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EVALUATION OF THERMAL INSULATION OF THE RIGID POLYURETHANE FOAM FILLED WITH GLASS POWDER

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Abstract. *Thermal insulation is used in surface protection heated or cooled by low thermal conductivity material, where the rigid polyurethane foams are most often used. Glass is an insulation, reusable, returnable and recyclable material. The production of rigid polyurethane foam (PUR) composite filled with glass powder GP is a combination of a known insulating polymer matrix with a reinforcement of ceramic material. Based on these respects, the work aimed to check the thermal conductivity of PUR composite filled with 5% wt, 10% wt and 20% wt of GP. These residual GP contents were generated from sieving into thermopanes; and they are separated in two particle size: particles less than 100 μm and particles between 100 μm and 300 μm. The highest values of thermal conductivity were forGP5-300, GP20-100 and GP20-300, while the GP5-100 and GP10-300 presented the smallest levels of thermal conductivity. Thus, these last composites were considered the most insulation materials. Thus, the inclusion of glass powder in the PUR matrix can promote a gain in its thermal properties; there is also a reject applicability of the vitreous, allowing its use as reinforcement in insulator composite foams.*

Keywords: *polyurethane composites, thermal conductivity, thermal insulation, glass powder.*

1. INTRODUCTION

The primary function of an thermal insulator is to reduce the rate of heat transfer between a system and the environment; so that energy can be conserved. For this, parts of the thermal systems must be coated with material that be stable at a given temperature range [Torreira (1980) and Mendes (2002)]. As in the case of pipelines that compose the cold lines, the insulation is necessary to prevent formation of condensate or ice on the surface of the pipeline. The insulating efficiency of a material varies in inverse ratio to its specific weight (RAPIN, 2001).

Torreira (1980) states that to be considered a good thermal insulating, material must have the following characteristics: low thermal conductivity, good mechanical strength, low density, low thermal diffusivity, high specific heat, non-flammability, low coefficient of thermal expansion; chemical and physical stability, resistance to environment of specific use, low hygroscopicity, no odor and low cost.

According to Oliveira (2010), the acoustic and thermal properties of PUR foam are related to the microstructure. The rigid foams have a microstructure with closed cells, which confine the air in its interior; flexible foam is composed of open cells allowing air flow between the pores. According Kipper (2008), rigid foams have a rigid structure is highly crosslinked and with closed cell which are responsible for its mechanical properties. Besides, the thermal conductivity of the gas (air), trapped in these closed cells, is the major factor in the insulating properties of the foam, as air is recognized as an excellent thermal insulator.

The use of foam expansion agents (FEAs or blowing agents), with low thermal conductivity, is also an important factor on the thermal conductivity of the PU foams. Thus, a good FEA has low solubility in the polymer matrix and the reagent mixture. This agent presents little tendency to diffuse through cell membranes; thus it can allow the formation of closed cells. The thermal conductivity of the gas decreases with increasing molecular weight, but it increases with the increase of temperature (Vilar, 2007). The main factor affecting the thermal conductivity of the thermal insulation is the thickness of the material; other factors to be considered include the specific weight and cell size of the material, humidity and temperature (Mendes, 2002).

The traditional raw material for the fabrication of PUR foams is the polyol and isocyanate. They cause a large-scale consumption of petroleum (nonrenewable feedstock) whose use may be reduced by combination with other products / fillers (Vilar, 2007). The polyurethane PU is composed of more than 90% air and the remaining is plastic; therefore it is not economically feasible to reuse as a feedstock. Another process that makes it expensive is its landfilling, which explains the large volume occupied due to its low density, as well as their long decomposing time, about 150 years (Siqueira *et al*., 2004).

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The raw materials of foam are from petroleum, not recycling foam, also represents a waste of non-renewable natural resources (Mello *et al*., 2006). Incineration consists in combustion of waste that reduces its volume in landfills. But it has a high cost and, in some cases, it may exhibit high risk because some materials can release harmful gas to the health of the population (Cangemi, 2006).

Glass, non-porous material, was added as filler in the fabrication of PUR foams. It is impermeable to the passage of oxygen or carbon dioxide; and if it is recycled of the trash, it can offer a number of advantages such as lower costs of collection, reducing environmental pollution, growing economy and reducing of consumption of natural resources (Santos, 2009).

In this work was studied the thermal conductivity and its inverse function (thermal insulation) of specimens of pure PUR foams (like standard) and PUR filled with GP in three weight percentages (5 wt%, 10 wt% and 20 wt%) of two particle sizes: less than 100 μm and between 100 μm and 300 μm. Also it was checked if there is correlation between density and thermal conductivity of the PUR specimens and, if they depend on the GP concentration and particle size.

2. MATERIALS AND METHODS

2.1. Process of fabrication of the PUR foams

This work was carried out through the study of seven types of PUR Pure and filled with GP specimens to investigate their thermal insulation through testing of thermal conductivity. The cure time was set at 48 hours (according to NBR 8082/83); and the mixture of PUR and GP was formed into rectangular molds (10 * 7 * 8 cm^3). The 30 PUR specimens filled with GP and the five pure PUR (reference standard) are classified on Table 1, which shows the GP weight percentage and particle size (GP < 100 μm and 100 μm ≥ GP ≤ 300 μm). Each specimen type had five replicates. The PU, purchased commercially, was originated from petroleum, while the GP (trash of the process of faceting glass) was ceded by DVN Vidros LTDA of Natal/ RN.

Table 1. Description of specimens of PUR filled with GP.

Specimen	Description
PUR-Pure	PU foam filled without glass powder
GP5-100	PU foam filled with 5 %wt glass powder, particle diameter 100 μm
GP5-300	PU foam filled with 5 %wt glass powder, particle diameter 300 μm
GP10-100	PU foam filled with 10 %wt glass powder, particle diameter 100 μm
GP10-300	PU foam filled with 10 %wt glass powder, particle diameter 300 μm
GP20-100	PU foam filled with 20 %wt glass powder, particle diameter 100 μm
GP20-300	PU foam filled with 20 %wt glass powder, particle diameter 300 μm

Figure 1 illustrated the process of obtaining of GP and fabrication in lab of specimens, i.e. the manufacture of PUR filled with GP. After the sieving of GP, average particle sizes were measured using CILAS 1180 laser granulometer (0.04 μm – 2,500 μm).

Figure 1. Process fabrication steps of the specimens

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The fabrication process of specimens was summarized in the following stages:

1 - Grinding of the waste glass with the aid of mortar and pistil;
2 - Using the ball mill with alumina balls to reduce the grain size;
3 - The hand sieving to obtain two particle sizes (small and large);
4 - Analysis and classification of the average particle size by laser granulometer;
5 - Preparation of rectangular molds (10 cm x 7 cm x 8 cm) for the fabrication of specimens;
6 - Weighing the reactants A-Polyol and B-Isocyanate (weight ratio 1:1) and, the GP to obtain the specimens of the PUR filled with glass powder using a Bel Engineering precision balance, capacity maximum 1000 g ± 0.001 g, available on the LMF of NTI / UFRN;
7 - Removal of the specimens of the molds.

2.2. Density test

The density of PUR and PUR-GP composite samples was measured based on its weight (in kg) and their volumetric dimensions (in m^3) using a Mitutoyo caliper rule and a Bel Engineering precision balance, maximum capacity 1000 g ± 0.001 g, both are available on the LMF of NTI / UFRN. Three measurements were performed for each sample after 72 hours of production of these samples.

2.3. Themal conductivity test

In the assay of thermal conductivity was used the equipment KD2 Pro, available in the Mecânica dos Fluidos Laboratory of the NTI, the Federal University of Rio Grande do Norte (UFRN). This equipment is used to perform measurement of thermal properties whose sensor HS-1 (thermal double needle) was inserted into the specimen for a time of 2 minutes. This sensor operates in the range 0.02 to 2.00 W/mK. The 12 measurements of thermal conductivity were made of on the six faces of each PUR specimen, as is schematized in Fig.2.

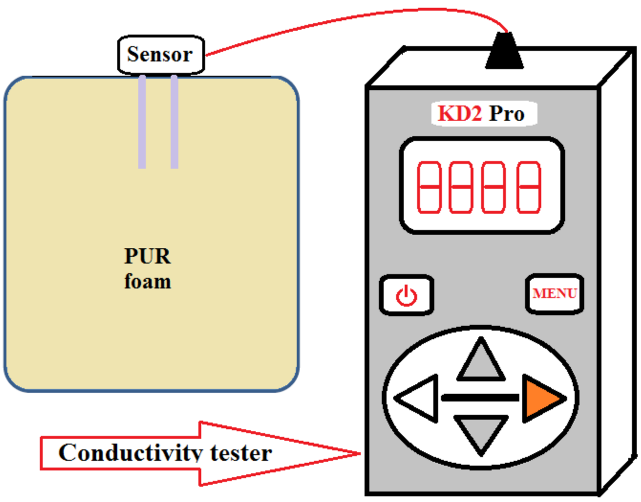
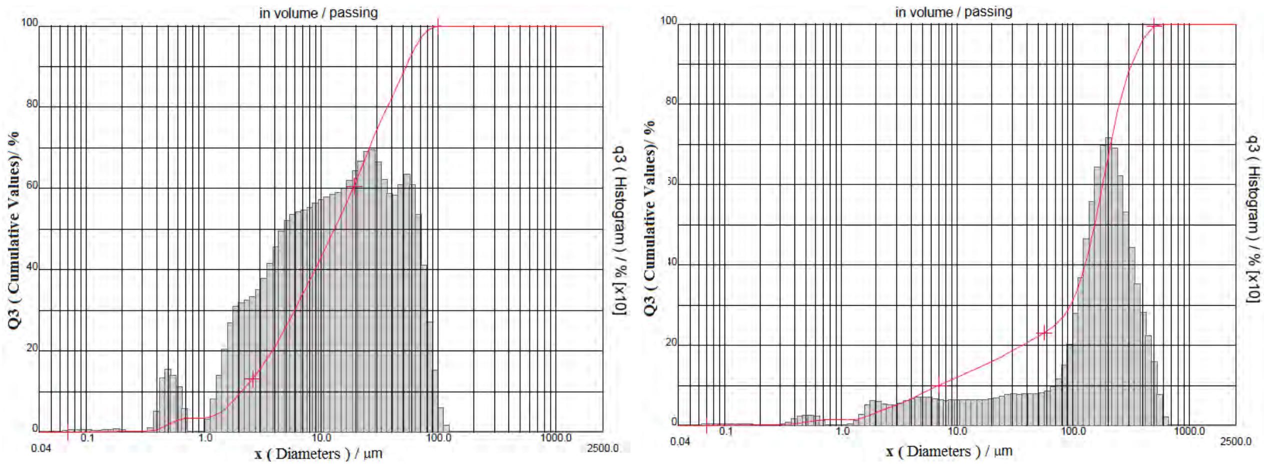


Figure 2. PUR foam specimen tested by KD2 Pro thermal conductivimeter.

3. RESULTS AND DISCUSSION

3.1. Average size of GP particles

The evaluation of the compressive resistance of PUR filled with GP was discussed considering the weight content (5 %, 10 % and 20 %) and size (100 µm and 300 µm) of the GP particles. Figure 3 shows two graphs generated by laser granulometer to evaluate the small and large GP particles.



(a) Small particles (b) Large particles

Figure 3. Histograms of cumulative values to the (a) small and (b) large particles

The particles were classified into average diameters D_{10}, D_{50} and D_{90}, whose measures are cumulative to 10 %, 50 % and 90 % of samples respectively. Thus, the values obtained were here D_{90} 52.80 µm to particles of smaller diameter and 320.45 µm for a larger diameter. Note in these graphs (Fig. 3) that there is a greater dispersion between the values obtained for the smaller particles. This is because during sieving were selected particles <100 µm, whereas in the case of larger particles, their particles were retained in a range between 100 µm and 300 µm. It can be seen that with the passage of GP of 140 mesh (106 µm) and 50 mesh (300 µm) resulted in the agglomeration of these particles between themselves. So, during this test, it was noted that these particles disperse when in contact with water, and the smaller particles were obtained in greater proportion.

3.2. Thermal conductivity and density

Figures 4 and 5 show, respectively, the results of the thermal conductivity and density, which were measured in the PUR specimens filled with GP weight percentages (5 % wt, 10 % wt and 20 % wt). The legends (in abscissa of graphics) indicate the averages and standard deviations of measurements that were carried out at room temperature (24.37 ± 0.54 °C).

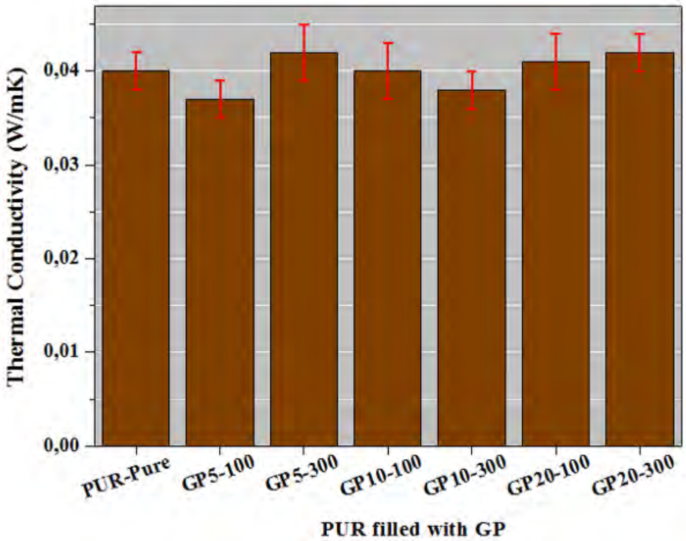


Figure 4. Thermal conductivity of the PUR specimens filled GP

The GP5-100 and GP10-300 composites showed higher thermal insulation than PUR-Pure, like is observed in graphic in Fig. 4, whose thermal conductivity values were lower than the values of PUR-Pure (0.040 W/ mK). The other samples presented thermal conductivity higher than PUR-Pure, ie, these samples presented the worst performance of thermal insulation, mainly the specimens with the lowest GP content, GP5-300. Thirumal *et al.* (2007) observed that

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there was a decrease in thermal insulation with increasing of the concentrations of SiO_2 and $CaCO_3$. This was explained by the shape of the cell structure generated: open and damaged. They also noted that when the GP content was used, the thermal conductivity decreased, but after increased with the increase of its content.

As expected, the density of these composites showed a proportional increase in the PUR with the GP content and the size of the particles increased in the PUR matrix, Fig. 5. Could not notice a strong correlation between the density and thermal insulation. Vilar (2007) reported that the low thermal conductivity of the PUR foam resulted of its low density and its structure small-cell and closed-filled as auxiliary blowing agents (FEAs) such as CFC, CO_2, HCFC's, pentanes, etc. But this study was restricted to the use of no filler PUR, so it was not possible to state the influence of filler on the density and thermal insulation. One should also consider the final thermal conductivity of the foam, factor, k, is determined as function of the contribution with relation to: convection, radiation, thermal conductivity of the gas and the polymer and foam density.

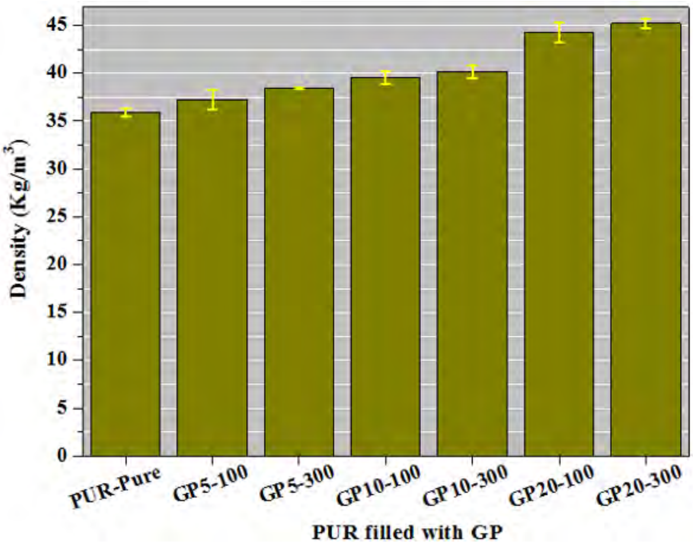

Figure 5. Density of the PUR specimens filled GP

This author also reported on his work that the crosslinked polymer structure with closed cells showed densities ranging from 10 kg/m^3 to 1000 kg/m^3. According to him, the best thermal insulators had densities from 28 kg/m^3 to 50 kg/m^3. The insulation characteristic, based on this density range, is due to the properties of low thermal conductivity (k factor) of gas that they are contained within the cellular structure of the foam. Should the use of the GP content, its chemical composition was the determining factor for the increased density of the composites.

Although all composites of PUR filled with GP did not promoted superior performance of thermal insulation over the PUR-Pure, the use of GP may decrease energy consumption in obtaining feedstock PUR pure and also can be an ecological alternative which assures the recycling of materials for landfills, as is the case of the glass.

4. CONCLUSION

During the experiments it was possible to observe a slight increase in thermal conductivity parallel to the increase in the proportion of adding glass powder and also in an increase in GP particle size. The results showed the lowest thermal conductivity values were obtained for GP5-100 and GP10-300. And the highest values of thermal conductivity were present for GP5-300, GP20-100 and GP20-300.

It was also observed that increasing the GP content promoted an small increase in thermal conductivity values, but it has no great influence on the behavior of the thermal conductivity of the material as a whole, since changes in its value given in the third decimal place and with minor variations. These results ensure that the composite remains studied with similar characteristics to those found in samples of PUR-Pure.

According to the literature review, the addition of particulate polymer matrices are widely used to reduce the cost of production of composites. Since the results obtained from the experiments it can be concluded that the addition of GP content in a matrix of PUR is rather a viable option for reducing the cost of production of PUR foams for thermal insulation purposes. So an option to be strongly considered because the glass powder is from a process where no recycling these wastes, thus bringing significant savings of feedstock production.

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