Experiment of Thermal Insulation Performance of Acrylic and Expanded Polystyrene for Chamber Wall

Q Laliyah1,*, P Bakti1, and W S Ramadhani1

Research Center for Quality System and Testing Technology Indonesian Institute of Science, Puspiptek Region Building 417, Setu, Tangerang Selatan, Banten, Indonesia - 15314

*E-mail: quds001@lipi.go.id

Abstract. Chamber with the controlled temperature is required in the energy efficiency test of a household product. Chamber wall plays an important role to keep the temperature inside the chamber so as not to be affected by the temperature from outside. Experiments were carried out to compare the thermal performance of two different material for chamber wall: 1) Acrylic and 2) expanded polystyrene. The boxes with dimension 40 x 40 x 40 cm were affected with fixed thermal loads in a climatic chamber. Meanwhile, temperature inside the box was monitored with data logger. The thermal loads for testing were 40°C, and 60°C. Based on the measurement, temperature in the acrylic box reach the load temperature from the outside and starts steady at 300 seconds, while the expanded polystyrene at 550 seconds. The result show that the insulating performance of expanded polystyrene is better than acrylic. The result of this study can be used not only for refrigerator manufacture, it can also use by another industry related to thermal dynamic. The industries include aeronautic industry related to aircraft wall coatings for external temperature protection, building industry in terms of building wall coatings to maintain temperature stability, and other related industries.

1. Introduction
In Indonesia, according to electricity statistics 2016 the use of electrical energy for the household sector ranks first at 43.35% followed by the industrial sector 31.5%, the business sector and the public respectively 6.55% [1]. The dominant use of electricity in the household sector is partly due to the increasing number of households from year to year. In addition, the increase in middle-class economy households has led to increasing use of electricity-based household appliances including air conditioners, ballast lamps, water pumps, refrigerators, fans, televisions, rice cookers, irons and washing machines. Responding to these conditions, it is deemed necessary to conserve energy. One of the efforts to support energy conservation is by implementing mandatory standards for energy labeling for household electrical appliances.

Refrigerator is one of the household electrical appliances which is the biggest contributor to the use of electrical energy, especially for the price class R1-450VA and R1-900VA [2]. In 2013 the Indonesian government through the BRESL program had targeted the labeling of energy for refrigeration products [3]. To support the labeling energy program, it is necessary to prepare the test laboratories in developing standard testing methods to provide a standard guide for uniform testing methods and can be repeated to measure the characteristics of an equipment [4]. Especially for refrigerators, the international standard referred to the energy consumption testing process is IEC 62552: 2015, Household Refrigerating appliances - Characteristics and Test methods. Based on these standards [5], testing the refrigerator's energy consumption must be carried out in a room with an ambient temperature of 32°C + 0.5°C (for tropical regions).
In order to fulfill the energy efficiency testing procedure of refrigerator, it is necessary to provide chamber with controlled temperature. Chamber wall plays an important role to keep the temperature inside the chamber so as not to be affected by the temperature from outside. Miskinis et al [6] presented in their paper how (expanded polystyrene and mineral wool) thermal insulation and coating (plaster) layers of ETICS (External Thermal Insulation Composite System) influence on sound and thermal insulation of a basic element (wall). The experimental results showed that added mineral wool thermal insulation layer of ETICS increases sound insulation up to 4dB, but in using EPS (Expanded Polystyrene) has no significant influence. The addition of a coating (plaster) layer over the thermal insulation material layer allows an increase in sound insulation in both cases from 3 dB to 7 dB, but does not change the thermal insulation. The addition layer of EPS thermal insulation increases thermal insulation of the basic wall up to 4.88 m²K/W and up to 5.09 m²K/W with mineral wool. The influence on sound insulation depends on the type of thermal insulation material used, the presence or absence of a coating (plaster layer) and its thickness. While the influence on thermal insulation only depends on the presence of the thermal insulation layer. Khoukhi [7] investigated the effect of the operating temperature on the thermal conductivity of polystyrene insulation material using the developed experimental apparatus based on the guarded hot plate principle. The result showed that the k-value is affected by the change in operating temperature. The result also showed that the lower material density is, the higher is the thermal conductivity.

In this study researchers tried to find out the thermal performance for acrylic and expanded polystyrene, the selection of both materials is based on the ease of getting it, cheap, and easy to install. Measurements in this study are limited to the material's response of heat from outside. From these measurements it is expected to be able to know which insulator material is better to be applied in the manufacture of a refrigerator energy efficiency test chamber. The result of this study can be used not only for refrigerator manufacture, it can also used for another industry related to thermal dynamic. The industries include aeronautic industry related to aircraft wall coatings for external temperature protection, building industry in terms of building wall coatings to maintain temperature stability, and other related industries.

### 2. Material and Method

#### 2.1. Material

Acrylic with a thickness of 2 mm and expanded polystyrene with a thickness of 5 cm was selected in this research. Acrylic and polystyrene glue needed to make the boxes. The sample test used is boxes from acrylic and expanded polystyrene with dimension 40 x 40 x 40 cm.

To measure temperature of boxes, a type K of thermocouple with wire diameter of 0.3 mm was used. Meanwhile, data logger used to monitoring the temperature. Measurement were carried out in a climatic chamber to control the ambient temperature.

![Figure 1. Sample box with dimension 40 x 40 x40 cm](image.png)
2.2. Method
Experiments were carried out to compare the thermal performance of two different material for chamber wall: 1) Acrylic and 2) expanded polystyrene. To identify thermal performance the boxes with dimension 40 x 40 x 40 cm were affected with fixed thermal loads in a climatic chamber. Meanwhile, temperature inside the box was monitored with data logger. The thermal loads for testing were 40°C, and 60°C. Sample boxes are inserted into the chamber when temperature of chamber already constant as same as a temperature load. A thermocouple type K for measure the temperature installed on the center of sample boxes and on center of outer and inner wall chamber as shown in Figure 1. Measurements were carried out for 3600 seconds. Temperature changes can be seen from the graph of measurement results. Based on the resulting graph can be analysed of thermal performance of each insulator material.

3. Results

3.1. Ambient Temperature
The ambient temperature during the measurement, which lasted for 3600 second, is shown in Figure 2.

![Figure 2. Graph of ambient temperature inside chamber during the measurement](image)

Figure 2 shown that the ambient temperature have a small fluctuations during constant temperature period on the regulation system of the climate chamber. The regulation was on during all the measurement. This temperature profile is chosen to represent the temperature required by the refrigerator efficiency energy test standard [5,8].

3.2. Acrylic Temperature Change
Thermocouple are installed on an acrylic box on three different places. The temperature on acrylic box was monitored with data logger.

![Figure 3. Graph of Temperature in three different places on acrylic (a) at 40°C, (b) at 60°C](image)
Temperature inside the acrylic box both on a wall and in the center of the box are shown in Figure 3. The graph shows that both on 40°C and 60°C, external heat can propagate quickly into the box through an acrylic wall. When the thermal load is 60°C, the heat propagation takes a short time to reach steady state at 60°C. Judging from the results, acrylic cannot hold thermal load from the outside properly.

3.3. Expanded Polystyrene Temperature Change
Same as in acrylic box, thermocouples are installed on the expanded polystyrene on three different places. The monitored temperature as shown in Figure 4.

![Figure 4](image_url)

Figure 4. Temperature graph in three different places on expanded polystyrene (a) at 40°C (b) at 60°C

Similar to the results on acrylic, figure 4 show that heat propagation in expanded Polystyrene requires less than 3600 seconds to reach steady state. Judging from the Figure 4, there is a difference in the heat transfer time on the outer wall and inside of the box. Outer wall of expanded polystyrene has a rapid rise in temperature before steady state. Meanwhile, temperature inside the box rises slowly before reaching steady state.

Comparison between Figure 3 and Figure 4 reveals that the difference between two insulator materials is not significant because the steady state conditions are achieved in less than 3600 seconds and the steady temperature is the same as the ambient temperature. However, from the graph in Figure 5 show that the heat propagation on the expanded polystyrene wall takes longer to get the steady state at the same temperature as the ambient temperature.

![Figure 5](image_url)

Figure 5. Graph of Temperature on the center of boxes (a) at 40°C, (b) at 60°C

Wall of thickness and average thermal conductivity are effect to heat transfer. The thicker wall will reduce heat transfer, while the greater the thermal conductivity, the greater the heat transfer will occur [8]. Based on the graph of measurement results, expanded polystyrene can hold the heat better than
acrylic, this can be caused by three factors. Firstly, due to the expanded polystyrene sample used has a thicker wall thickness. Secondly, expanded polystyrene has a lower thermal conductivity than acrylic. Thermal conductivity of expanded polystyrene is 0.03 W/m.K and thermal conductivity of acrylic is 0.2 W/m.K [9]. Thirdly, expanded polystyrene contains up to 98% of its volume of tiny closed bubbles of air which inhibit the passage of heat or cold [10].

There is a study conducted by Lakatos (2014) related to this study. The material used is expanded polystyrene with different qualities, namely EPS 30, EPS 100, EPS 150, and EPS 200. The result of that study is that the longest delay can be reached with the use of EPS 200. It has relatively big material constants and small thermal conductivity compared to other insulators. So, in order to reach a long retardation time, small thermal diffusion coefficient is needed. It can be reached by relatively small thermal conductivity and with big material constants [11].

4. Conclusion
Thermal performance of materials insulation for chamber wall has been investigated in this study. Based on the measurement, insulating performance of expanded polystyrene slightly better than acrylic. Wall of thickness, average thermal conductivity of materials and its closed cell structure which filled with air are effect to the thermal performance of insulation material.

References
[1] Electrical Power Statistics 2016. Directorate General of Electricity of the Ministry of Energy and Mineral Resources. Edition No. 30 Year Budget 2017.
[2] Energy Efficiency and Elasticity Planning 2012. Balai Besar Teknologi Energi, Badan Pengkajian dan Penerapan Teknologi
[3] http://www.id.undp.org/content/indonesia/en/home/operations/projects/environment_and_energy/barriers-removal-to-the-cost-effective-development-of-energy-eff.html accessed on September 29th 2017 at 4.16pm
[4] Mahlia T M I, Masjuki H H and Choudhury I A 2002 Theory of energy efficiency standards and labels Energy Convers. Manag. 43 743–761
[5] International Electrotechnical Comission (IEC) 2015. IEC 62552-1 Household Refrigerating appliances - Characteristics and Test methods
[6] Miskinis K et al 2018 Influence of EPS, mineral wool and plaster layers on sound and thermal insulation of a wall: a case study Applied Acoustic 137 62-68
[7] Khauki M 2016 Change of the Thermal Conductivity of Polystyrene Insulation in term of Temperature at the Mid Thickness of the Insulation Material: Impact on the Cooling Load. Word Academy of Science, Engineering and Technology International Journal of Mechanical and Mechatronics Engineering 10 5
[8] Yunus A Cengel. Heat Transfer A Practical Approach. Textbook. Second Edition
[9] The Engineering Toolbox. Thermal conductivity of Common Material and Gases. https://www.engineeringtoolbox.com/thermal-conductivity-d_429.html accessed on September 15th 2018 at 10.20pm
[10] Poletto M Junior L O and Zattera A J 2014 Expanded Polysterene: Thermo-Mechanical Recycling, Characterization and Application in Polystyrene: Synthesis, Characteristics and Applications, New York, Nova Publishers 53-74
[11] Lakatos A 2014 Comparison of the Thermal Properties of Different Insulating Materials Advanced Materials Research 899 381-386