COMPOSITE FOR THERMAL ISOLATION IN HOT WATER CONDUCTORS TUBES IN SYSTEMS OF HEATING FOR SOLAR ENERGY

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Abstract. *Is presented a new type of thermal isolator for hot water conductor tubes, in the heating solar system that consists of a based in gypsum composite, to substitute the CPVC tubes conventionally used. It will be presented constructive details of the proposed isolator composite tube. It will be shown comparative data relative to the thermal and materials tests of the proposed tubes. It will be studied some diameters of the isolator composite tube to determine the most efficient one. It will be demonstrated that the considered tube presents thermal, economic and materials viabilities.*

Keywords: *Composite, thermal resistance, thermal isolate, thermal efficiency, low cost*

1. Introduction

The use of thermal isolators for the conduction of hot fluid is one of the applications in the thermal and materials fields that has been more studied in scientific researches, in search for a material that has the characteristics of good thermal efficiency, good resistance mechanical and low cost.

Countless researches have been implemented being used new materials that allow the improvement of the thermal resistance, in relation the passage of a hot fluid in its interior; that is resistant to the bad weather; have low weight and good mechanical resistance; have easiness of assuming lots of forms and mainly that be of lower cost than the conventional isolators. In this field the polymeric materials, ceramic and composites are the more studied Souza (2002).

In such studies the principal parameters that characterize the thermal isolator efficiency are: density, forms, composition, thickness, minimum and maximum temperature that it tolerates, compression resistance, water absorption, thermal conductivity coefficient, smell, color, flexion resistance, shear resistance, mechanical vibration resistance, thermal stability, water steam diffusion resistance factor and fire resistance Souza (2004).

Among the materials more used in the isolator tubes for the heat conduction we can mention: polyurethane, expanded polystyrenes (EPS), gutters, plates, elastomeric foams, glass wool, calcium silicate, being the most appropriate for tubes, the polyurethane in gutter and the elastomeric foams Mano (2000).

The CPVC tube is also quite used, mainly for this work object, which is the thermal efficiency of hot water conductor tubes in a solar energy water heating system. Such tubes, that possess isolation capacity up to 80°C, are manufactured containing more 10% the of chlorine than the PVC tubes with 57% of chlorine, however they present a serious inconvenience, that it is cost, 2.5 dollars for the tube with external diameter of 22mm Souza (2002).

With the objective to get an alternative thermal isolator, cheaper, thermally efficient and viable in terms of mechanical resistance, was manufactured and was studied a new type of thermal isolator tube, constituted by a ceramic composite composed of gypsum and EPS, two materials of low cost and of low thermal conductivity.

2. Composites materials and characteristic and properties of the plaster and EPS (expanded polystyrene)

2.1. Composite materials

Materials composites can be defined as materials formed of two or more elements with different compositions, structures and properties and separated by an interface. The main objective when a composite is produced is the combining of different materials to produce another material with superior properties to the unitary components Ferrante (2002).

With the composite materials it is possible to obtain products with different properties, as: lightness, hardness, and high temperatures resistant materials, hard materials and shock resistant.

A composite material is a mixture of two or more materials that are different in form and chemical composition and they are essentially insoluble in the other, and generally is produced synthetic by the combination of some type fibers with different matrices, increasing the force, hardness, and other properties. The composite material produces properties much more interesting than one with only a material Piazza (2000).

Most of the studies of composites seek the obtaining of a material with mechanical, electric and optical properties more appropriate than the conventional materials. In the thermal field it has been prioritizing the obtaining of materials that resist to temperature abrupt gradients and the high and low temperatures. In the specific case of this work, the search is for a new material that has a smaller thermal conductivity coefficient to be a good thermal isolator and also present appropriate mechanical resistance to make easier its handling and transport Machado (2003).

2.1.1. Plaster

Found practically all over the world, the plaster is found in Brazil abundantly in cretaceous sea formation lands, mainly in the states of Ceará, Rio Grande do Norte, Piauí and Pernambuco Antunes (1999).

Plaster, is a mineral fundamentally composed of hydrated calcium sulphate ($CaSO4.2H2O$) and of the hemidrato obtained by the calcinations ($CaSO4.½H2O$). It crystallizes in monoclinic system forming crystals of different thickness, called selenita. The plaster can still be found in granular form, when it is called alabaster, or in fibrous veins, with the espato-of-satin name, because of its silky shine. The powdery form, not crystallized, receives the gypsum name. In general it has white color, but several smudges can give ash aspect, yellowish, rosy or brown Nielsen (1994).

When the plaster is humidified with about a third of its weight in water, it is formed a plastic mass that hardens in about ten minutes and it suffers expansion, and after it is dry it is used in different forms molds. Plaster is also used in construction, with objectives of tow and, modernly, in the confection of partition walls, together with cardboard.

The plaster also enters in the composition of the cement Portland. It is still used in orthopedic apparels, in dental prosthesis and in other fields that is necessary the making special molds.

The plaster has a thermal conductivity coefficient of 0.46W/m.°C, being, therefore, considered a thermal isolator Incropera (2003).

2.1.2 Expanded polystyrene (EPS)

The EPS is a cellular and rigid plastic that can present forms and applications variety. It comes as molded foam, constituted by an agglomerate of granules Mano (1999).

In the EPS production the prime matter is subjected to a process of physical transformation, not altering chemical properties. This transformation is processed in three stages: the pay-expansion, the intermediate storage, the molding.

Two EPS characteristics have been strengthening its presence in the consuming market, where it is obtaining growing participation: the lightness and thermal isolation capacity and low cost.

It is quite used in the making of thermal boxes for foods and drunken preservation, and in the building site. The EPS principal characteristics are Silveira (2004):

Thermal conductivity low - the structure of closed cells, full of air (97% in volume), makes it difficult the passage of the heat, granting to the EPS a great isolating power - K = 0.030W/m°C.

Lightness - the EPS densities vary among the 10-30 kg/m^3, allowing a substantial reduction of the weight of the constructions.

Mechanical resistance - in spite of its great lightness, the EPS has a high mechanical resistance, which allows it employment where this characteristic is necessary. Its resistance to the compression usually varies from 7,000 kgf/m² to 14,000 kgf/m², larger than the resistance of many soils.

Low water absorption - the EPS is not hygroscopic. Same when submerged in water just absorbs small amounts of it. Such property guarantees that the EPS does maintain it thermal and mechanics characteristics under the action of the humidity.

Easy to handle and transport - is a material that with the tools habitually works available, guarantee its perfect adaptation to the work. The low weight of EPS facilitates its handle. All the movement operations and placement result significantly shortened.

Economical – Considering the several parameters as the breaks, labor, low weight, transport, storage, the EPS packing results in economical advantages.

Of the same format that the elastomeric foams, the proposed thermal isolator was made to involve a PVC tube of 20mm of diameter, but it can be produced for larger diameters.

They were manufactured starting from molds constituted by tubes of PVC, of different diameters, being obtained tubes drained with internal diameter of 21mm and external, corresponding to 34mm, 44mm and 54mm Chawla (1995). The samples of the built tubes are shown in Fig. (1).

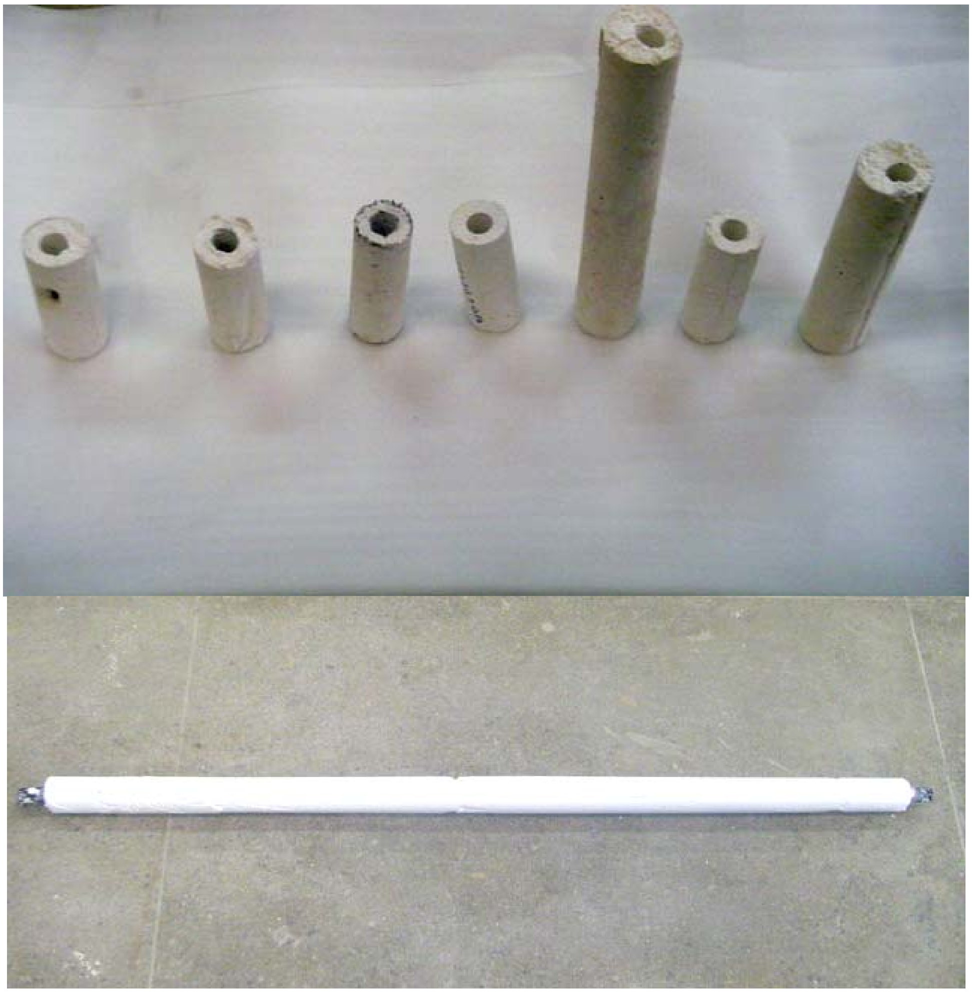
Figure 1. Isolator tube samples.

The manufacture process of such isolator tubes consisted of the following steps:

1. Preparation of the mold in agreement with the intended isolation thickness - cuts of the PVC tube corresponding to each intended thickness and preparation of the EPS covers of each mold for vedation;

2. Centralization of the tubes of PVC of 20 mm in each mold - obtained with the aid of screws that penetrate inside of the mold;

3. Oil application in the external surface of PVC tube of 20mm and in the internal surface of the mold;

4. Preparation of the composite - the gypsum was mixed with the EPS fragments, is tended the care so that the same becomes the most homogeneous possible, and it was placed in the water (30% in volume) for the obtaining of the intended mixture;

5. Placement of the composite in the mold - the mold was placed in the vertical position and soon after it spilled out to the mixture in the same for the superior opening, until being completely full;

6. Mixture dry - the mold was left evaporating in the sun for 30 minutes and later it was removed the mold and the internal PVC tube, being taken to a solar greenhouse for the retreat of the excessive humidity of the same. It was left drying off about 8 hours and later on the obtained thermal isolation was retired to be tested;

7. Polymeric resin application in the composite to make it waterproof.

The mixture used for the obtaining of the deserved composite it obeyed the following proportions, in volume: 1.0 part of gypsum + 1.0 part of powder EPS + 0.3 part of water. The very low dimensions EPS particles had been produced by use of equipment, which consists of a perforated disc with multiple punctures of very low diameter, set in motion by an electric engine that produces its turn. When it suffers attrite with the record the EPS is practically transformed into powder.

Due to the thermal conductivity coefficient of the EPS be much smaller than the one of the gypsum, the composite that has a EPS greater percentile in volume will have a smaller thermal conductivity, however it is also had that to take in consider the composite resistance, and when a proportion is used in volume of 1.5 EPS for 1.0 gypsum the thermal isolator obtained it becomes very fragile, hindering your handling.

It is standed out that such isolation is already in experimentation phase in field there is more than one year in a solar heating alternative system developed and built in LES/UFRN, isolating the conduction tube of hot fluid that leaves the collector for the hot water storage box, being subjected of bad weather, and it behavior is quite appropriate, coherent with the objectives proposed for it use.

4. Experimental procedure

To determine the composite thermal conductivity several samples of the composite were made of different compositions, being varied the proportion of the phase (EPS), corresponding to 1.5 parts for 1.0 part of gypsum and 1.0 part for 1.5 parts of gypsum, besides of the samples of pure gypsum. Those samples were mischievous to a device to measure heat conduction coefficient, built at the Heat Transmission Laboratory of UFRN, coupled to a system of acquisition of data, where was determined the thermal conductivity of the samples. The samples were of 150 mm of diameter and 10 mm of thickness.

The insulating thermal composite obtained was tested for the evaluation of its thermal efficiency being followed the procedures: the PVC tube involved for the composite was filled with hot water in the temperature between 70°C and 80°C, and with the use of two thermocouples were measure the temperature of the water was measured inside the PVC tube and the composite external temperature, during 40 minutes, being measuring the temperature decrease of water. Such procedure was also done for the PVC tube without thermal isolation and CPVC Souza (2002).

Through the thermal gradient measured it can be compared the results for each isolator composite thickness, that uses the same proportions, which are: 1.0 gypsum parts; 1.0 parts EPS; 0.3 water parts of. The external diameters of the composite rehearsed they were: 34mm, 44mm and 54mm.

It also took place a microstructure analysis being used an optical microscope with images analyzer, to diagnose the phases distribution inside the obtained composite.

5. Analysis resulted

The Table (1) displays the measured conductivity values, for the samples of different compositions.

Table 1. Measured values of thermal conductivity.

TYPE OF SAMPLE	K ($W/m^2.°K$)
GYPSUM	0.49
GYPSUM + EPS (1.5: 1.0)	0.36
GYPSUM + EPS (1.0 : 1.0)	0.26
GYPSUM +EPS (1.0 : 1.5)	0.25

The analysis of the data shows that the thermal conductivity coefficient measured for the sample of gypsum is quite close to the presented for literature around 0.46 $W/m^2.°K$. In what it concerns the values measured, it can be verified that were closer of the corresponding value the gypsum conductivity than of the value of the EPS, around 0.03 $W/m^2.°K$ Incropera (2003). Such composite presents a low thermal conductivity coefficient characteristic of the good thermal insulator, which turns it viable for the proposed application.

The temperature data of the intern and external surface of the thermal isolator composite tube, for the forty minutes of the thermal test duration, are shown in Tab. (2) and the behavior of the curves assumed by the same ones in the graphs of Fig. (2), (3), (4), (5) and (6).

Table 2. Data temperature of the intern and external surface of the thermal isolators.

Time (minutes)	T_{int} (ºC)	T_{ext} (ºC)	T_{int} (ºC)	T_{ext} (ºC)	T_{int} (ºC)	T_{ext} (ºC)	T_{int} (ºC)	T_{ext} (ºC)	T_{int} (ºC)	T_{ext} (ºC)
	Composite 54mm		Composite 44mm		Composite 34mm		CPVC		PVC	
0	77.0	29.9	78.0	30.0	78.0	37.0	76.0	45.3	75.0	65.0
2	65.8	33.5	71.0	34.0	67.1	40.8	71.8	54.7	65.5	57.0
4	62.5	36.9	67.0	35.3	62.5	45.1	67.8	50.4	62.0	53.5
6	58.2	38.2	62.7	35.6	57.6	45.5	65.0	50.3	58.6	51.5
8	56.1	39.4	60.0	34.5	51.5	44.3	62.1	48.6	55.9	49.6
10	53.3	39.5	56.8	34.0	48.3	42.4	59.0	46.0	51.4	47.4
12	51.7	39.7	54.8	33.4	45.8	41.4	57.0	43.5	50.7	45.3
14	49.7	39.7	52.5	32.8	43.9	40.0	54.8	44.0	48.6	44.7
16	48.5	39.6	50.7	32.5	41.8	39.2	53.0	42.8	47.3	43.3
18	47.0	39.4	49.5	32.2	40.3	38.4	51.0	41.2	45.3	41.6
20	46.2	38.9	48.0	32.9	38.8	37.5	49.4	40.7	43.9	40.3
22	45.0	38.6	46.4	32.6	37.6	36.4	47.8	39.8	42.3	39.4
24	44.0	38.3	45.0	32.5	36.4	36.0	46.4	39.0	41.1	38.3
26	43.1	37.9	43.7	32.4	34.8	34.0	45.1	38.1	40.0	37.2
28	42.3	37.5	42.6	32.6	34.2	33.5	43.8	37.4	39.0	36.7
30	41.5	37.2	41.5	32.5	33.3	32.0	42.8	36.7	37.9	35.7
32	40.8	37.0	40.6	32.0	32.5	31.5	41.9	36.0	37.2	35.3
34	39.8	36.3	39.7	31.2	32.0	31.0	40.9	36.0	36.8	34.7
36	39.3	35.9	38.9	31.7	31.0	30.3	40.1	35.1	35.4	32.8
38	38.6	35.7	38.0	31.6	30.5	30.0	39.2	34.9	35.0	32.8
40	38.0	35.4	37.4	31.0	30.0	29.5	38.5	34.5	34.5	32.5

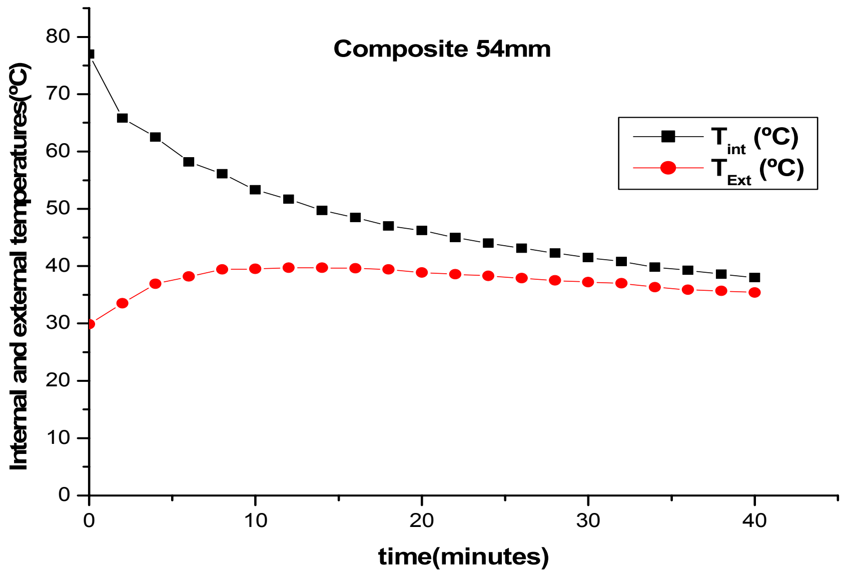

Figure 2. Behavior of the internal and external temperatures in the thermal isolator tubes.

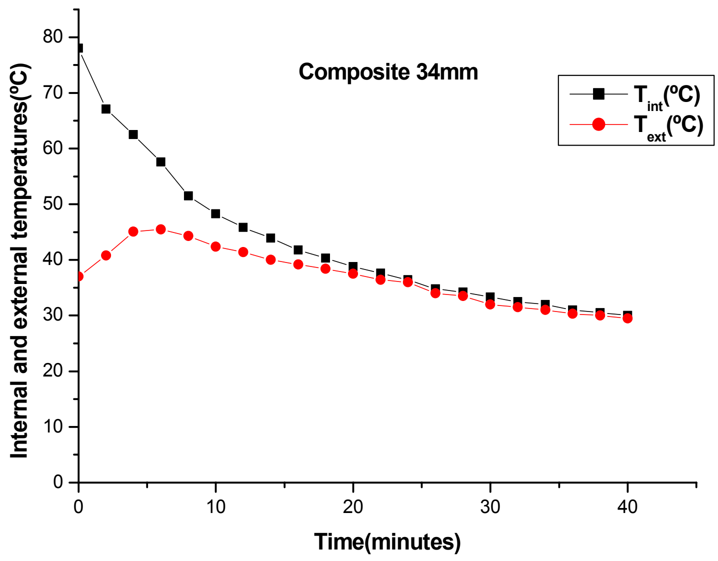

Figure 3. Behavior of the internal and external temperatures in the thermal isolator tubes.

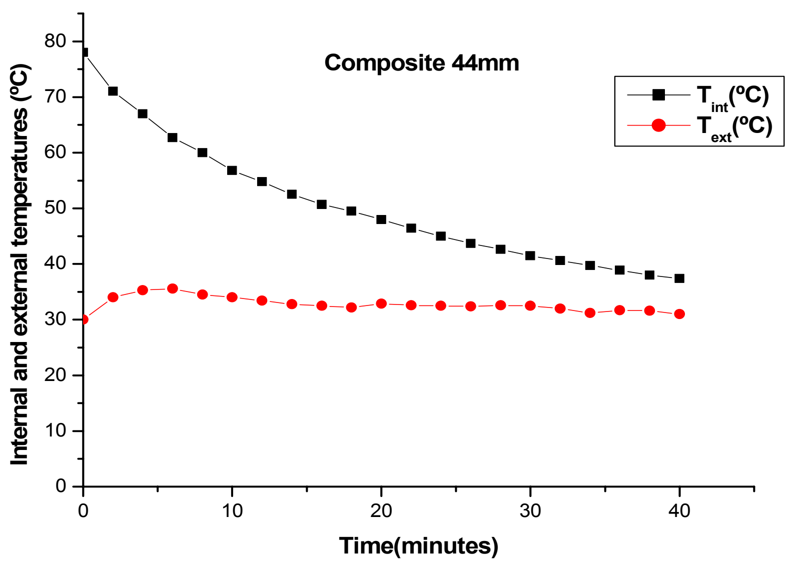

Figure 4. Behavior of the internal and external temperatures in the thermal isolator tubes.

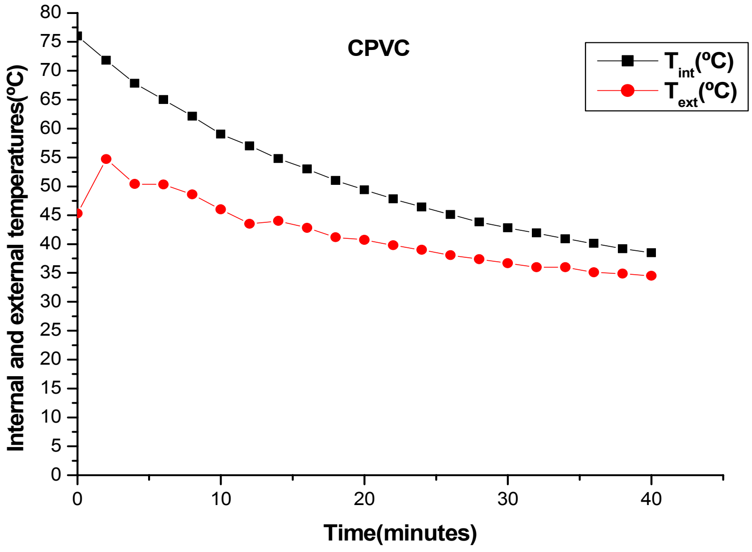

Figure 5. Behavior of the internal and external temperatures in CPVC tubes.

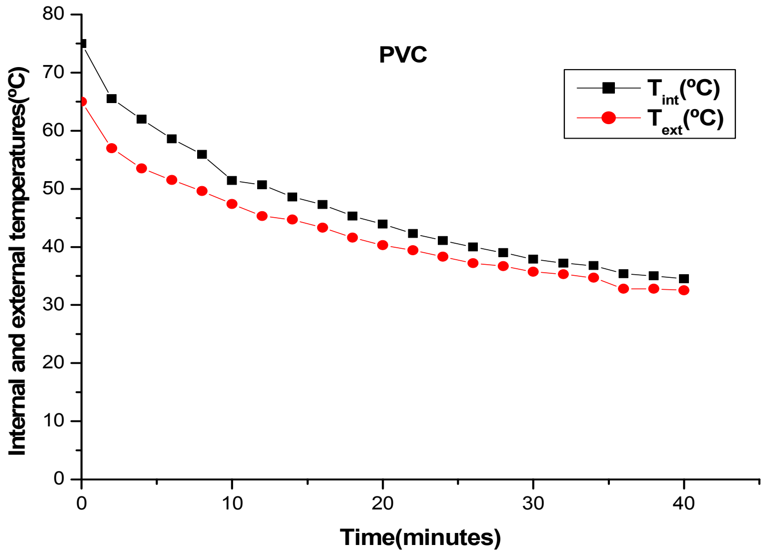

Figure 6. Behavior of the internal and external temperatures in PVC tube.

It is noticed of the data analysis contained in the Tab. (1), and of the graphs of Fig. (2), (3), (4), (5) and (6), which the profiles that denote its behaviors are almost identical, just differing gradients among the internal and external temperatures of the isolator tube, whose values are shown in Tab. (3) and its profiles in Fig. (7).

Table 3. Data of the thermal gradient obtained in the thermal isolator tubes.

Time(min)	ΔT(°C) Composite 54mm	ΔT(°C) Composite 44mm	ΔT(°C) Composite 34mm	ΔT(°C) CPVC	ΔT(°C) PVC
0	47.1	48.0	41.0	30.7	10.0
2	32.3	37.0	26.3	17.1	8.5
4	25.6	31.7	17.4	17.4	8.5
6	20.0	27.1	12.1	14.7	7.1
8	16.7	25.5	7.2	13.5	6.3
10	13.8	22.8	5.9	13.0	4.0
12	12.0	21.4	4.4	13.5	5.4
14	10.0	19.7	3.9	10.8	3.9
16	8.9	18.2	2.6	10.2	4.0
18	7.6	17.3	1.9	9.8	3.7
20	7.3	15.1	1.3	8.7	3.6
22	6.4	13.8	1.2	8.0	2.9
24	5.7	12.5	0.4	7.4	2.8
26	5.2	11.3	0.8	7.0	2.8
28	4.8	10.0	0.7	6.4	2.3
30	4.3	9.0	1.3	6.1	2.2
32	3.8	8.6	1.0	5.9	1.9
34	3.5	8.5	1.0	4.9	2.1
36	3.4	7.2	0.7	5.0	2.6
38	2.9	6.4	0.5	4.3	2.2
40	2.6	6.4	0.5	4.0	2.0

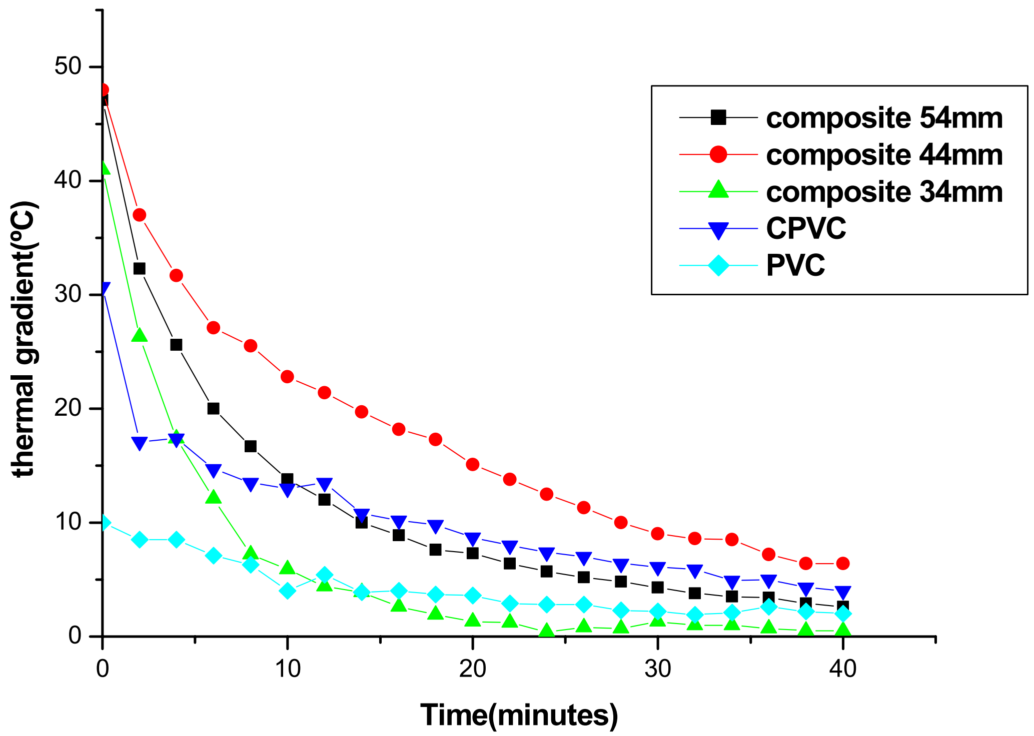

Figure 7. Thermal gradient behavior obtained in the thermal isolator tube.

The data of Tab. (3) shows that the composite of 44mm has a larger isolation capacity, being more efficient than CPVC, that is the conventionally tube used for hot fluid conduction in solar heating installations. The tube of 54mm still presents competitiveness with CPVC; however the composite tube of 34mm has shown unviable to be used for the proposed finality.

In what concerns the resistance, all the composite diameters produced were shown appropriate in relation to handling and transport, however they don't present significant traction, compression, flexion and torsion resistances. That verification doesn't make unviable the use of the composite tube as thermal isolator once that in the application finality there is not solicitation of such efforts.

With relationship to the weight of the obtained composite, the tube of 54mm presents a weight of 1.0Kg/m, the one of 44mm, 0.875 Kg/m and the one of 34mm, 0.4Kg/m. Therefore, for all the diameters used the equivalent weight for meter, presents low values, what represents a quite positive factor, when compared with other isolator ones, being pointed out that such composite is made of ceramic matrix.

The cost of production of composite tube presents a low value, being used for the obtaining of a meter of thermal isolator, of the largest experienced diameter, about 1.0 Kg of gypsum and 10g of granulate EPS, besides water, what corresponds to a total cost corresponding to the gypsum cost, R$ 0.20/Kg, once the EPS is considered a recycled material and the cost of the water is considered despicable.

In what concerns to the microstructural analysis, the images shown in Fig. (8) prove the good adherence of the EPS in the ceramic matrix, not presenting vacant nor crack that could occur in the composite retraction during its drying. The small size of EPS particles, practically in powder form, contributes in significant way to the composite adherence. The presented micrograph is relative the composite sample in the ratio, gypsum and EPS, 1.0:1.0.

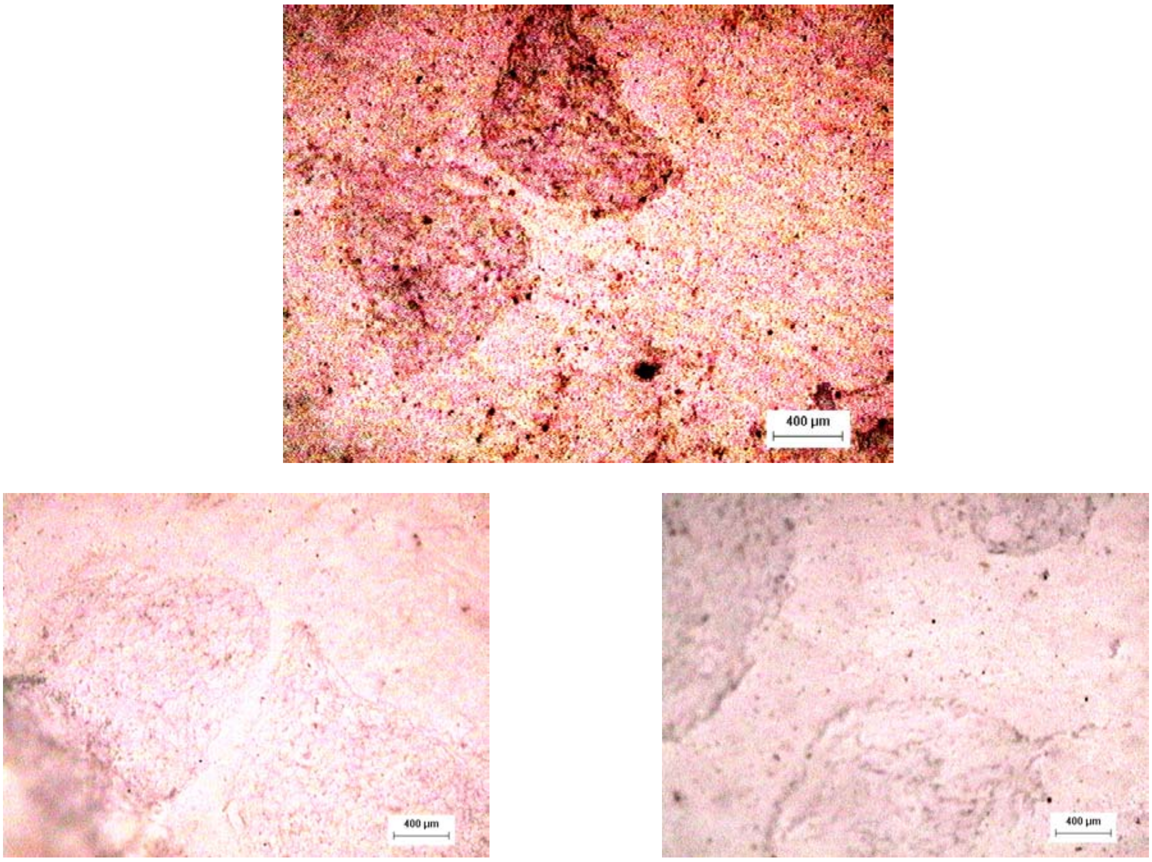

Figure 8. Composite optical micrographic.

6. Conclusions and suggestions

1. The proposed thermal isolator presents wide viabilities thermal, economical and of materials, for the proposed finality;
2. For all the used diameters the equivalent weight for meter, presents low values when compared with other isolator ones, what represents a great advantage. For the largest experienced diameter, its weight corresponds to 1.0 Kg / meter;
3. The manufactory cost of such composite (R$ 0.20/meter) is plenty low, when compared to other conventional isolator;

4. The production process is quite simple, needing just demanding knowledge in what concerns the wanted proportions, particles mixture and use of water appropriate proportions;
5. The resin used to grant impermeability to the composite has shown efficient, once such an isolator tube already is already in tests since more than one year, isolating the hot fluid conduction tube that leaves the collector to the box storing;
6. The molds used for the production composite are of simple making, because they are obtained starting from PVC conventional tubes;
7. The proposed isolator tube presents wide competitiveness with the CPVC tube used in hot water installations, being its cost many times inferior, once the CPVC tube of 22mm of external diameter has a cost around R$ 6.00;
8. Intends to grow a technological structure that is able to transform that handmade product in a market product.

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