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Numerical Investigation of Household Refrigerator by Recovering Heat from the Condenser

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ABSTRACT

The refrigerating machines are used extensively in our life, with their use they are losing a quantity of thermal energy which is very important without being properly exploited. To study these machines, we chose a Household refrigerator to perform experimental tests. The investigation results showed that the domestic refrigerator work normally using waste heat recovery for water heating. The water temperature in the tank reached 50°C, with a continuous use of the domestic refrigerator the temperature will be better. The values of different thermo-physical properties was determined by using EES software based on relationship between pressure and temperature obtained from experiment that has been conducted.

Keywords: *Numerical investigation, Water Cooled condenser, water tank, condenser design.*

INTRODUCTION

Refrigerating machines are today part of our daily life. Through their various applications, they ensure a better quality of life. They also meet the needs of users in many applications (freezing, preserving alimentary products,...), but also to refresh locations (supermarkets, apartments, places of commerce, cinemas or sports complexes,…). These refrigerating machines have cycle that extract heat from locations to be cooled at low temperature and reject it to external environments at a higher temperature.

These refrigerating equipments are intended to produce cold in all areas that need refreshing and / or freezing. The cooling technique is through a heat exchanger called evaporator against the other side, another heat exchanger (condenser) that provides a large amount of heat energy at a higher temperature.

These thermal discharges born from the condenser will be lost in the atmosphere if they are not invested.

So these refrigeration machines produce two different heating energies that we only use one of them to meet our daily needs and the other one that is produced by the condenser will be rejected in the environment and itself contributes to the degradation of the environment **[1].** The use of this free source of energy lost in the environment is able to meet the heating need at all temperatures while keeping good thermodynamic performance **[2, 3].**

For this reason, why not invest these different heat discharges provided by the condenser in the field of heating water which may be used for different purposes like washing, cleaning, etc **[4, 5 and 6].**

LITERATURE REVIEW

The technical use of the waste heat of the condenser of household refrigerator for heating water is increasing with the increase of energy cost and the pollution environment.

Many authors have studied this technique using many different prototypes with few modifications. Some of these authors and those works are presented:

Romdhane Ben Slama [7]

Refrigerator Coupling to a Water-Heater and Heating Floor to Save Energy and to Reduce Carbon Emissions. He concluded, when using the refrigerator for one day, the value of temperature is about 60°C. This value of temperature will be better with continuously using the refrigerator.

Jadhav. P. J et al [8]

Heat Recovery from Refrigerator Using Water Heater and Hot Box. They concluded that when using the waste heat from condenser of the domestic refrigerator, the temperature of water heater is between 50 and 60°C and maintain the temperature up to 45 and 50°C in hot box. Also they concluded, that this type of refrigerator with recovered waste heat of the condenser has good utilization in many purpose such as in hotels, dairy, industry and also useful for domestic purpose.

G.G. Momin et al [9]

Cop Enhancement of Domestic Refrigerator by Recovering Heat from the Condenser. They recovered the waste heat from the condenser of the household refrigerator. Those experimentations found that after recovering heat from the condenser of the conventional refrigerator, its performance gets improved than conventional refrigerator.

Lakshya Soni et al [10]

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, so it is 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. Also they observed that this system is technically feasible and economically viable and it can be used for many purposes: heating food and water.

N. B. Chaudhari et al [11]

Heat Recovery System from the Condenser of a Refrigerator – an Experimental Analysis. They observed that the quantity of heat recovered from the condenser of a domestic refrigerator is found experimentally: 202 to 410 W. Also, they concluded that the Theoretical COP without heat recovery is about 1.88 and with heat recovery system it is 2.53. The actual COP of air cooled condenser system is 1.078 and for water cooled with heat recovery system practically COP is 3.79. The hot water available per hour is about 7.2 liters at 51°C and for 24 liters per hour at 41.7°C.

Omkar Borkar et al [12]

A Review on Utilization of Waste Heat from a Refrigerator. They observed that the domestic refrigerator dissipated the heat out in the atmosphere, for this reason, the efficiency of this machine is reduced. The aim of this work is to utilize the dissipated heat for some other purpose and increase overall efficiency. They concluded that when using the waste heat from the condenser of household refrigerator, we get cooling at low energy cost, no harmful effect to environment and also a low initial cost.

Pratik Kumbhar et al [13]

Design and Development Waste Heat Recovery from Domestic Refrigerator. They concluded that the waste heat recovery has many advantages such as System Performance Improved, Hot water Output, decreases the cost of fuel & energy consumption and Hot water output can be used for a number of applications.

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).

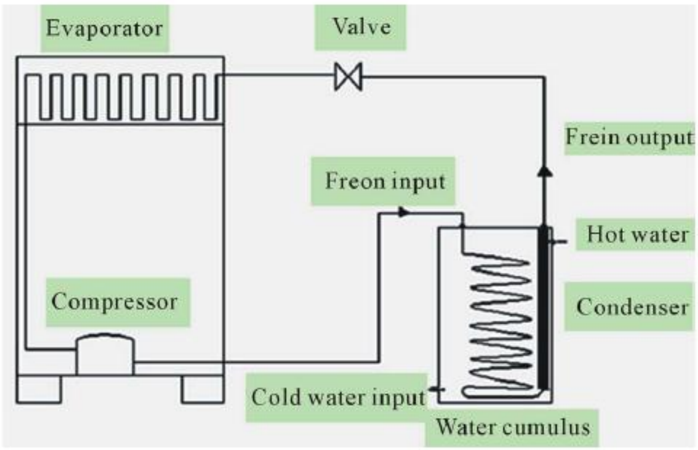

Fig1. *Domestic Refrigerator with Water Heater Tank*

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.

Fig2. *Domestic Refrigerator with Water Heater Tank photograph*

Table1. *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	

For the measurement of the different temperatures, a digital display thermocouple is used to measure the temperatures of water, the inlet and outlet of the condenser, the inlet of the evaporator and 2 mercury thermometers for the measurement of the temperature inside the refrigerator (evaporator outlet) and the ambient temperature.

Calibration of the thermocouples was done in ambient air to identify the percentage of error between them.

The capacity of water used in the tank to cool the condenser is 24 liters (V=0,024m^3) and the compressor speed is constant.

Mathematical Model of Water – Cooled Condenser

In the natural convection type water cooled condenser of domestic refrigerator, the refrigerant flow inside the tube is cooled by the water flowing outside.

Water Side Heat Transfer Coefficient (h_0)

In the natural convection, the correlation proposed by **D. Azzouzi et al. [14]** to calculate the water side heat transfer coefficient of the condenser was expressed by the following equation: **[16]**

$$if \quad 10^{-5} < Ra < 10^{12}$$

$$Nu_L = \left[0.60 + \frac{0.387Ra^{1/6}}{(1+(0.559/Pr)^{9/16})^{8/27}}\right]^2 = \frac{h_0 D}{\lambda} \quad (1)$$

$$if \quad 10^{-6} < Ra < 10^{9}$$

$$Nu = 0.36 + \left(\frac{0.518Ra^{(1/4)}}{\left(1+\left(\frac{0.559}{Pr}\right)^{(9/16)}\right)^{(4/9)}}\right) = \frac{h_0 D}{\lambda} \quad (2)$$

Rayleigh number is determined from;

$$Ra = \frac{g\beta(T_{wall} - T_{water})D_e^3}{\upsilon_{water}^2} * Pr_{water} \quad (3)$$

$$Ra = \frac{9,807 * 0,0004334 * 16,8 * 0,006^3}{(5,867.10^{-7})^2} * 3,8126 = 170835,13$$

Then, the water side heat transfer coefficient can be defined as follow;

$$h_0 = \frac{\lambda.Nu_L}{D} = \frac{0,6366 * 10,5204697}{0,006} \quad (4)$$

$$h_0 = 1116,22 \; {W}/{m^2.K}$$

Condensing Heat Transfer Coefficient(h_i)

The single-phase refrigerant side heat transfer coefficient (h_i) is developed by Dittus and Boelter: **[15]**

$$Nu = 0.023 * Re^{0.8} * Pr^{0.3} = \left(\frac{h_i D}{\lambda}\right) \quad (5)$$

The Reynolds number of the internal flow of the tube is demonstrated by the following expression:

$$Re = \left(\frac{\rho V D}{\mu}\right)_{R134a} \quad (6)$$

$$Re = \left(\frac{17{,}63 * 5{,}68058 * 0{,}004}{0{,}00001207}\right)_{R134a} = 33189{,}27$$

The Prandtl number is expressed as follows:

$$Pr = \left(\frac{\mu Cp}{\lambda}\right)_{R134a} = 0{,}76 \quad (7)$$

Then, the refrigerant side heat transfer coefficient can be defined as follow;

$$h_i = \frac{Nu.\lambda}{D} = \frac{87{,}712 * 0{,}0146}{0{,}004} \quad (8)$$

$$h_i = 320{,}15 \,{}^{W}/_{m^2.K}$$

The log mean temperature difference$(LMTD)$ is calculated from:

$$LMTD = \frac{\Delta\theta_1 - \Delta\theta_2}{Ln(\frac{\Delta\theta_1}{\Delta\theta_2})} \quad (9)$$

The temperature differences can be determined as follows:

$$\Delta\theta_1 = |T_{R134a.outlet} - T_{Water\ .inlet}| \quad (10)$$

$$\Delta\theta_1 = |34 - 26| = 8\ °C$$

$$\Delta\theta_2 = |T_{R134a.inlet} - T_{Water\ .outlet}| \quad (11)$$

$$\Delta\theta_2 = |50 - 48| = 2\ °C$$

Overall Heat Transfer Coefficient(U_0)

The Overall heat transfer coefficient is given by: **[7]**

$$U_0 = \frac{1}{\frac{1}{h_i} + di \cdot \frac{\ln\left(\frac{d_e}{d_i}\right)}{2 \cdot \lambda_{copper}} + \frac{1}{h_o}} \quad (12)$$

$$U_0 = \frac{1}{\frac{1}{320{,}150469} + 0{,}004 * \frac{\ln\left(\frac{0{,}006}{0{,}004}\right)}{2 * 386} + \frac{1}{1116{,}22184}}$$

$$U_0 = 248{,}66 \,{}^{W}/_{m^2.K}$$

Calculations For Condenser Length (L)

The heat transfer through the condenser of domestic refrigerator to water is given by;

To calculate the heat absorbed by the water we use the following equation;

The heat gained by the water =the heat recovered by the system

$$Q_w = \rho * V * Cp_w * \frac{\Delta T}{t} \quad KW \quad (13)$$

$$Q_w = 996{,}7858 * 0{,}024 * 4{,}1809 * \frac{(26 - 25)}{(30 * 60)} = 55{,}56\ W$$

Where,Q_w represent the heat gained by the water, ρ is the density,V is the volume of water, Cp_w is the specific heat of water, ΔT is the water temperature difference and (t) is the time of operation.

To calculate the condenser length of domestic refrigerator we use the following equation:

$$Q = U_0 A(LMTD) \quad (14)$$

$$A = \pi DL = \frac{Q}{U_0 \cdot LMTD} \quad (15)$$

$$L = \frac{Q}{U_0 \cdot \pi \cdot D \cdot LMTD} \quad (16)$$

$$Q = U_0 A(LMTD)$$

Then, the Length of tube (L) is,

$$L = 4{,}10\ m$$

Result and Discussion

Figure 3 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 as 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.)[17]**

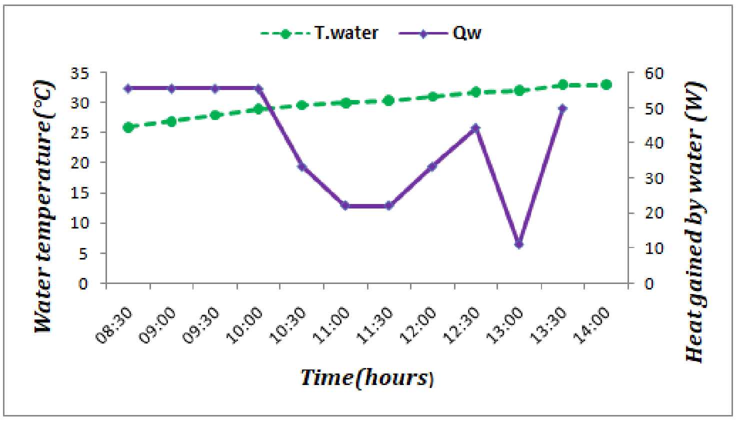

Fig3. *Variation of water temperature and heat gained by the water with time*

Figure 4 illustrate the variation of mass flow rate of refrigerant and water temperature as function of time. According to this Fig., the mass flow rate of refrigerant is change with increasing of water temperature in the tank. We concluded that, the mass flow rate of Freon is not related to the increase of water temperature.

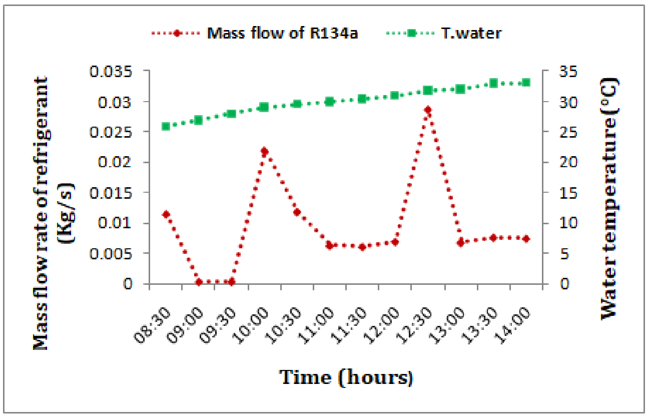

Fig4. *Variation of mass flow rate of refrigerant and water temperature with time*

CONCLUSION

The advantage of this machine (Household Refrigerator) is that it can make use of heated water, keep good thermodynamic performance, save more energy and reduce more emissions of greenhouse gases.

- The electric consumption for water heating is less as compare to conventional water heating.
- The value of water temperature in the tank will improve with the continuous use of the refrigerator.
- The warm quantity of heat rejects in a room from the air cooled condenser of household refrigerator is recovered for heating water that is used for many purposes like washing, cleaning,
- The maximum temperature achieved in the water storage tank is 50°C.
- The condenser of household refrigerator immersed in water tank will lead to reduce the rising temperature of environment and contribute to protect the ozone layer.

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