

Techno-economic Assessment of a Domestic Refrigerator with Aluminium-based Suction Line and Capillary Tube

Ankit¹, Anil Kumar^{2,3,*}

Abstract

The present work reports the experimental performance evaluation of aluminum suction line-based domestic refrigerators. Furthermore, it compared domestic refrigerators with conventional copper capillary tubes and suction lines using R600a as a refrigerant. Performance parameters: energy consumption, ice-making time, and pull-down time was reduced significantly compared to conventional copper suction and capillary tube. Refrigerants having Ambient temperature for ice making test and pull down were initially set at 43°C and that for rated energy consumption test was at 32°C. For ice making test, the test thermostat was set in such a manner that stable operating conditions were obtained in the coldest position before starting the test. For the rated power consumption test, the refrigerator has to run on no load condition and the temperature of the evaporator does not exceed $5 \pm 0.5^\circ\text{C}$ at the geometric center. Power consumption was reduced by 7.24%, Ice making time was reduced by 6.27%, and Pull downtime was reduced by 6.39% using an aluminum-based suction line and capillary tube. 68.49% reduction in the cost of aluminum-based capillary tubes and suction lines was observed. All the performance tests were done in a testing chamber at particular conditions. This research work will be helpful to the researchers in developing a new low-cost model of the domestic refrigerator without degrading the quality.

Keywords: Domestic refrigerator, capillary, copper, aluminum, suction

INTRODUCTION

The most widely used domestic refrigerator type works on the vapor compression refrigeration cycle (VCRS) principle. For food preservation domestic refrigerator is an essential appliance. Today, most domestic refrigerators use R600a as a refrigerant, as R600a has low ozone potential depletion and low global warming potential. In refrigerators, a capillary tube is a fixed restriction device used as an expansion valve in a domestic refrigerator. The pressure drop through the capillary tube is mainly due to friction of fluid viscosity and acceleration due to the flashing of liquid refrigerant into vapor. Given refrigerant pressure drop is inversely proportional to the bore diameter and directly proportional to the length of the capillary tube [1]. Thus, low pressure in VCRS helps in achieving lower evaporator temperature.

*Author for Correspondence

Anil Kumar
E-mail: anilkumar76@dtu.ac.in

¹Student, Department of Mechanical Engineering, Delhi Technological University, Delhi, India

²Associate Professor, Department of Mechanical Engineering, Delhi Technological University, Delhi, India

³Additional Coordinator, Centre for Energy and Environment, Delhi Technological University, Delhi, India

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Edison et al. [2] experimentally studied and developed an effective suction gas heat exchanger for the hermetically sealed compressor. Water is taken as a coolant for a single-tube counterflow heat exchanger. When the inlet temperature is low compressor consumes less work as superheating losses are less. Using a heat exchanger energy consumption value is 12% less than without a heat exchanger within a time frame of 90 minutes. Density, mass flow rate, and volumetric efficiency increase by using a heat exchanger. The required refrigeration temperature is achieved in less time by using a suction heat exchanger.

Therefore, the liquid suction heat exchanger greatly impacted the mechanical refrigeration system investigated by Mahmood [3] theoretically. Using a liquid suction heat exchanger COP can be improved and enhanced by up to 20% based on operating conditions. Refrigerating or cooling effects using R600a were recorded high when used in modified and non-modified systems. Khalsa et al. [4] employed an evaporative heat exchanger of helical type before a hot wall condenser, which can be used to defrost water evaporation. This reduces superheated refrigerant temperature and condenser load to improve the overall performance. Using evaporative cooling run time of the compressor was reduced by 10.6% and energy consumption was reduced by 7.3%.

Similarly, Sathawane et al. [5] experimentally concluded the effect of suction and discharge line evaporative cooling using a wood fiber and coconut coir to cover the suction line, which acts as an insulator to reduce the temperature of refrigerant going into the compressor that reduces the specific volume and work required by the compressor. The performance was evaluated for pull-down load and found using a cool pad and wood fiber. On both suction and discharge lines, evaporative cooling saved time by up to 12% in the system and increased energy saving by up to 14%.

Recently, some researchers experimentally studied capillary tube length. Pathak et al. [6] experimentally studied the effect of capillary tube diameter and configuration on the performance of a simple vapor compression refrigeration system. The data shows that the diameter of the capillary decreases the evaporator temperature. Telang et al. [7] experimentally studied the effect of the capillary tube in different lengths and configurations on the performance of simple VCRs. The data shows that the maximum mass flow rate is for a straight capillary tube, refrigerating effect is maximum for a helical coiled capillary tube because the helical coiled capillary tube takes the least space and the straight capillary tube takes maximum space. Therefore, COP increased by increasing the length of the capillary tube.

Rajput et al. [8] studied the flow of refrigerants through a capillary tube. The domestic refrigerator used a capillary tube of diameter 0.5 mm to 2.0 mm and length 2 m to 6 m. The capillary tube is bonded with a suction line using wrapping, increasing the refrigerating effect. Flow is adiabatic inside the capillary tube as long as the refrigerant is in a liquid state and as flashing occurs, the temperature falls rapidly. Flashing causes the total energy to be converted into kinetic energy.

Since India has a tropical climate, refrigerators in India experience higher condensation temperatures and lower evaporation temperatures. The environment temperature is about 43°C, according to ISO standards, condenser temperature up to 64°C and evaporator temperatures lower than -20°C are experienced for different charges and capillary tubes [9].

Gowd et al. [10] concluded the pull-down test, COP, and load consumption and found that R436a, a mixture of hydrocarbons (R290a and R600a), has better performance characteristics.

Currently, limited literature is available for the direct replacement of copper suction and a capillary with aluminum suction and capillary. In the present study, an attempt has been made to experimentally optimize the performance of domestic refrigerators using R600a as a refrigerant. The best advantage of using aluminium suction and capillary is that it is cost-effective and helps reduce the overall cost of the refrigerator. Rated energy consumption, ice-making time, and pull-down time were reduced using aluminium suction and capillary. This experiment is believed to play an important role in developing a low-cost model refrigerator.

MATERIAL AND METHOD

System Description

Figure 1 shows an experimental test rig that uses R600a as a refrigerant for single-door household refrigerator with a total capacity of 200 L. The property of Refrigerant is discussed in Table 1. The

experiment consists of the thermostat, deep freezer, chiller tray, hermetically sealed reciprocating compressor, air-cooled condenser, aluminum and copper suction tube, and aluminum and copper capillary tube. Initially, copper suction and capillary were used for conducting ice-making and pull-down tests. and measuring energy consumption. For better performance Aluminium suction and capillary were used and the same test was conducted for Aluminium too. Several thermocouples were used to calibrate the temperature inside the freezer section, chiller compartment, fresh food compartment, and crisper zone. The capillary outlet is attached to the evaporator; the refrigerant starts flowing. The test setup was located at the test condition during experimentation, as shown in Figure 1.

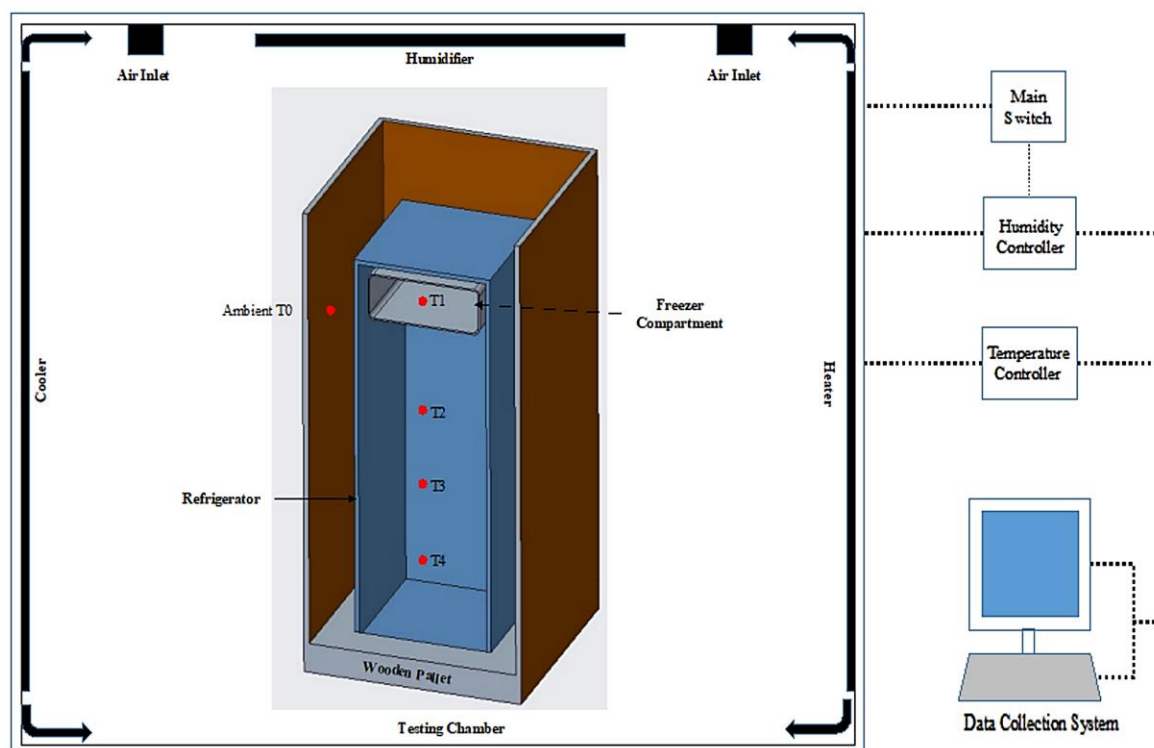


Figure 1. Schematic view of test rig.

Table 1. Property of refrigerant

Name of refrigerant	Critical pressure (MPa)	Critical temperature (K)	ODP (Yes/No)	GWP
R600a	3.63	407.81	No	4

Conventionally Copper was used in suction and capillary in the domestic refrigerator (Figure 2). Now, Aluminium is used in suction and capillary in the domestic refrigerator (Figure 3). The use of Aluminium decreases the cost of production and increases overall performance. Domestic refrigerator consists of the following parts for experiments:

1. Compressor
2. Condenser
3. Dryer
4. Capillary tube
5. Drip tray
6. Capillary soldered with suction
7. Evaporator with evaporator panel

Initially, the vacuum pump was used for evacuation; refrigerant R600a was fused into the system. BEE standards were taken as a reference for conducting energy consumption tests.

Ice-Making Test

The purpose of the Ice-making test is to check the ice-making capability of the refrigerator. For this process, the temperature is maintained at an ambient temperature that is $+43^{\circ}\text{C}$. After attaining stable operating conditions, the test was continued till freezing time. The thermostat was set in such a manner that stable operating conditions were obtained in the coldest position before starting the test. Water filled up to 5 mm from the top in ice and placed in the evaporator. Figure 4 (a, b) shows the thermocouple attached to different compartments for ice making and pull down test.



Figure 2 Copper Suction and capillary.



Figure 3 Aluminium Suction and Capillary



(a)



(b)

Figure 4. Thermocouples attached at different compartments for ice-making and pull-down test

Pull Down Test

For pull-down test experiments, the compartment doors of the cabinet were kept open, and it remained electrically disconnected at an ambient temperature of $+43^{\circ}\text{C}$ for at least 8 h immediately before the start of the test. During the test, all refrigeration systems control like a thermostat, automatic defrost control, etc. were electrically disconnected or inactivated to ensure the compressor should perform continuously. If the motor overload protector (OLP) is provided, it should not be

inactivated or disconnected. After soaking, the cabinet door was kept closed and the pull-down time required for the mean cabinet air temperature was measured from +43°C to +7°C. Test duration is 6 hours continuous run after soaking refrigerator for 8 hours at 43°C. The refrigerator run at 230 V, 50 Hz supply

Rated Energy Consumption Test

The purpose of the rated energy consumption test is to measure the energy consumption value comparatively for the refrigerator operating under identical conditions for the refrigerators made by different manufacturers. For the rated energy consumption test, the ambient temperature was maintained at +32°C in the standard test room [10]. The refrigerator ran on no load condition and the temperature of the evaporator was not exceeded by $5 \pm 0.5^\circ\text{C}$ at the geometric center. After the stabilized conditions were reached, energy consumption was measured for 6 hours. Uncertainties for testing conditions are discussed in Table 2.

Table 2. Uncertainties for testing condition

Parameter	Uncertainty
Chamber Temperature	$\pm 0.5^\circ\text{C}$
Relative humidity	$\pm 0.5\%$
Voltage	$\pm 0.5 \text{ V}$
Frequency	$\pm 0.5 \text{ Hz}$
Pressure of Refrigerant	$\pm 0.13 \text{ psi}$ (for Evap. outlet)
Temperature of refrigerant	$\pm 0.5^\circ\text{C}$
Compressor run%	$\pm 0.3\%$
Energy meter reading	$\pm 0.001 \text{ kWh}$
Amount of water evaporated	± 0.03

RESULTS AND DISCUSSION

Rated Energy Consumption

Yearly energy consumption per year in kWh for 200 Liter, 1 Star non-Inverter with Copper suction was compared with aluminium suction. Copper is a better conductor than aluminum, thus having better thermal and electrical conductivity and lesser resistance. Using ohm law $V = IR$, as the voltage is the same and resistance offered by copper is lower than aluminum, copper offers more current. Using equation $P = I^2R$, I denotes current and R denotes resistance. The value of I is more for copper than aluminium suction and capillary. Thus, power consumption is more when copper is used. It was found that Copper suction consumes 244.6 kWh/year while energy consumption for Aluminium suction is 226.88 kWh/year (Figure 5). It was observed that 7.244% of total energy could be saved using Aluminium suction instead of copper suction.

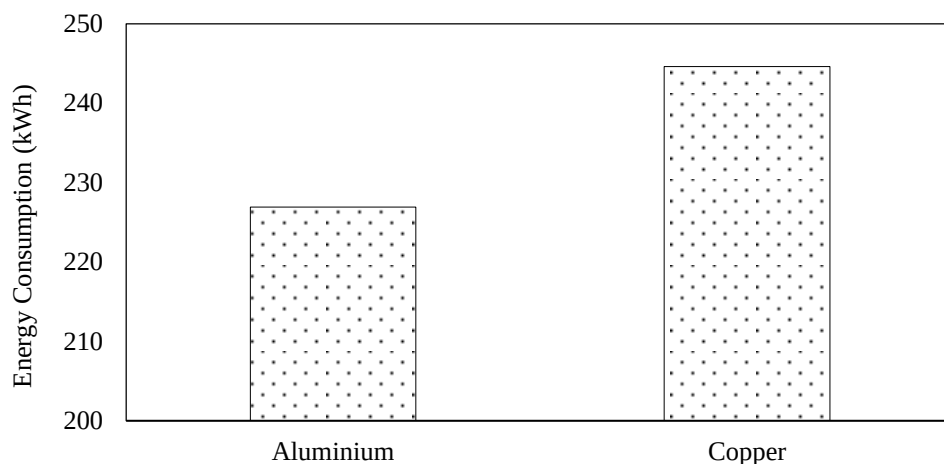


Figure 5. Variation in energy consumption in kWh per year for Aluminium and Copper.

Ice-Making Time

Ice-making time for 200 liter, 1 Star Non-Inverter with Copper suction compared with Aluminium Suction. The inside temperature of -5°C was achieved in 96.54 minutes for copper suction and 90.48 minutes for Aluminium suction. Thus, 6.06 minutes or 6.27% of the time was saved for achieving a lower temperature of -5°C . Machine run time was 90 minutes; voltage maintained at approximately 230 V with approximately 0.43 ampere current supply. Necessary conditions were maintained while performing experiments. Variation in ice-making time in minutes for Aluminium and Copper is presented in Figure 6.

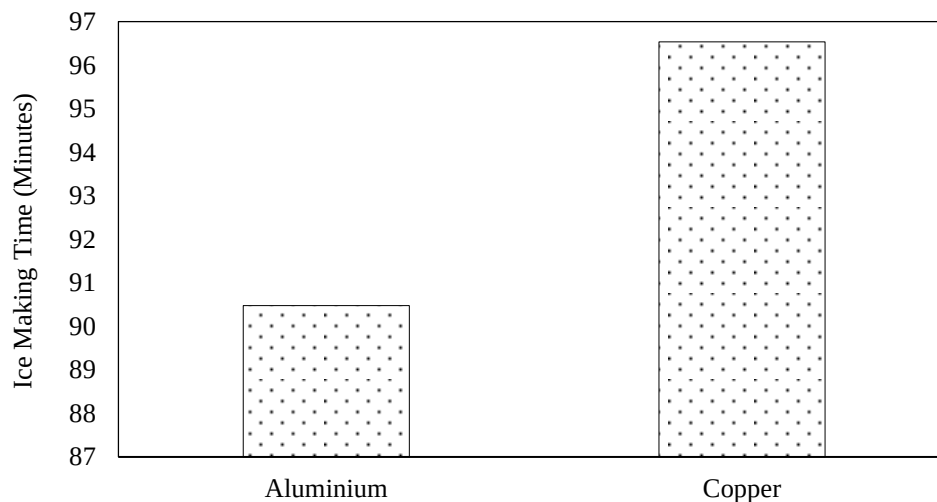


Figure 6. Variation in ice-making time in minutes for Aluminium and Copper.

Pull Down Time

Pull-down test conducted for 200 Liter, 1 Star Non-Inverter with Copper Suction and Aluminium suction whose test conditions are mentioned in the test procedure. Pull-down time for the freezer compartment at -8°C of copper suction was 111.1 minutes. Pull down the temperature for the freezer compartment at -8°C was 104 minutes. Figure 7 shows the variation in the pull-down time in minutes for aluminum and copper.

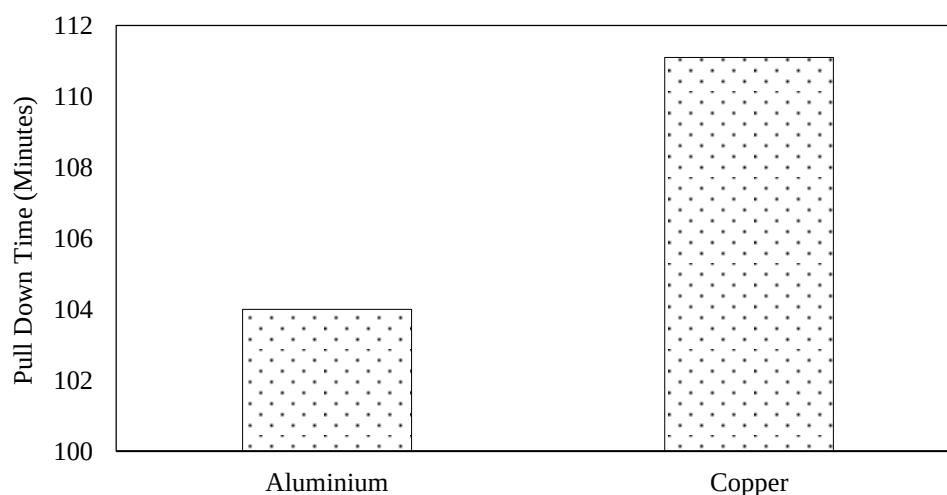


Figure 7. Variation in the pull-down time in minutes for Aluminium and Copper.

Cost Analysis

Cost is one of the crucial factors throughout the project. Market conditions, procurement methods, and planning capability are one of the most significant factors affecting cost and quality. The

procurement cost of Aluminium and Copper is Rs 235 per kg (\$3.04) and Rs 745.8 (\$9.65) per kg, respectively. Thus, the total cost reduction is 68.49%, which helps the project save costs. Figure 8 shows the variation in cost for Aluminium and Copper.

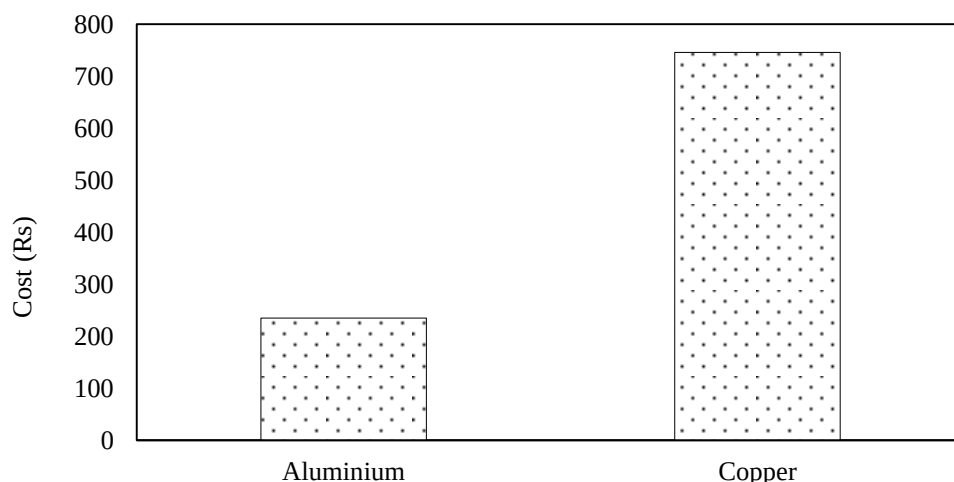


Figure 8. Variation in cost for aluminum and copper.

CONCLUSIONS

This work is intended on domestic refrigerator modification, which utilized the techno-economic effect on the domestic refrigerator. The use of Aluminium suction and capillary enhanced the performance of the refrigerator. Based on experimental results, conclusions can be drawn as follows:

- Electricity can be saved by using Aluminium suction instead of copper suction and power consumption is reduced by 7.24%
- In the freezer compartment, ice can be prepared in a shorter period. Thus, the use of an aluminium suction line reduces ice-making time by 6.27%.
- Pull-down time for the given refrigerator also decreased by using aluminium suction. Thus, saving 6.39% of the time by using aluminum suction.
- The total reduction in expenditure by replacing copper suction and capillary with aluminum suction is 68.49%. From the perspective of life cycle costs, copper and aluminum are both seen as providing equal options.

The research work will instruct in developing a new low-cost model of domestic refrigerators and will help enhance the overall performance.

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