Performance Analysis of a Domestic Refrigerator in Malaysia using Experimental Method

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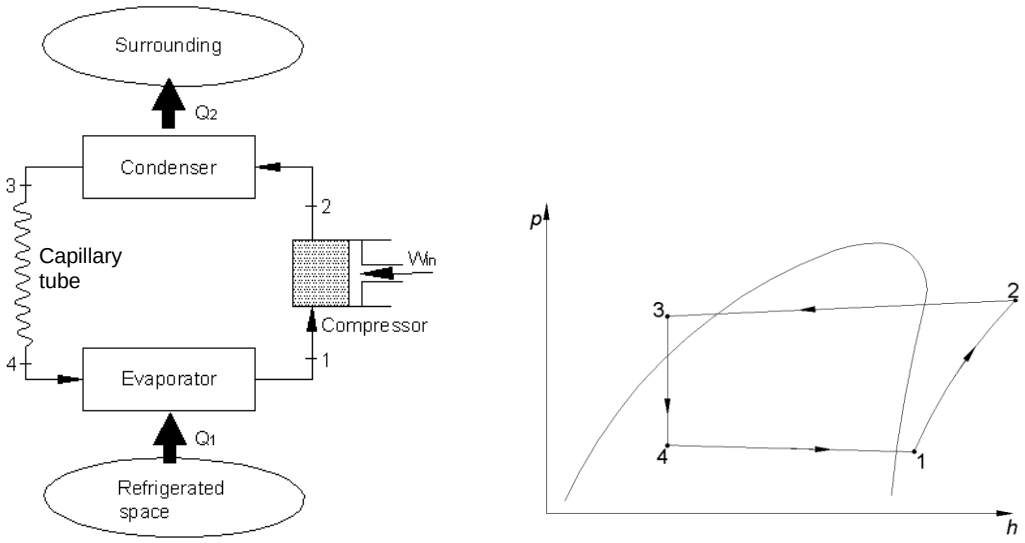
Abstract — Refrigerator is one of the home appliance utilizing mechanical vapour compression cycle in it process. Performance of the system becomes main issue and many researches are still ongoing to evaluate and improve efficiency of the system. Therefore, this paper presents the development process of refrigerator test rig and performance evaluation of a domestic refrigerator that has been used in Malaysia. The experiment platform which called test rig was developed from refrigerator model NRB33TA National brand. The main objective in this study was to obtain performance of the refrigeration system in term of Coefficient of Performance (COP) by determining three important parameters during in operating mode which are temperature, pressure and refrigerant flowrate. In the test rig, all temperature probes were connected to thermocouple scanner to measure temperature at particular points on the refrigeration system. Pressure gauges were used to measure pressure and a magnetic flowmeter was used to measure refrigerant flowrate. In order to avoid effects of a changing the measured data, the environmental of testing was controlled according to Association of Home Appliance Manufacturers (AHAM) standard. There are five sets of experiment data were collected in order to evaluate the COP of the refrigerator. Each data was collected for a cycle of operation in about 2 hours. The result shows that the average COP of the refrigeration system using the refrigerator test rig was about 2.7.

Keyword: *Refrigerator Test Rig, Refrigeration Cycle*, COP

1. INTRODUCTION

Refrigerator is a cooling appliance comprising a thermally insulated compartment and a refrigeration system to produce cooling effect to the insulated compartment. Meanwhile, refrigeration is define as a process of removing heat from a space or substance and transfers that heat to another space or substance. Nowadays, refrigerators are extensively used to store foods which deteriorate at ambient temperatures; spoilage from bacterial growth and other processes is much slower at low temperatures.

In refrigeration process, the working fluid called refrigerant employed as the heat absorber or cooling agent. The refrigerant absorbs heat by evaporating at low temperature and pressure and remove heat by condensing at a higher temperature and pressure. As the heat is removed from the refrigerated space, the area appears to become cooler. The process of refrigeration occurs in a system which comprises of a compressor, a condenser, a capillary and an evaporator arranged as depicted schematically in Figure 1(a).



(a) **(b)**

Figure 1. (a) Schematic diagram of refrigeration system (b) *p-h* diagram of vapour compression cycle

Compressor is a mechanical device to compress and pump the refrigerant vapour from a low-pressure region to a high-pressure region. The condenser is a device for removing heat from the refrigeration system. Then the capillary tube controls the refrigerant flow from the condenser to the evaporator and separates the system to high-pressure and low-pressure sides. The evaporator is a device for absorbing heat from the refrigerated space into the refrigeration system by evaporating the refrigerant (Jordan and Priester, 1985).

To accomplish the heat removing process from the refrigerated space, a system called refrigeration plant is created and the plant works in a thermodynamic cycle which obeys Second Law of Thermodynamic and based on vapour compression cycle as shown in Figure 1(b). There are two main parameters that were considered in this study; refrigeration capacity and coefficient of performance. The refrigeration capacity, $\dot{Q_{in}}$ is defined as the amount of heat absorbed by a unit mass of refrigerant in the evaporator. The refrigeration capacity can be obtained using equation below.

$$\dot{Q}_{in} = \dot{m}(h_1 - h_4) \text{ Watt} \qquad (1)$$

The coefficient of performance (COP) is a measure of efficiency of the refrigerator. The COP of a domestic refrigerator is the ratio of the refrigeration capacity, $\dot{Q_{in}}$ to the energy supplied to the compressor, *P*. It can be expressed by equation below (Dincer, 2003).

$$COP = \frac{\dot{Q_{in}}}{P} = \frac{\dot{m}(h_1 - h_4)}{\dot{m}(h_2 - h_1)} \qquad (2)$$

The values of enthalpy *h* are determined by using NIST Refrigerant Properties Database based on relationship between temperature and pressure data from experiment.

Currently, refrigerator is used widely around the world and this appliance become necessity for household. The performance of the refrigerator is very efficient but the researches still ongoing to optimize the system. Thus, the performance study of the refrigeration system in Malaysia is one of the efforts to discover performance of the refrigerator.

2. METHODOLOGY

Methodology of this work is concentrated on two important things that need to be developed in order to investigate the performance of the domestic refrigerator which is location of measurement points and it devices, and experiment set-up.

2.1 Development of Location of Measurement Points

Refrigerator test rig was developed in order to investigate the performance of the system. Figure 3 shows the photograph of the refrigerator model that was used in the study. In developing the reliable refrigerator test rig, consideration should be highly addressed especially the development method, measurement locations of pressure and temperature. These are very important to ensure that the test rig can produce reliable data. To accomplish this, the author referred to the several technical papers related to the study. Previously, (Pannock et al., 1994: Philipp et al., 1996: Mc keller & Tree, 1988: Melo & Pereira, 1988) discussed the development of refrigerator test rig. They discussed the locations of temperature and pressure measurement points, measurement devices and measurement methods. As a result, a refrigerator test rig was developed as shown in figure 4. There are eight points of temperature measurement, four points of pressure measurement and one point of flow rate measurement.

From the eight points of temperature measurement, six points have been placed inside the refrigeration circuit to measure refrigerant temperature and another two points have been placed in refrigerator compartments. The same number of points and locations were adopted by (Pannock et al., 1994: Philipp et al., 1996: Mc keller & Tree, 1988: Melo & Pereira, 1988) who followed several standards such as ANSI/AHAM HRF-1-2008 (AHAM, 2008) and European standard for measuring the energy consumption of electric mains operated on household refrigerators (DIN EN 153) (Philipp et al., 1996). The thermocouple wire (ASHRAE, 1986) was used to measure the temperature of refrigerant in the tube. The technique to measure the temperature is the same as (Philipp et al., 1996), whereas the thermocouple wire was put inside the refrigerant tube so that the measurement made was exactly the temperature of the refrigerant. Figure 2(a) shows the method to construct the temperature measurement point in the refrigerant tube.

By applying this method, a suitable length of ¼” copper tube with flared end as shown in Figure 2(a-i) was used to hold a thermocouple wire which was inserted into the tube and effectively sealed, as shown in Figure 2(a-ii). The flared tube is fitted securely on to a copper T-junction which was then joined mechanically to the tube to reconnect every two consecutive components (Langley, 1982). The temperature of the refrigerant which now flowed through each T-junction was measured by the hot thermocouple junction or head, as shown in Figure 2(a-iii).

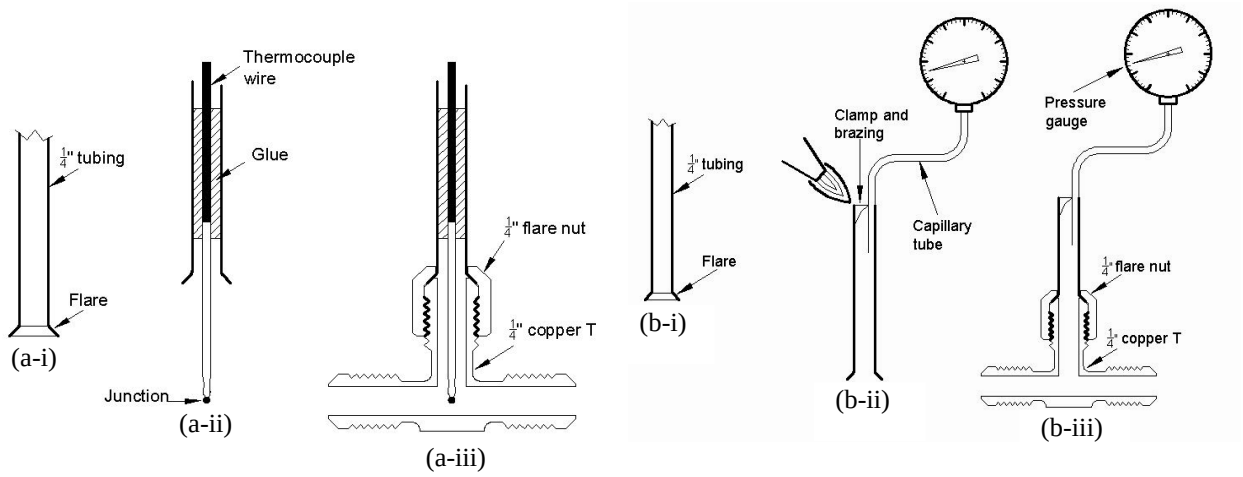


Figure 2. a) Construction method of temperature measurement point and b) Construction method of pressure measurement using Bourdon type pressure gauge

Besides that, four points of pressure were tapped respectively made on pipes connecting all main components. Experimental works of (Pannock et al., 1994: Philipp et al., 1996: Melo & Pereira, 1988) only measured suction and discharge pressures of compressor while the present works allowed pressure drops across each component and along connecting pipes to be known as well as (Jones, 2001: ASHRAE, 2001). Bourdon Tube pressure gauges (ASHRAE, 1989: ARI, 1998) were used for each pressure measurement in this test rig. A tube with diameter 2.1 mm was used to connect the refrigerant tube to each pressure gauge as what was done by (Philipp et al., 1996). Figure 2(b) shows the detail construction of the pressure measurement points. In this work also, a metal tube flowmeter with magnetic coupled indicator was used. This flow meter was manufactured and calibrated by Brooks Instruments. The flowmeter was assembled between condenser and capillary tube to measure the refrigerant flowrate in liquid form.

2.2 Experiment Set-up

The experiment was conducted conventionally by taking all of data manually. The all eight points of thermocouple wire were connected to T-type mini plugs and these plugs were connected to the thermocouple scanner. Thermocouple scanner is a device to read the measured temperature. The time interval between consecutive scans was five minutes and printing was done immediately. Besides that, the pressure gauges were fitted on a panel. The data was collected manually every five minutes and at the same time when the temperature of each point was recorded by the printer. The flowmeter which was connected to the pipe between condenser and filter dryer was fixed to the panel next to the pressure gauges. The data was read manually through visualization and recorded every five minutes. Figure 3 shows the illustration of above discussion. There are five set of data were recorded from five experiments in order to investigate the performance of the refrigerator.

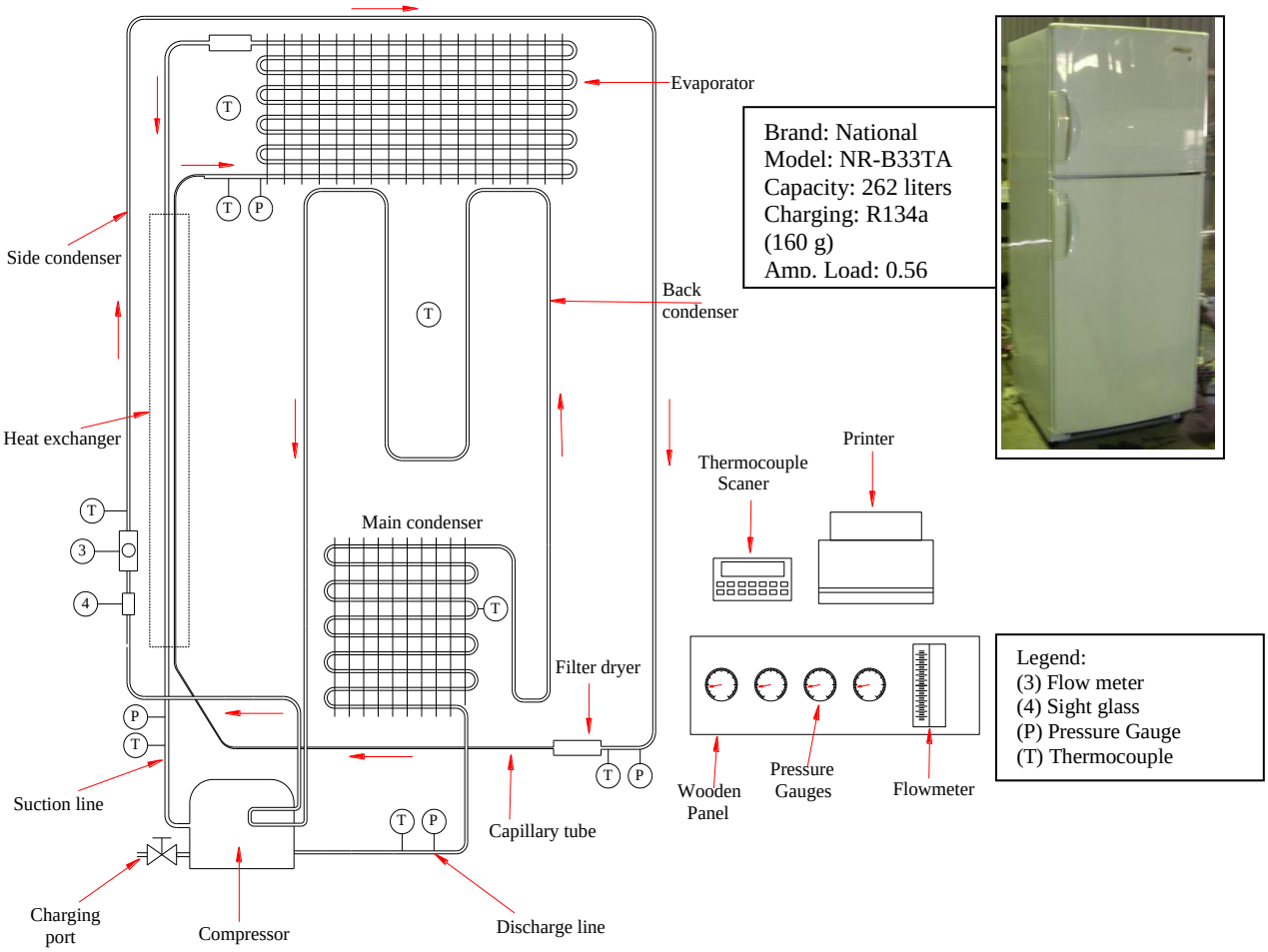


Figure 3. Schematic diagram of test rig and experiment set-up

3. RESULT AND DISCUSSION

There are three important parameters that were recorded which are temperature, pressure and refrigerant flowrate. The data were analyzed according to the theory of refrigeration system and the result is tabulated in Figure 4 and Figure 5.

3.1 Refrigeration Capacity

Refrigeration capacity is determined using equation 1. Figure 4 shows graph of the refrigeration capacity versus time for the all data. The graph shows a general trend at the first 5 to 10 minutes operation. In the period of time the refrigeration capacity is significantly high and then decreases towards almost constant value. Experiment 5 (Exp. 5) is more stable than others that was around 208 W to 263 W. This was caused by the setting of temperature level in the freezer compartment which influenced the values of the refrigeration capacity.

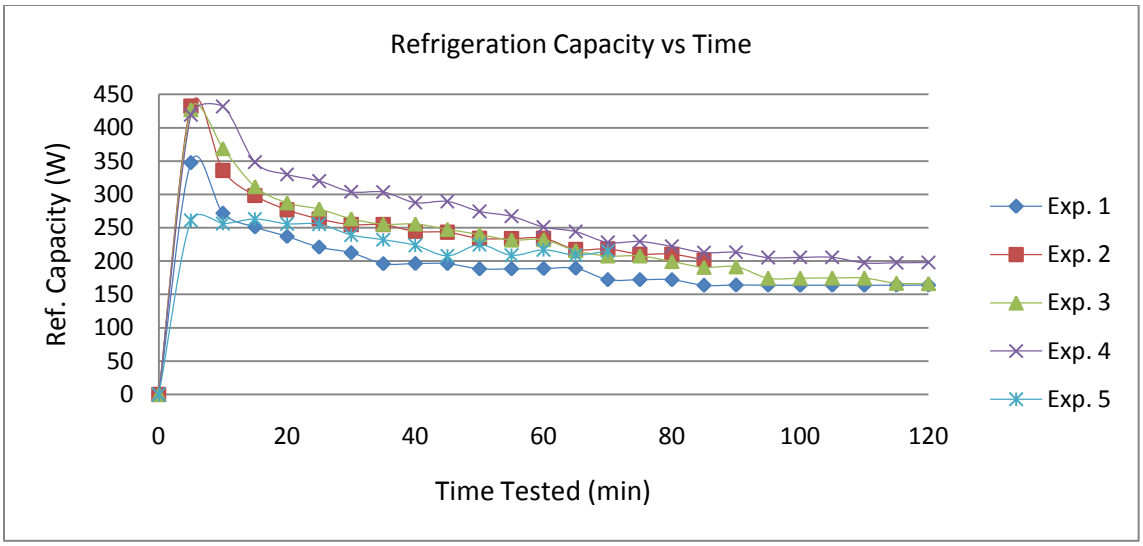


Figure 4. Graph refrigeration capacity versus time

3.2 Coefficient of Performance

Coefficient of performance (COP) was calculated using equation 2 and Figure 5 shows the graph of COP versus time. Referring to the figure, the COP values are higher at the beginning of each test run, and then it was achieved the steady state condition after 10 minutes of running. The variance between each dataset was due to the condition of test such as quantity of refrigerant charged or initial pressure, initial cooling load, ambient temperature and humidity all of which could not be set constant. However, the differences became smaller at the end of each test run.

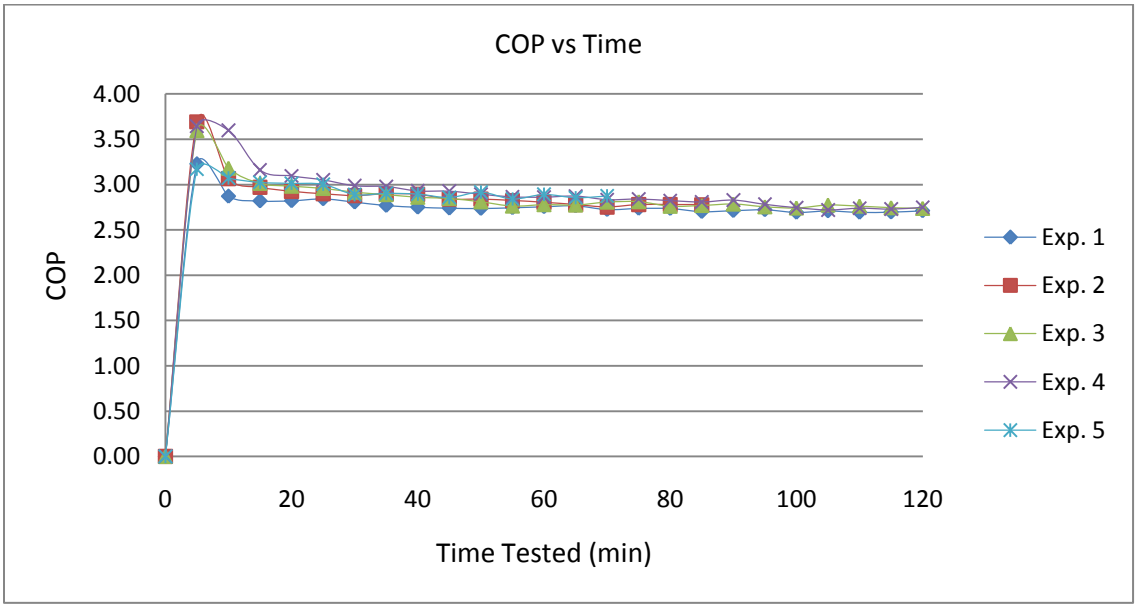


Figure 5. Graph COP versus time

4. CONCLUSION

Performance of the domestic refrigerator was investigated with indicator of COP was about 2.75 and refrigeration capacity was ranging from 150 watt to 205 watt. Besides that, test rig development method that has been presented in this work was plays important role in order to investigate the performance of the refrigerator. The correct data from experiment can be produced from a reliable test rig as such presented and the method must be parallel with high skill of work and reliable measurement devices.

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