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PERFORMANCE ANALYSIS OF A DOMESTIC REFRIGERATOR

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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 analysis of a domestic refrigerator. 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 Refrigeration Capacity, Compressor work and 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 three sets of experiment data were collected in order to evaluate the refrigerator performance. Each data was collected for a cycle of operation for 2 hours. The result shows that the average COP of the refrigeration system using the refrigerator test rig was about 2.7.

Keywords: Refrigerator Test Rig, Refrigeration Cycle, Refrigerator Performance

INTRODUCTION

Refrigerator is a cooling appliance comprising a thermally insulated compartment and a refrigeration system is a system to produce cooling effect in 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 in refrigerator that has low temperatures. In refrigeration process, the working fluid employed as the heat absorber or cooling agent is called refrigerant. 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.

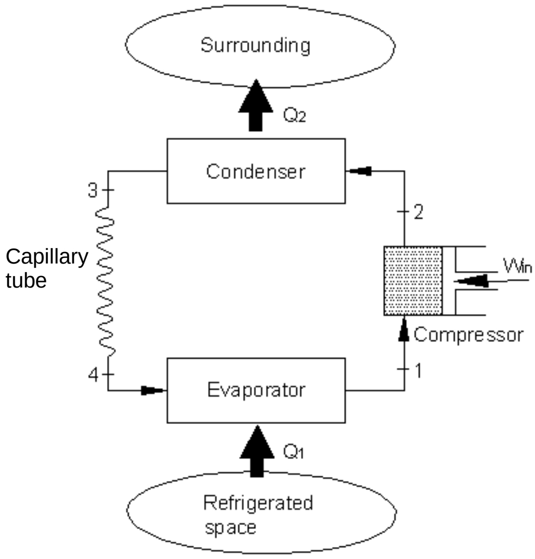

Figure 1: Schematic diagram of a refrigeration system

Compressor is a mechanical device to compress and pump the refrigerant vapour from a low-pressure region (the evaporator) to a high-pressure region (the condenser). The condenser is a device for removing heat from the refrigeration system. In the condenser, the high temperature and high-pressure refrigerant vapour transfers heat through the condenser tube wall to the surrounding. When the temperature of the refrigerant vapour reaches the saturation level, the latent heat is released causes condensation process and the refrigerant vapour changes it phase into liquid form. 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, Whitman et al., 2000).

To accomplish the process of the heat removing 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. The refrigeration plant used in the present work is called refrigerator. Currently, the refrigerator is used widely around the world and this appliance become necessity for household. Performance of a modern refrigerator is very efficient but the research still ongoing to optimize the system. In fact, the same system would produce different performance if it is operated in different countries especially between tropical climate countries and countries with four climate seasons. Performance study of the refrigeration system in the present work is one of effort to discover performance of the refrigerator by analyzing three important parameters which are refrigeration capacity, compressor work and coefficient of performance (COP).

THEORY OF REFRIGERATION SYSTEM

It has been mentioned before that the refrigeration is defined as the process of removal of heat from a region or state or a substance to reduce and maintain its low temperature and transferring that heat to another region, state or substance at higher temperature. The refrigeration process that employed in the domestic refrigerator is based on a vapour compression cycle as shown in Figure 2 and collaborated with Figure 1. There are three main parameter that were considered in this study; compressor power, refrigeration capacity and coefficient of performance (COP).

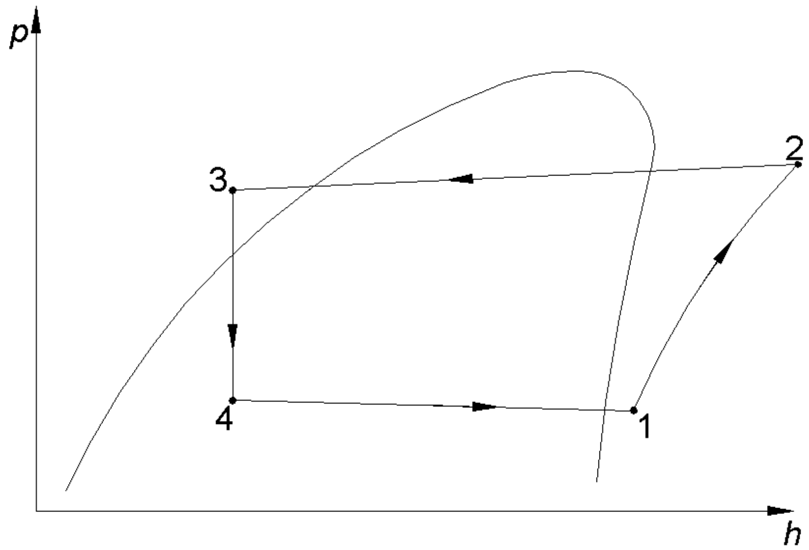

Figure 2: *p-h* diagram of vapour compression cycle

Process line from 1 to 2 represents compressor power. Compressor power is defined as the power needed to do the compression process in watt. The compressor power is determined by multiplying enthalpy change across the compressor to the mass flowrate, thus,

$$P = \dot{m}(h_2 - h_1) \tag{1}$$

Meanwhile, process from point 2 to 3 represents heat rejection through condenser. The amount of heat rejected is not significant in the present study. Process from point 3 to point 4 shows throttling effect through capillary tube whereby the working pressure of refrigerant will be reduced from discharge pressure to suction pressure. Refrigeration capacity, which is represented by process line 4 to 1, is defined as the amount of heat absorbed by a unit mass of refrigerant in evaporator. The refrigeration capacity can be obtained using equation below:

$$\dot{Q}_{in} = \dot{m}(h_1 - h_4) \tag{2}$$

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 to the energy supplied to the compressor. It can be expressed by equation 3 (Dossat, 1978; Dincer, 2003).

$$\text{COP} = \frac{\dot{Q}_{in}}{P} = \frac{\dot{m}(h_1 - h_4)}{\dot{m}(h_2 - h_1)} \tag{3}$$

The value of enthalpy h is determined by using NIST Refrigerant Properties Database based on relationship between temperature and pressure data from experiment that has been done.

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.

Development of Location of Measurement Points

Refrigerator test rig was developed in order to investigate the performance of the system. In developing the reliable refrigerator test rig, consideration should be highly addressed especially the development method and 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 had referred to several technical papers related to the study. Previously, Pannock, J *et al.* (1994), Philipp, J *et al*. (1996), Mc keller and Tree, D.R (1988) and Melo, C and Pereira, R. H (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, J *et al.* (1994), Philipp, J *et al*. (1996), Mc keller and Tree, D.R (1988) and Melo, C and Pereira, R. H (1988) who followed several standards such as ANSI/AHAM HRF-1988 (AHAM 1988) and European standard for measuring the energy consumption of electric mains operated on household refrigerators (DIN EN 153). The thermocouple wire was used to measure the temperature of refrigerant in the tube (ANSI/ASHRAE Standard, 1986). The technique to measure the temperature is the same as Philipp et al (1996), where the thermocouple wire was put inside the refrigerant tube so that the measurement made was exactly the temperature of the refrigerant. However, the method to construct the sensor was different. Figure 3 shows the method to construct the temperature measurement point in the refrigerant tube.

By using this method, A suitable length of ¼” copper tube with flared [10] end as shown in Figure 3(a) was used to hold a thermocouple wire which was inserted into the tube and effectively sealed, as shown in Figure 3(b). 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. 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 3(c). Prior to installation each thermocouple was calibrated using a platinum thermocouple against temperature of freezing point, room condition and boiling point of water. Table 1 shows the three sets of data with different conditions of water used during calibration. The thermocouple used was of T-type, 0.3 mm diameter and designed for temperature range between -50°C to 250°C. The accuracy is about ±2%.

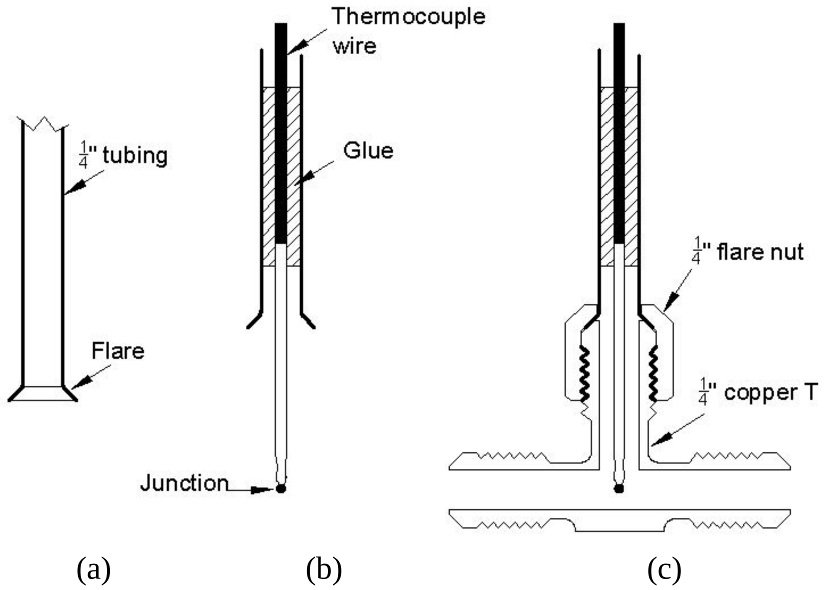

Figure 3: Construction method of temperature measurement point

Table 1: Calibration data of thermocouple points

Thermocouple Type / No.	**Temperature Measurement**		
	Freezing	**Room**	**Boiling**
Platinum	0°C	20.1°C	99.4°C
No. 1	-0.3°C	20.1°C	99.1°C
No. 2	-0.2°C	19.9°C	99.3°C
No. 3	-0.2°C	20.0°C	99.2°C
No. 4	-0.2°C	20.1°C	99.2°C
No. 5	-0.2°C	20.0°C	99.1°C
No. 6	0°C	20.1°C	99.1°C
No. 7	-0.1°C	20.0°C	99.2°C
No. 8	-0.1°C	20.1°C	99.1°C

Besides that, four points of pressure were tapped respectively made on pipes connecting all main components. Experimental works of Pannock, J *et al.* (1994), Philipp, J *et al.* (1996), and Melo, C and Pereira, R. H (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 (Jones, 2001, ASHRAE, 2001). Bourdon Tube pressure gauges were used for each pressure measurement in this test rig (ANSI/ASHRAE Standard, 1989, ARI 1998). A tube with diameter 2.1 mm was used to connect the refrigerant tube to each pressure gauge as what was done by Philipp. Figure 4 shows the detail construction of the pressure measurement points.

In this work 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 in g/s. A sight glass was installed before the flowmeter to observe the liquid phase of the refrigerant. When there were no bubbles observed the flow was taken as that of a fully liquid refrigerant (Eugene, 2002, Jones, 2001).

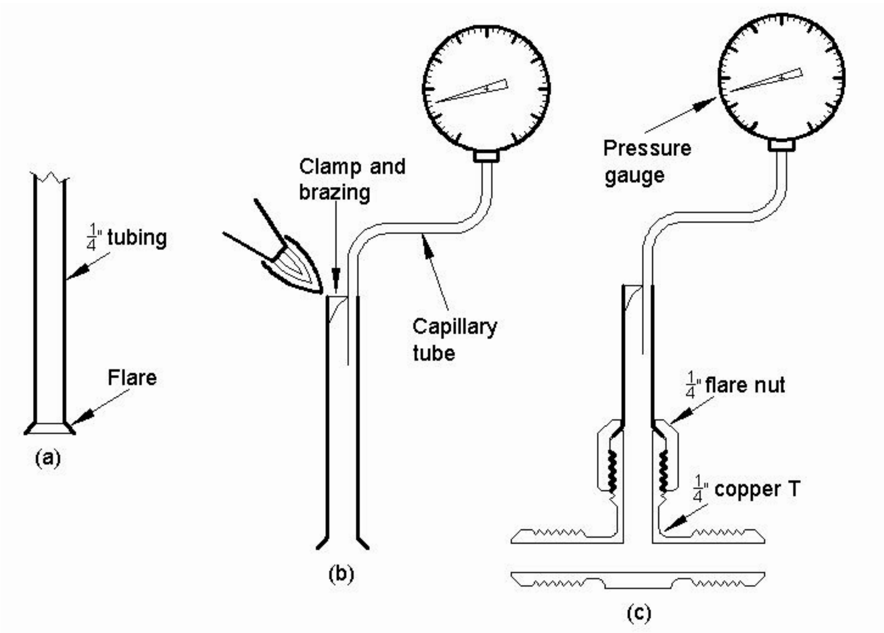

Figure 4: Assembly method of pressure measurement using Bourdon type pressure gauge

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. Four pressure gauges were used and were respectively installed before and after each main component as discussed in previous section. All of these pressure gauges were fitted on a wooden panel to ensure that the gauges did not vibrate during testing. 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 a wooden panel next to the pressure gauges. The data was read manually through visualization and recorded every five minutes. Figure 5 shows the illustration of above discussion. There are three set of data were recorded from three experiments in order to investigate the performance of the refrigerator. The setting condition for each experiment is shown in Table 2.

Table 2: Setting condition for each experiment

Exp. No.	Time	Ambient Temp.	Atm. Pressure	System Temp. Setting	System Initial Pressure
Exp. 1	10.03	29.3	1.018	medium	4.5 Bar
Exp. 2	09.21	28.5	1.018	medium	4.8 Bar
Exp. 3	09.52	29	1.02	medium	5.3 Bar

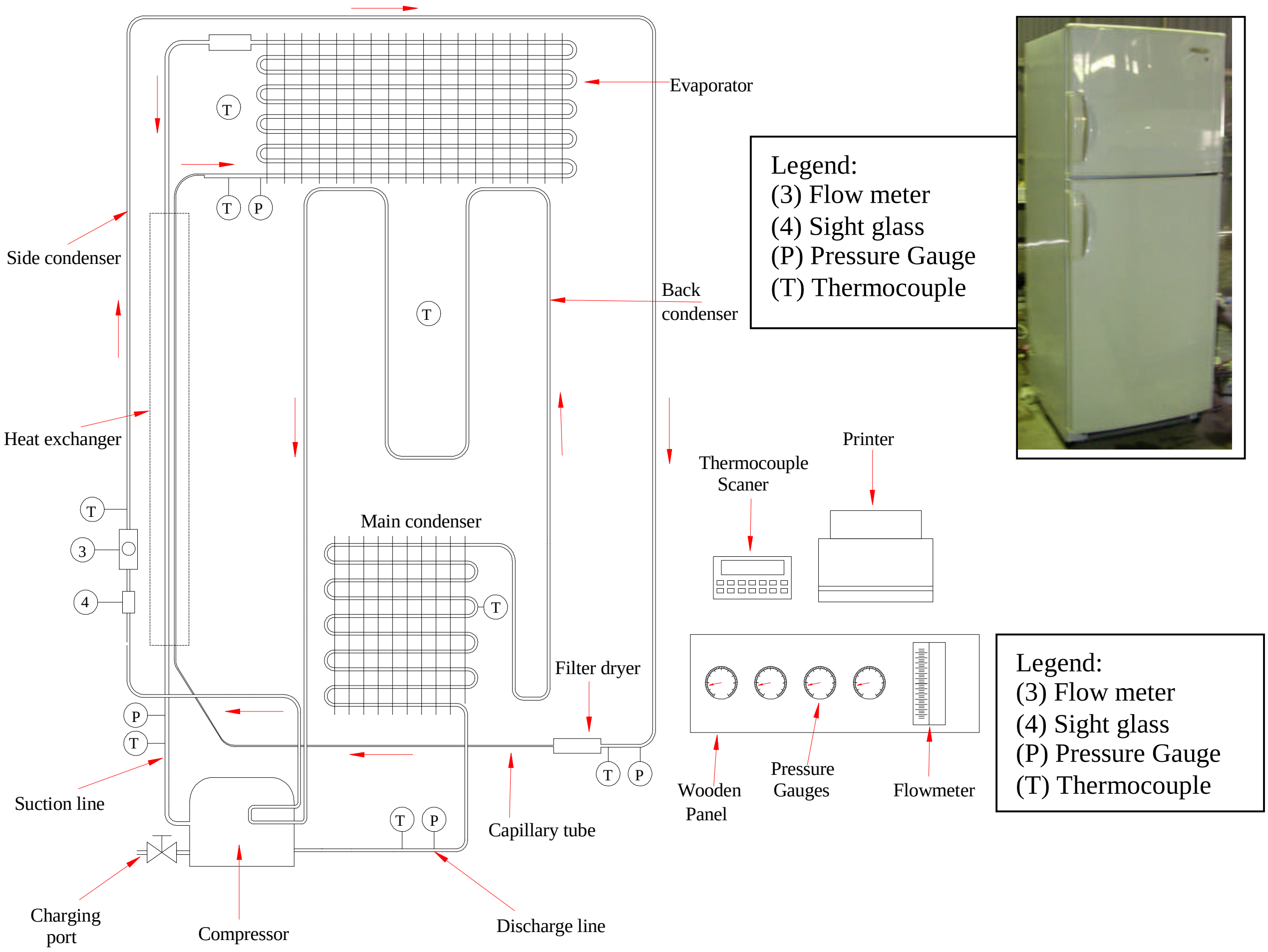

Figure 5: Schematic diagram of test rig and experiment set-up

RESULTS AND DISCUSSION

The experiment was conducted for 3 times in order to evaluate the performance of the domestic refrigerator. There are three important data that were taken which is temperature, pressure and refrigerant flowrate. The data were analyzed according to the theory of refrigeration system and the result is tabulated in Figure 6 until Figure 8. Since the objective of this work was to investigate the COP of the domestic refrigerator, therefore it's also closely related to refrigeration capacity and compressor power produced by the system.

Refrigeration Capacity

Refrigeration capacity is determined using equation 2. Figure 6 shows graph of the refrigeration capacity versus time for the all data. The graphs show 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. Data 5 is more stable that is 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. The refrigeration capacity depends partly on the mass flow rate and partly on the enthalpy difference which depends on the temperature setting of the freezer compartment. Hence, at certain temperature setting greater mass flowrate is required to absorb more heat from the freezer compartment.

Compressor Work

Figure 7 shows graph of compressor work for 120 minutes of test run. The value is determined by using Equation 1. The graph shows that the curve for experiment 1 is the lowest compared to the other curves. Although the curve for experiment 2 is started higher than curve for experiment 1, but it shows decrement in it trend until at time 115 minute of test run the value of compressor work is the same with experiment 1. This situation also is the same trend with graph curve for experiment 3. Author can say that at one time, this three graph curve will have the same value of compressor work although at different charge of refrigerant amount.

Coefficient of Performance

Coefficient of performance (COP) was calculated using equation 3 and figure 8 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.

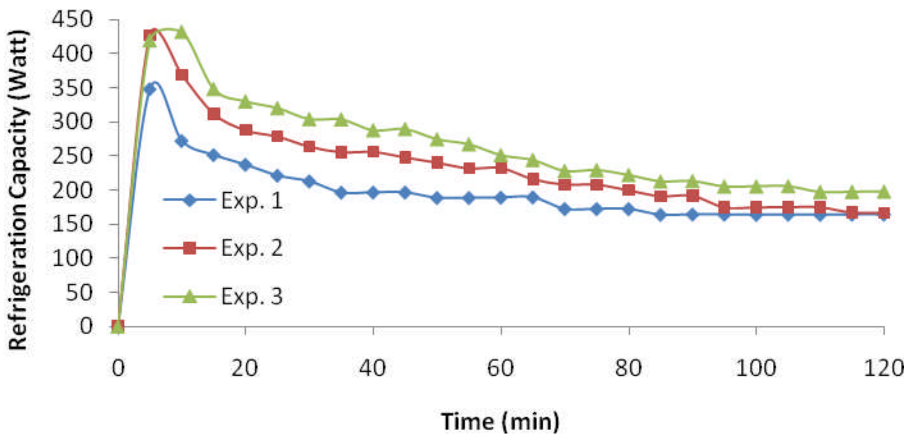

Figure 7: Graph refrigeration capacity versus time

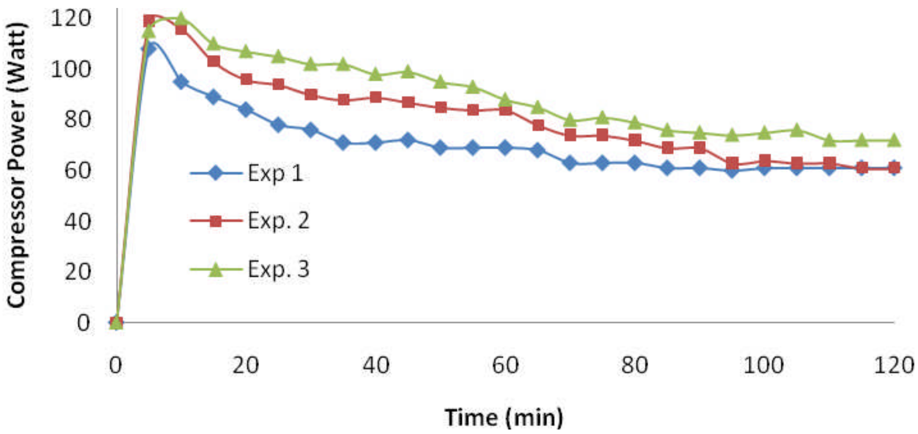

Figure 8: Graph compressor power versus time

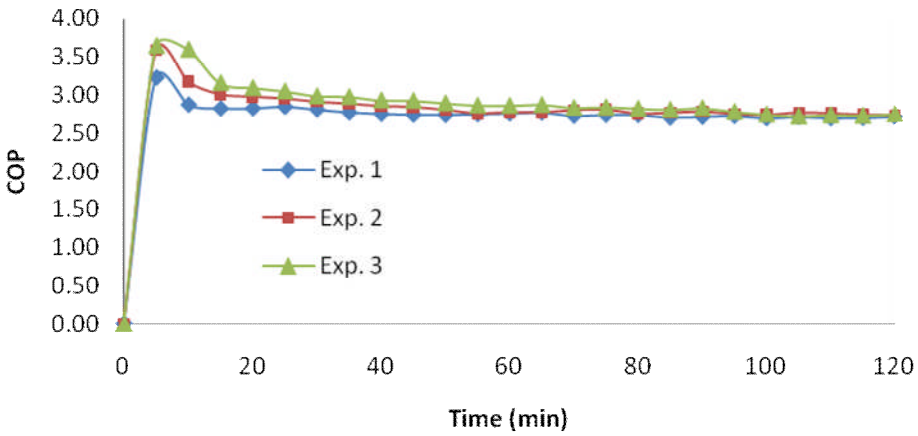

Figure 9: Graph COP versus time

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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REFERENCES

Air Conditioning and Refrigeration Institute (ARI) (1998). "*Refrigeration and Air Conditioning*." 3rd edition. Prentice Hall, USA.

American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). "*2001 ASHRAE Handbook CD*." 1.12.

ANSI / ASHRAE Standard (1986). "*Standard Method for Temperature Measurement*." Atlanta: (ANSI / ASHRAE 41.1-1986 (RA 2001).

ANSI/ASHRAE Standard (1989). "*Standard Method for Pressure Measurement*." Atlanta: (ANSI / ASHRAE 41.1-1986 (RA 2001).

Dincer, I. (2003). "*Refrigeration System and Application*." John Wiley & Sons Ltd, England.

Dossat, R. J. (1978). "*Principles of Refrigeration*." John Wiley & Sons, New York.

Eugene, Silberstian (2002). "*Heat Pump*." Thomson Delmar Learning, United State.

Jones, W. P. (2001). "*Air Conditioning Engineering*." 5th edition. Butterworth Heinemann, Britain.

Jordan, R. C. and Priester, G. B. (1985). "*Refrigeration and Air Conditioning System*." 2nd edition. Prentice-Hall of India Private Limited, New Delhi.

McKellar, M. G. and Tree, D. R. (1988). "Steady State Characteristics of Failures of a Household Refrigerator." *Preprints of the 1988 Purdue – International Refrigeration (IIR) Conference*. West Lafayette, Indiana: IIR, 1988. 257 – 265.

Melo, C. and Pereira R. H. (1988). "Steady State Characteristics of Failures of a Household Refrigerator." *Preprints of the 1988 Purdue - International Refrigeration (IIR) Conference*. West Lafayette, Indiana: IIR, 1988. 98 – 106.

Pannock, J., Liu, Z., Radermacher, R. and Yu, K. (1994). "Evaluation of R-134a And R-152a as Working Fluids in a Domestic Refrigerator / Freezer." *ASHRAE Transaction: Symposia, Volume 100, Part 1*. ASHRAE Inc. 1344 – 1350.

Philipp, J., Kraus, E. and Meyer, A. (1996). "Presentation of a Test Rig To Record Mass Flow Rate, Pressures and Temperatures of a Household Refriherator During On/Off Cycling Mode." *Proc. of the 1996 International Refrigeration Conference at Purdue.* West Lafayette, Indiana: IIR, 1996. 477 – 482.

Whitman, C. W., Johnson, W. M and Tanczyk, J. A. (2000). "*Refrigeration and Air Conditioning Technology*." 4th edition. Delmar Thomson Learning, USA.