the application of this type of valorization of thermal discharges is common in industry but given the gradual increase in energy costs and environmental problems this number can only grow.

Acknowledgment

The Authors would like to thank the University of Tunis and the University of Gabes for supporting this research work.
I would also like to thanks to my friends for their guidance, moral boosting, support and encouragement throughout many times.

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