ROOF INSULATION WITH RICINUS COMMUNIS L. (CASTOR OIL) RESIN FOAM

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Abstract. *On the equatorial zone, one of the most important factors that determine the thermal load inside the edifications is the radiation from the sun that reaches the roofs. Many studies have been made about this problem, most of them concerning the ways to reduce the heat transfer by conduction through the roofs. Some of these studies are related to the use of alternative materials as thermal insulation. In the present work, we describe the results obtained from experimental analyses made with castor oil resin foam (COF) used as thermal insulation material. Due to its composition, the COF has a low density and a low capacity of water absorption. These two characteristics are essential to applications in civil construction. To quantify the feasibility of the use of the COF as a thermal insulation material in civil construction, particularly when applied in roofs, and compare it with the performance of the expanded polystyrene (EPS), we adopted a very simple experimental methodology, which requires instrumentation, easily available in most of the technical universities of South America. The analyses of the results allowed to conclude that, mainly due to its structure endowed with a great amount of incommunicable and uniformly distributed air bubbles, forming a closed multicellular structure, the COF has technical feasibility to be used as thermal insulation material to be applied in roofs, causing a significant decrease of the thermal load inside the test chambers that were constructed to simulate an edification.*

Key-words: *thermal insulation, ricinus communis (castor oil) resin foam, roofs.*

1. INTRODUCTION

Several materials have been studied aiming at to minimize the thermal conductivity in environments. Ünal et al (2005) studied block elements with diatomite, which have different aggregate granulometries and cement contents, getting the best conditions of thermal insulation for 30% of diatomite. Binici et al (2006) produced fibre reinforced mud bricks, with plastic staple fibers, the fibre reinforced mud brick house has been found to be superior to the concrete brick house for keeping indoor temperatures stationary during the summer and winter. Jabri 2004 had studied lightweight concrete (LWC) blocks for thermal insulation, and your research is briefly highlighted.

Based on the results of researches developed all over the world, there is an improvement of the potential to applications of natural fibers and vegetal resins in industry, particularly in the packing industry, automotive components and civil construction. The possibility of aggregating value to these natural resources has a vital importance to peasants of the northeast region of Brazil, especially to provide new job opportunities and promote the development of life quality. The region has one of the highest solar radiation rate of the planet and, consequently, this is the mainly factor of thermal load inside the habitations, that can reach values of 560W/m^2 (OLIVEIRA, 1986). This same region is characterized by semi-desert vegetation, where the occurrence of "mamona" (*Ricinus communis L.*) is endemic.

The Ricinus communis L. is a plant from where the castor oil is extracted. It is found in equatorial regions of the world, mainly in the native state, as can be seen in Fig. 1.

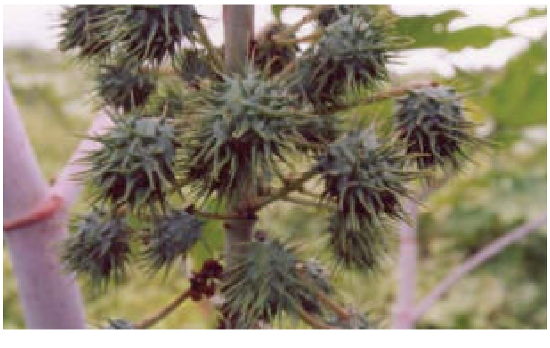

Figure 1 – *Ricinus communis L.* (http://www.tecnologiaetreinamento.com.br, 2006)

Castor oil is a mixture of fatty acids, esters and glycerin. The great potential of castor oil as raw material for the use in the chemical manufacturing industry is due to its differentiated chemical structure. It provides the production of more than 100 products already known and with a competitive use among the other industrial oils. The typical composition of the fatty acids in the castor oil is shown in Tab. 1.

Table 1 - Composition of the fatty acids in castor oil (PROQUINOR, 2006).

Ricinoleic Acid	89,55%
Linoleic Acid	4,2%
Oleic Acid	3,0%
Stearic Acid	1,0%
Palmitic Acid	1,0%
Dihidroxystearic Acid	0,7%
Eicosanoic Acid	0,3%
Linolenic Acid	0,3%

The major quantity of fatty acid in the composition provides commercial value to the castor oil. Consequently it allows the obtainment of a great number of chemical products. Several chemical processes may be accomplished taking into account the functional groups present in the castor oil, as can be seen in Tab. 2.

Table 2 – Characteristics of the castor oil (PROQUINOR, 2006)

Density (at 25°C)	0,957 – 0,961
Acidity Rate	181%
Iodine Rate	84 - 88
Saponification Rate	176 - 184
Specific Weight (at 25°)	0,94
Gardner Color (Maximum Value)	2
Viscosity (at 25°)	6,5 - 8 Stokes
Pour Point	12°C
Hidroxyl Rate	160 - 168
Refrection Rate	1,4764 – 1,4778
Solubility in Ethanol	Completely

Considering the functional groups present in the castor oil, several chemical processes can be consummated to obtain important chemical products, as it is shown in Tab. 3.

Table 3 – Castor oil application areas (PROQUINOR, 2006)

Paint additives - color enhacer
Solubleoil additives - lubricant and anti-rushing;
Cutting oil additives
Germicide, metalic and transparent soaps
Soaps – softner and plasticizer
Pharmaceutical products - emolient, solvent
Loam rubber stabilizers
Plasticizer, mold release
Esters production
Penetrating and plasticizing grease
Textile processes, lubricant, surface moisturizer
Dye and pigment disperser

Based on castor oil, it is also possible to synthesize pre-polymers to produce polyurethane. The COF is composed by ricinoleic polyurethane acid and other derivatives. It is produced by processing the seeds of ricinus communis. In order to obtain the COF polyurethanes, a chemical treatment has to be made to change the molecular chain and the amount of reactive hydroxyl in the chain. Besides, the addiction of a catalyst and a chemical expansion agent is necessary. The presence of tensoactives allows a close control of the process, which has the main advantage of requiring low cost equipments. This product has a great versatility and two differential aspects that make it better than the polymeric derived of petroleum: it comes from natural and renewable raw material and its price is 30% smaller (PROQUINOR, 2006).

Regarding the applications to civil construction, the thermal properties of the foam produced with expansible resin based on castor oil make this material quite appropriate for insulations of coverings of buildings and even in compositions with several structural elements, as external walls, closing of roofs, floors, walls division and connections in latticework devices (PROQUINOR, 2006).

Due to its composition, the COF has a low density and a low capacity of water absorption (see Fig. 2). As it must to be applied in the liquid phase (resin), it can penetrate any part of the constructions; thus, when expanded, it causes the full filing and total obstruction of the parts.

Figure 2 – COF polyurethane production.

Thermal insulation is one of the most important aspects of providing energy conservation decisions, mainly in the architectural projects. Concerning this problem, in the present work the possibilities of the use of COF as a thermal insulation material applied to roof were investigated.

2. METODOLOGY

In order to analyze the performance of COF used as a thermal insulation material applied to roofs, and comparing it with EPS, two test chambers were constructed with exactly the same dimensions (0.50m high, 0.50m wide and 0.50m long) with the purpose of simulating buildings (see Fig. 3).

Figure 3 – Test chamber simulating buildings.

The four walls and the floor of the chambers were made in plywood, while a plate of MDF (medium density fiber) served as roof. A plate of steel, with the same dimensions of the MDF plate, was put over the roof of each chamber. In order to increase the absorption of thermal energy, the plates of steel were painted in opaque black paint. COF plate was made in a wood cast with the same width and length (0,50m x 0,50m) of the simulation chambers, and 0,03m of thickness (see Fig. 4).

Figure 4 – Stages of COF plate fabrication process

In Figure 5 it is possible to observe the COF and the EPS plates used during the analyses to compare the thermal performances as insulation materials. Both plates had the same dimensions (0.50m x 0.50m) and thickness (0.03m)

COF EPS

Figure 5 – Insulation materials used in the analyses

The COF and EPS plates were set between the plate of steel and the MDF roof respectively of the first and second chamber. A third chamber was used as standard, without insulation material between the plate of steel and the MDF roof. In Figure 6 there is a representative sketch of the chambers.

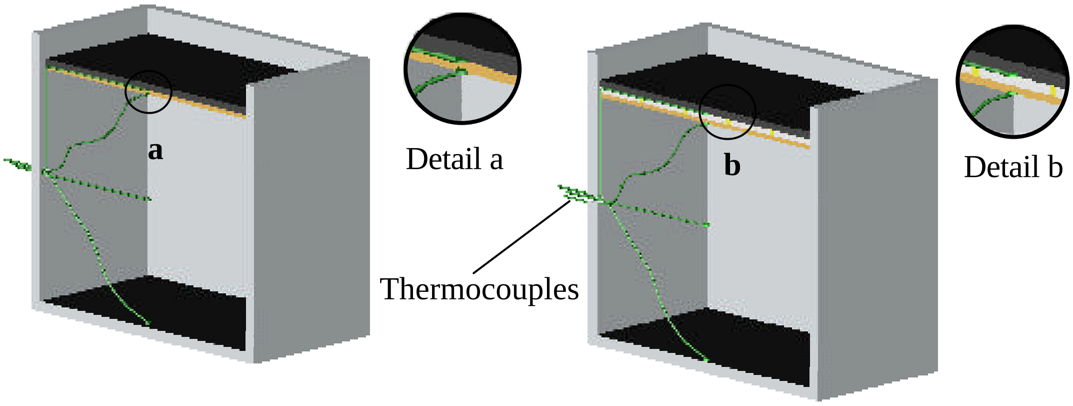

Figure 6 – Sketch of the chambers used in the experiments:
(a) chamber 1, without insulation; (b) chamber 2, with insulation

Thermocouples (T-type, copper-constantan, AWG 32) were installed inside of each chamber and on the inferior and superior faces of the plates of steel. A data acquisition system, with a transducer of thermocouples signals, was used recording the temperature data in a computer.

The temperature measurements were made in intervals of 5 min, during approximately 15 hours. A device composed by 24 incandescent light bulbs of 200W was used as a 4800W thermal radiation source, as can be seen in Fig. 7.

During the experiments (see Fig. 8), in order to compare the efficiency of the two insulation materials, three distances between the thermal radiant source and the chambers were considered, respectively: 1.00m, 0.75m and 0.50m. The experiments were performed five times, in order to obtain more accurate results.

Figure 7 – Thermal radiant source

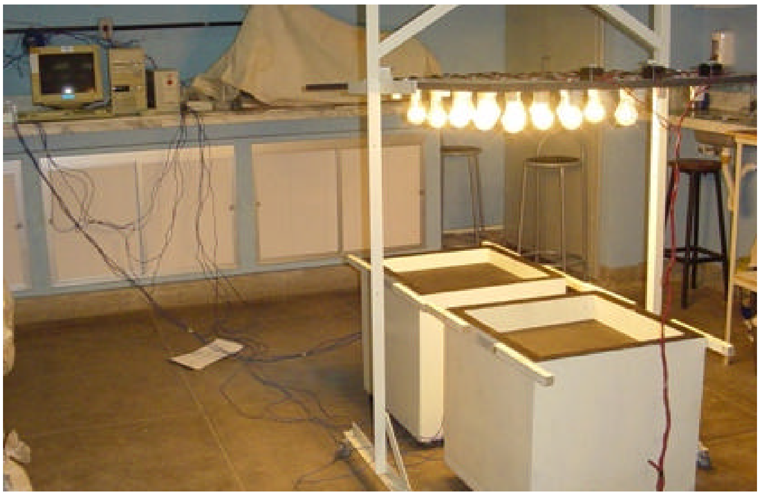

Figure 8 – Experiment in course

The thermal properties of the COF were determinated using a thermal properties analyzer (Quick Line TM–30/Anter Corp.), that provided the thermal conductivity (*k*), the thermal diffusivity (α) and the calorific capacity (see Fig. 9).

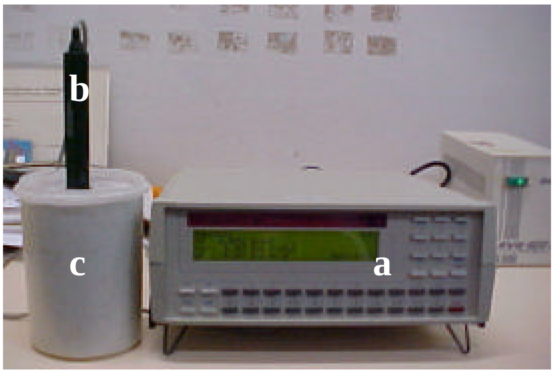

Figure 9 – Thermal properties analyzer: (a) TM–30; (b) probe; (c) COF sample

3. RESULTS AND DISCUSSION

In Tables 4 and 5 there are data of COF's properties provided by the producer of COF at Rio Grande do Norte – Brazil (PROQUINOR, 2006). Some of these data will be compared with the results obtained during the tests performed using the thermal analyzer.

Table 4 – COF's load capacity mechanics (PROQUINOR, 2006).

Apparent Density (DIN 53420)	Compressive Strength (DIN 53421)	Flexural Strength (DIN 53423)	Tensile Strength (DIN 53430)	Elasticity Modulus (DIN 53457)
kg/m^3	N/mm^2	N/mm^2	N/mm^2	N/mm^2
40	0,25	0,45	0,50	7

Table 5 – COF's thermal and chemical data (PROQUINOR, 2006).

Thermal Conductivity	0,019 W/(m.k)
Dilation Coefficient	$6{,}5 \times 10^{-5}$ 1/k
Thermal Stability	-50° C a + 110° C
Water Absorption	0,48 %
Dimensional Stability	0,098 %
Index of OH	340 mg KOH/g
Water	2%
Viscosity	400 cps
Burning Speed	0,667 mm/s

In Table 6 it some properties of EPS used in the experiment and provided by the manufacturer are presented (http://www.knauf-isopor.with.br, 2006). Some of these data will be used during the comparative analysis of the performances of the two materials.

Table 6 – EPS properties (http://www.knauf-isopor.with.br, 2006)

Apparent Specific Mass	30 (+/– 10%) kg/m^3
Coefficient of Thermal Conductivity	0,030 W/mK
Compressive Strength 10% of Deformation	2 a 2,5 Kgf/cm^2
Flexural Strength	4,3 a 4,9 Kgf/cm^2
Thermal Resistance	1,035 $m^2h°C/kcal$
Coefficient of Linear Dilation	5 a 7 x 105°C
Water Absorption through Immersion after 7 days	0,5 a 1,5 Vol%
Water Absorption through Immersion after 28 days	1,0 a 3,0 Vol%
Permeability to the Steam of Water	= 5ng/Pa.s.m

In Figure 10 it is observed that the temperatures of the steel plate of the chamber with COF foam were higher than the temperatures of the chamber without insulation.

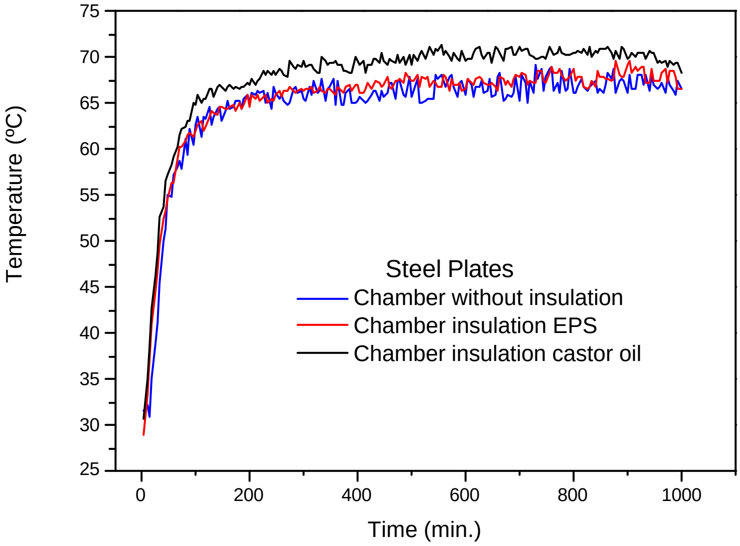

Figure 10 – Average temperature distribution in the steel plates

In the case without insulation, the heat spreads from the steel plate, goes through the MDF plate and reaches the air inside the chamber. On the other hand, in the chambers with insulation material, there is less heat passing through the MDF. According to the 1st Law of Thermodynamics, the radiant energy that reaches the upper (external) face of the black-painted plate of steel is fragmented in four parts, as specified in the following Eq. (1) (to steady state conditions):

$$E_S = E_R + E_E + E_C + E_A \tag{1}$$

where:

E_S is the total energy from the thermal radiant source that reaches the plate.
E_R is the energy reflected by the plate.
E_E is the energy emitted by radiation to the external environment.
E_C is the energy transferred by convection to external environment.
E_A is the energy absorbed by the steel plate and transferred by conduction through the materials that compose the roof arrangement.

If the term EK decreases, it must be compensated by the increasing of others terms, in order to guarantee the equilibrium in Eq. (1). Thus, the temperature of the steel plate rises. Considering the average of the last 120 minutes, the temperature of the steel plate of the COF insulated chamber was approximately 2.0°C higher than the temperature of the steel plate of the standard chamber. Using the same analysis to the EPS, it was verified that the temperature of the steel in the COF chamber was 0.8°C higher than in the chamber with EPS. This means that the COF works little better as insulation material than EPS one.

In Figure 11 the temperature evolution in the MDF plates can be seen, showing expressive differences between the situations with and without insulation. Again, this behavior is a consequence of the effect of the conservation law: in the chamber without insulation material, the heat flow from the steel plate to the MDF plate is higher than the other situations. During the last 120 minutes, the average temperature difference between the MDF plates of the COF chamber and the standard chamber was about 13.6°C. As expected, the temperatures of the MDF plate of the EPS chamber were higher than in the COF chamber, consequence of the behavior already explained in the analysis of figure 10. The average difference between the two cases was approximately 1.3°C.

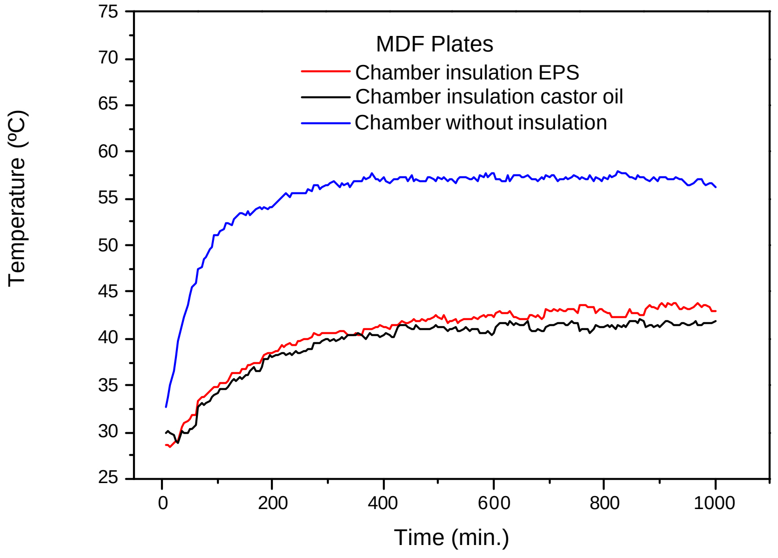

Figure 11 – Average temperature distribution in the MDF plates

According to Figure 12, there was a significant difference between the air temperature inside the chambers with and without insulation material between the steel plate and the MDF roof. This was a clear consequence of the less heat flow rate between the steel and MDF plates, due to the presence of insulation. The average of the temperature differences (during the last 120 minutes) between the situations "COF insulated" and "standard" chambers was about 11.7°C. Comparing the COF and the EPS situation, the average difference was approximately 4.3°C. In this case, considering that the uncertainty of the thermocouples is about 1°C, the difference between the two situations (COF and EPS) could be considerably non significant.

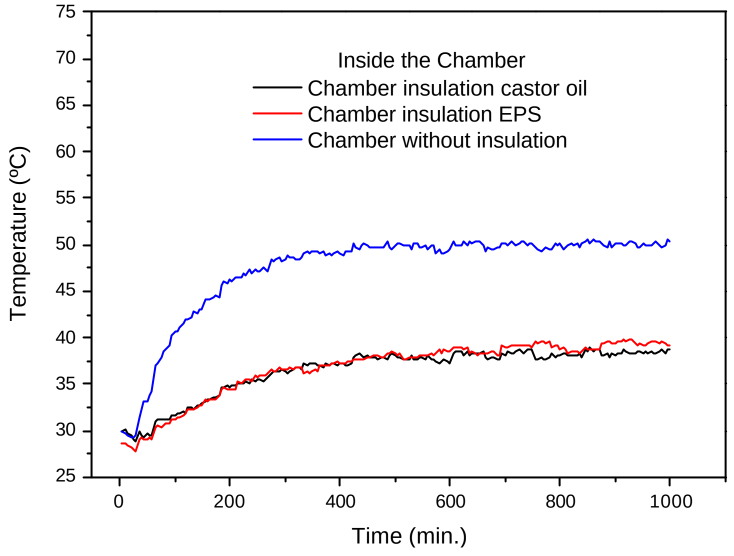

Figure 12 – Average temperature distribution of air inside the chambers

The results of the thermal properties analyses of the COF and EPS samples are shown in Tab. 7.

Table 7 – Average thermal properties of the COF and EPS samples.

Material	Thermal Conductivity *k* (W/mK)	Thermal Diffusivity (m^2/s)	Heat Capacity ($J/m^3.K$)
COF	0,0406	0,112	0,362
EPS	0,0470	0,052	0,890

There is a remarkable difference between the values of thermal conductivity presented in Tables 5 (producer) and 7 (present experiments). The discrepancy could be associated to the differences between the other properties of the samples considered by the producer and in the present experiments. The difference between the values of the thermal conductivity determinate to COF and to EPS, presented in Tab. 7, is almost insignificant. However, it is possible to observe that the performance of the COF proved that it can work as a thermal insulation material in roof applications.

In Table 8 the temperatures along the 15 hours of the experiments were considered. The results of the difference between the temperatures of the steel plate and the air inside the chambers showed the advantage of the COF as a thermal insulation material very clearly.

Table 8 – Average temperatures differences (transient and steady state)

Chamber	Average Temperature		
	(A) Steel Plate	(B) Inside the Chamber	(A) – (B)
Standard	64.4ºC	48.4ºC	16.0ºC
EPS Insulated	65.5ºC	37.4ºC	28.1ºC
COF Insulated	68.9ºC	36.7ºC	32.2ºC

The temperature difference between the chamber without roof insulation and the chamber with EPS was 12.1ºC, corresponded to a value approximately 43.1% smaller in the insulated roof chamber. Meanwhile, the temperature difference between the chambers without roof insulation and the chamber with roof insulated by COF was 16.2ºC, corresponded to a value approximately 50.3% smaller. Comparing the COF and EPS situations, the results obtained to COF roof insulated chamber was 7.2% better than the EPS one.

4. CONCLUSIONS

Due to its structure, endowed with a great number of incommunicable air bubbles and uniformly distributed, forming a closed multicellular structure, the COF has potential for use in other situations where it the use of thermal insulation is necessary. The use of COF plates as insulation material of roofs is a feasible alternative to the reduction of the thermal load inside of buildings, mainly in regions of low latitudes, as the northeast of Brazil. Thus, the material can be used to improve the conditions of thermal comfort inside habitations of peasants and to promote the reduction of the expenses due to climatization systems at public and commercial buildings. It is possible to avoid the use of derived materials from the petroleum (like EPS) using new materials that offer similar or even better performance to thermal insulation in applications of civil construction without causing damages to the environment (like COF). During the last two years, the economic importance of the ricinus communis has increased in Brazil due to the governmental program of incentive to the production of “biodiesel”, where the intention is to use castor oil as an alternative to Diesel oil. Nevertheless, there are many other possibilities to the use of castor oil that still remain unexplored. Some research groups at universities of the northeast region are starting to work on it. According to the ABRAPEX – The Brazilian Association of Expanded Polystyrene, the energy loss due to badly isolated systems represents a loss of R$ 12 million (approximately US$ 5 million) per day of work" (ABRAPEX, 2006). Therefore, the importance of thermal insulation for the energy conservation is evident. In this work, we pointed out the technical feasibility of a material that could be used as an alternative to the EPS.

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To the Proquinor – Produtos Químicos do Nordeste Ltda.

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