QUANTIFICATION OF HEAT GENERATED IN THE CONDENSER OF A DOMESTIC REFRIGERATOR ACCORDING TO THE POSITION OF THE THERMAL STORAGE

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Abstract. *In the study of recycling thermal energy it is known that domestic refrigerators dissipate heat to environment through the condenser. This heat can be recycled by a water flow, as a coolant in a modified condenser, and stored in a Domestic Hot Water Storage Tanks (DHWST). Thereby, an experimental apparatus was built containing two domestic refrigerators, each one with capacity of 263 liters in the cooling cabinet and 74 liters in the freezing cabinet. One of the refrigerators had the condenser substituted by a shell and pipe heat exchanger with a counter-current flow, which has the function of replace the original finned exchanger, condensing the coolant with water flow. Then, this warmed water is stored in a hot water storage tanks via thermal stratification. The thermal storage unit via sensitive heat, when applied in a heat generator system (e.g. a condenser in a refrigeration system), allow to manage with two different temperature level of work fluid, in other words, application of storage via thermal stratification process. When the hot water storage tank comes totally loaded, reaching a thermal balance point, the cooling system can enter in collapse, since the process of condensation of the coolant will be inefficient due the small temperature difference. Due that, another refrigerator was built preserving the original condenser following the shell and tube heat exchanger, increasing the volume of coolant in the refrigeration system. So, in case it happen the complete thermal load of the storage tank, the system will work likely the original condenser system, dissipating heat to environment. This project presents an experimental result analysis obtained from the modified refrigerators and thermal storage tank. According to these results, the experiment optimization is effective and it is totally possible to reuse the warm water from modified condenser system, what could reduce the electric energy consumption in water heater and minimize the heat dissipation to environment.*

Keywords: *thermal energy, thermal storage, thermal losses, refrigeration of system, condenser*.

1. INTRODUCTION

Since the industrial revolution the compulsive consumption of nonrenewable natural resources is growing, and over the years, the dependence on them intensifies, primarily driven by increasing production and human need. In search of materials for survival or just for pleasure of mankind, do not set parameters for the environment that is increasingly degraded. Due to this reckless exploitation of society, in general, is facing critical situations of the environment, which reflect on humanity in many different ways. The reasons for these environmental disasters are also interference of people in nature, through the introduction of polluting activities, resulting from the processing of large amounts of nonrenewable natural resources into goods and services, where their production or operation to dissipate large amounts of pollutants to atmosphere. In view of this transformation uncontrolled, there is the depletion of traditional sources of energy, thereby intensifying the search for new sources of alternative and renewable energies. Considering these factors we seek to form a continuous new forms of energy alternatives, the more efficient, less costly and mostly less harmful to the environment. The use of renewable energy sources contributing to the reduction of environmental pollution, thus improving quality of life on Earth. From the foregoing, the present work is an example that provides an overview of recycling heat generated in the condenser of a domestic refrigerator, minimizing and reusing the heat now dissipated to the environment.

2. LITERATURE REVIEW

Jordan and Furbo (2005) analyzed through theoretical and experimental study, the influence of the entry of cold water on a hot water storage thermally stratified. For both commercial tanks capacity 144 and 183 liters of storage was a used device to prevent mixing between hot and cold water at the entrance of the tank. At the entrance of tank 183 liters was fixed a flat plate located 30 mm from the edge, while in the tank of 144 liters a device shaped half sphere located 10 mm from the edge. Compared with unmodified systems, tank of 144 liters was more efficient to use hot water storage.

Ievers and Lin (2009) analyzed about a three-dimensional numerical simulation for heat flow in a process of hot water storage tank on. To analyze the effects of thermal stratification in the tank were studied geometric and operational conditions on the thermal stratification. The level of stratification was quantified by means of exergy analysis, observing the influence of results on the behavior of thermal stratification. Relations height to diameter and position of entry / exit near the top of the tank, resulting in improved levels of stratification, increasing the amount of stored energy.

Using numerical modeling, Bin Li (2009) studied the vapor compression cycle (VCC) used in refrigeration. The model describes the transient behavior of heat exchangers (evaporator / condenser) and the operation of the compressor. Two studies of model validation in an experimental system show that the full dynamic model, calculated in Matlab / Simulink, describes well the dynamics of the system.

Amaral Filho (2005) built and analyzed the efficiency of a heat exchanger shell and tube type with water flow counter-current gas. The exchanger was used as a condenser of a refrigerator modified, providing smooth operation and high efficiency for water as coolant gas. The shell and tube type heat exchanger maintained the normal operation of the refrigerator modified compared with the original, and does not dissipate heat to the environment, yet provides heated water for domestic use.

With experimental work, Marchi Neto (2007), obtained and compared the coefficient of performance (COP) of two refrigerators, conventional and modified. The refrigerator modified, has a heat exchanger shell and tube type, which replaces the original refrigerator condenser, with water flow counter-current gas. By studying the amount of heat stored in the tank attached to the refrigerator changed, we calculated the Coefficient of Thermal Performance System (COPS) of new storage and refrigerator modified. The cooler condenser amended, was more efficient when compared with the conventional system, reducing electricity consumption. The results show that the modified refrigerator does not dissipate heat to the environment and also to the walls of the compartment to be chilled.

Through an energy balance for the storage system by thermal stratification, Padilha (1982 and 1983) proposed a semi-empirical one-dimensional and transient, which obtained the behavior of the profiles of temperatures of the liquid and the reservoir wall during periods of loading, unloading and natural cooling. It was verified the influence of height / diameter of the storage on the efficiency of thermal stratification, through the First and Second Laws of Thermodynamics. The theoretical results were compared with available experimental literature.

3. OBJECTIVES

The objectives of study are to obtain experimental data of flow and temperature of the heated water from the heat exchanger used for the condensation of gas in domestic refrigerator. Determine the amount of heat absorbed by water in the system heat exchanger / condenser, via the technique of thermal stratification in storage tank of water heated. It measured the energy consumption of refrigerators modified and unmodified, for the same operating conditions. The data are also used to obtain the coefficients of performance of energy conversion systems of refrigerators and the amount of energy recovered as heat.

4. MATERIALS AND METHODS

The experimental apparatus consists of two domestic refrigerators duplex of 263 liters for the cabinet and 74 liters of cooling to the cabinet for freezing. One of refrigerators has increased its condenser by a heat exchanger shell and tube type water cooled in counter flow to the refrigerant. The function of the heat exchanger is to condense the refrigerant, thus becoming an alternative to the finned condenser coolant. The heated water is then stored in the tank through technique of thermal stratification. A brand equipment SAGA 4000, model 1380 is used to measure the electricity consumed by refrigerators modified and original.

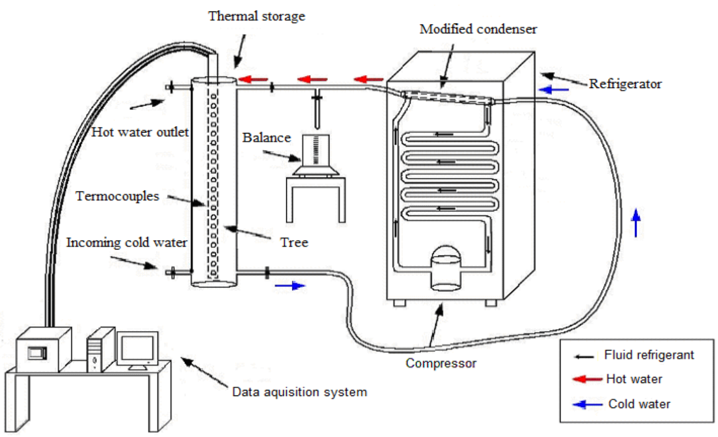

Figure 1. General diagram of the experimental apparatus

We used thermocouples of type "T", arranged, equidistant from h = 0.05 m in a probe inserted into the storage tank. The dynamic loading of the storage is performed by injection of heated water by top and extraction from the same and cold water flow in the bottom of the tank, setting up the process of thermal stratification of the water, or three regions within the thermal reservoir a hot region, a cold and an intermediate, known as isocline, between the first and two regions. By studying the movement of the warm front, obtained through the process of thermal stratification is determined the same travel time between the thermocouples and thus determining the mass flow of heated water that circulates through the system.

Thus, we get the flow of heated water through the relation:

$$\dot{m} = \frac{\pi r^2 h}{t} \tag{1}$$

Equation (1) describes the mass flow of heated water as a function of tank geometry and the travel time of the warm front.

By calculating the flow of heated water, we also get indirectly the flow of refrigerant (R-134a), circulating through the heat exchanger shell and tube of the physical property input and output of that exchanger, assuming equality in the heat flux exchanged between water and refrigerant, namely:

$$\dot{Q}_{Gás} = \dot{Q}_{Água} \tag{2}$$

Thus:

$$\left[\dot{m}\left(h_{sai} - h_{entra}\right)\right]_{Gás} = \left[\dot{m} \cdot c_p \cdot \left(T_{sai} - T_{entra}\right)\right]_{Água} \tag{3}$$

In other words:

$$\left[\dot{m}\right]_{Gás} = \left[\frac{\dot{m} c_p \cdot \left(T_{sai} - T_{entra}\right)_{Àgua}}{\left(h_{sai} - h_{entra}\right)_{Gás}}\right] \tag{4}$$

The enthalpies of the refrigerant are obtained by means of the properties temperature and pressure, measured on entry and exit of the heat exchanger shell and tube, as temperatures in and out of the water, and its specific heat (c_p) tabulated. Thus, we obtain the mass flow of refrigerant depending on the mass flow of water.

Was constructed an experimental apparatus to simulate the normal operation of the refrigerator, with cycles on/off as in everyday use in homes. In normal operation, the refrigerator works on full power for a range of approximately 6 hours. After that time the temperatures of the refrigerator tend to nominal values, in other words, the lowest temperature reached by the system. Them from the refrigerator only works for maintenance of heat loss through walls.

5. RESULTS AND DISCUSSIONS

With the system's functioning was measured the mass flow of heated water as a function of displacement of the isoclines inside of the storage. It was assumed that the amount of heat absorbed to water as part of the amount of heat removed from the compartments to be cooled. The fall of the mass flow of hot water as the temperature of the refrigerator tends to nominal values. In Fig. (2), shows the mass flow of warm water in the function of temperature.

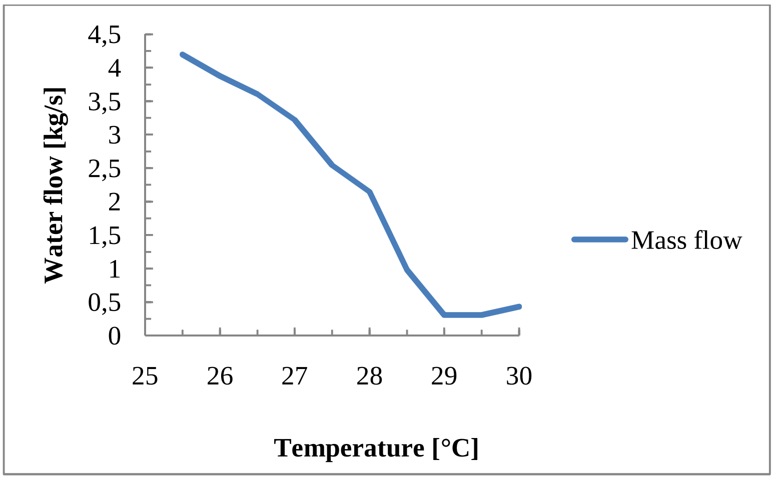

Figure 2. Water flow a function of temperature

In Fig (2) is observed that with increasing temperature in the first thermocouple at the top of the tank, decreasing the water flow and this effect is due to reduced thermal load in the compartments of the refrigerator.

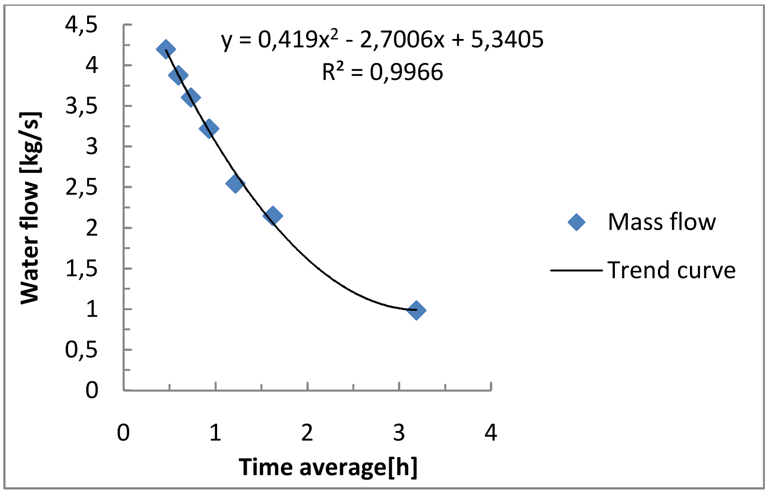

Figure 3. Mass flow of water as a function of average

In Fig (3), we present the experimental points for the mass flow of heated water, since it is not constant, i.e., the same variations occur according to the refrigerator heat load and displacement of isocline. With a trend line added to the graph, it appears that on average the flow of heated water is within the parameters observed by the experimental points. There is also that over time the flow rate decreases, in other words, the refrigerator, with the passage of time dissipates less heat.

In Fig (4) can be verified on the thermal stratification of the water inside the tank for a test period of 24 hours, according to the position of each thermocouple. With the passage of time it is noticed the start of the thermal stratification, demonstrating the formation of the hot region. Is observed the formation of three distinct regions of temperatures distributed over the height of the storage, a hot region at the top, a cold region in the background and a region between those two. The history of temperature profiles due to variations in flow and temperature of heated water, i.e. the higher the water temperature, the higher the quality of thermal stratification.

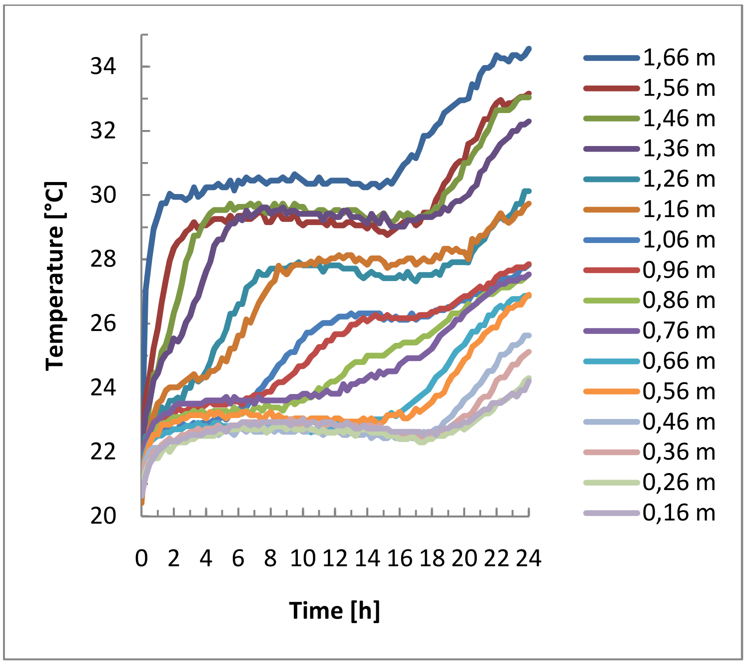

Figure 4. Evolution of temperature profiles of each thermocouple inside the thermal storage

In Figure (5), presents the results of the behavior of isocline along the height of the tank every two hours to test a loading period of 24 h. Observe the initial deformation of the isocline (t = 0 h) over time, which simulates the dynamic load of warm water in the tank. The case is tested for a difference in height of 0.70 meters, between the exit of the exchanger and heated water entering the tank, which produces a low flow of heated water of 0,00105 kg/s, compared to the case studied by Marchi Neto (2007), Fig (6) whose flow rate was 0,00199 kg/s to a height difference of 0.85 meters. It is observed that for a lower flow rate, as in the case tested, the isocline are presented with a tendency to partial loading of the storage, but due to this flow, it is observed in Fig (5) the temperature at the bottom of storage tank did not exceed 25 ° C.

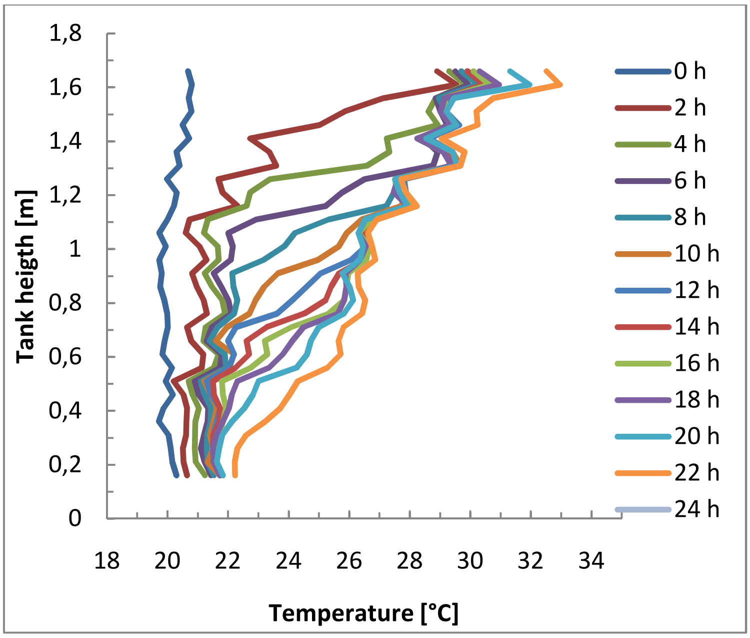

Figure 5. Behavior of isocline along the height of the tank

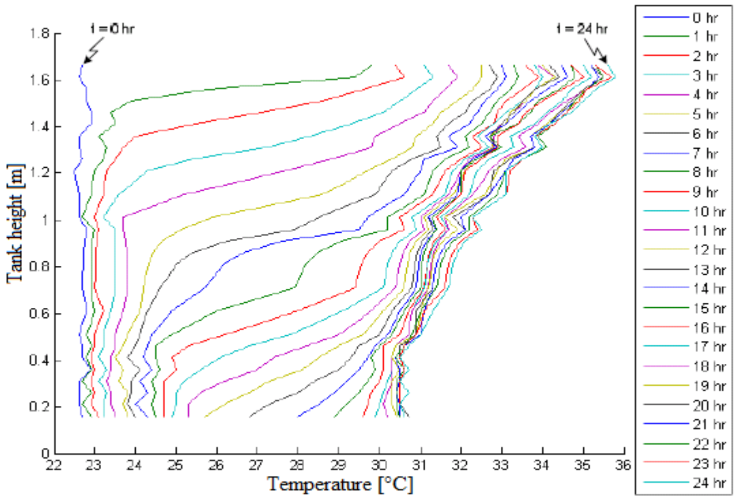

Figure 6. Behavior of isocline along the height of the tank, according Marchi Neto (2007)

Table 1. Physical Properties

	Water		R-134a		
	Temperature [°C]	c_p [KJ/kg K]	Temperature [°C]	Pressure [MPa]	h [KJ/kg]
Input shell and tube	24,7	4,18	48,2	0,8764	284,24
Output shell and tube	29	4,18	33,2	0,8718	96,49

From the values of Table (1), using Eq. (4) and the data obtained for the flow of heated water Fig (3), calculate the flow of refrigerant R-143a, to which was obtained a value of 0,0001 kg/s.

5. **CONCLUSIONS**

The results obtained in this work, can conclude that increasing the thermal load of the cooler also increases the flow of water heated by the amount of heat dissipated. Increasing the temperatures of the circulating water through the reservoir, increasing the efficiency of thermal stratification of the water by the second law of thermodynamics.

The new proposed condensation, or by entering the hull exchanger shell and tube condenser to conventional supplies both a normal system usage as in the case where the storage is fully charged, not interrupting the condensation of the refrigerant gas.

For future projects can be developed themes such as commercial feasibility of the new condensing system. Also, it can be studied the possibility of greater control over the dynamics of flow of the refrigerant according to the proposed new condenser.

6. ACKNOWLEDGEMENTS

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