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Optimum length of a condenser for a domestic refrigerator for water heating

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Abstract

The condenser design plays a very important role in the performance of a domestic refrigerator. The main objective in the present work is to optimize condenser length for domestic refrigerator. The results show that the design of condenser length is made through theoretical calculations and found that the optimum length of condenser is 4, 10 m instead of standard value 4m. It is concluded that the condenser with 4,10m of length is the optimum length and is recommended for domestic refrigerator for water heating.

Keywords: Domestic Refrigerator, Optimized design, waste heat recovery, Water heating

INTRODUCTION

The refrigerating machines have cycles that extract heat from locations to be cooled at low temperature and reject it to external environments at a higher temperature. This refrigerating equipment is intended to produce cold in all areas that need refreshing and freezing. The cooling technique is performed by 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 without using them. 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 (Ben Slama, 2012). The use of this free source of energy lost in the environment can meet the heating needs at all temperatures while keeping good thermodynamic performance. For this reason, why not value these different heat discharges provided by the condenser in the field of heating water which may be used for different purposes (Ben Slama, 2011; Ben Slama, 2014).

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 changed by another one immersed in water to recover the quantity of heat rejected in the 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).

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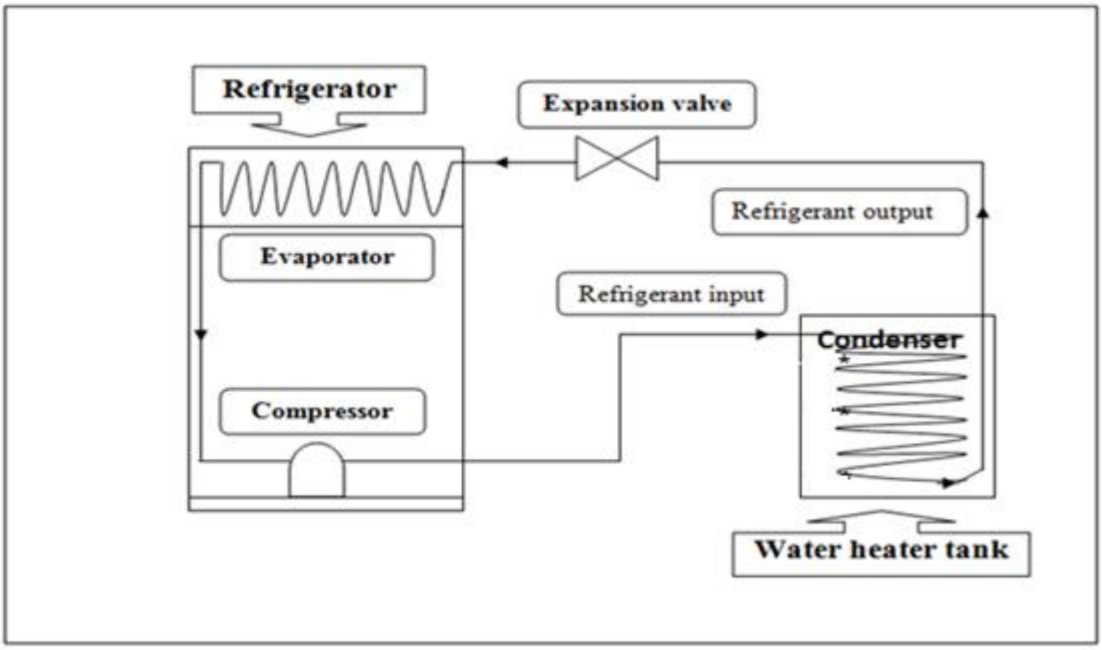

Figure 1: Domestic Refrigerator with Water Heater Tank

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.

Figure 2: Domestic Refrigerator with Water Heater Tank photograph

Table 1: Specifications of the refrigerator (New Star, Model MP0500)

Refrigerator model: (New Star 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	

Note: The values of different thermo-physical properties were determined by using EES software based on the relationship between pressure and temperature obtained from the experiment that has been conducted.

MATHEMATICAL MODEL OF WATER-COOLED CONDENSER

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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, 2017) to calculate the water side heat transfer coefficient of the condenser was expressed by the following equation: (O.Ibrahim, 2013).

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

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

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

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

Rayleigh number is determined from;

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

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

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

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

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

Condensing heat transfer coefficient(h_i)

The single-phase refrigerant side heat transfer coefficient(h_i) is developed by Dittus and Boelter: (Farouk Fardoun, 2011)

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

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

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

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

The Prandtl number is expressed as follows:

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

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

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

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

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:

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

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

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

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

By LMTD:

$$LMTD = 4{,}32\,°C$$

Overall heat transfer coefficient $(\boldsymbol{U_0})$

The Overall heat transfer coefficient is given by (Ben Slama, 2013)

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

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

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

Calculations for Condenser Length $(\boldsymbol{L})$

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

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

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

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:

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

$$L = \frac{Q}{U_0 \cdot \pi \cdot D \cdot LMTD} \quad (15)$$

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$$L = \frac{0{,}05556 * 10^3}{248{,}66273 * \pi * 0{,}004 * 4{,}328}$$

Then, the Length of the tube (L) is, $L = 4{,}10\ m$

CONCLUSION

Looking towards the results, it is concluded that:

- The design of condenser length is made through theoretical calculations and found that the optimum length of the condenser is 4, 10 m instead of standard value 4m.
- The design of condenser length plays a very important role in the performance of domestic refrigerator system.
- The condenser with 4,10m of length gives higher COP.

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