ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

OBTAINMENT AND COMPARATIVE STUDY OF SELECTIVE SURFACES FOR LOW COST SOLAR THERMAL COLLECTORS

Karine Pereira Bezerra
Felipe Pereira Rodrigues
Universidade Federal do Ceará – Campus do Pici, Bloco 714 – R. Humberto Monte s/No – Pici - Fortaleza/CE/Brazil – 60455-760
felipefpr@gmail.com and karinebezerra8@gmail.com

Francisco Nivaldo de Aguiar Freire
Ana Fabíola Leite Almeida
Felipe Sá Esmeraldo
Universidade Federal do Ceará – Campus do Pici, Bloco 714 – R. Humberto Monte s/No – Pici - Fortaleza/CE/Brazil – 60455-760
nivaldo @ufc.br; anfaleal@yahoo.com.br ; felipesmeraldo@hotmail.com

Abstract. *This paper describes the obtainment, deposition and test of selective surfaces based on granite powder and a mixture of granite powder with CRFO, as well as shows a describing of the testing equipment. The compounds to be deposited on the substrate were obtained by adding a binder and a flux to the granite powder. The selective surfaces were tested in a solar collector prototype wood made, with a glass cover, which reduces the convection heat losses. The temperature data was measured by thermocouple type K and stored in a computer. The results shown that this new selective surface technology based on granite powder could be part of the flat-plate collector market in the future, because the temperatures achieved were similar to that reached by commercials surfaces.*

Keywords: *selective surface, granite powder, flat-plate collectors*

1. INTRODUCTION

Nowadays there is a worry about the environment, so that many technologies and scientific research are made in order to develop "green" and more efficient equipment. In this context there is a kind of renewable energy source that seems to be the most promising, considering your availability and the fact that it doesn't pollute the environment when it's in operation. This source is the Solar Energy. According to Quaschining (2005), $3,9x10^{24}$ J = $1.08x10^{18}$ kWh of solar energy reaches the surface of the Earth, annually. This is about ten thousand times more than the annual global primary energy demand and much more than all available energy reserves on earth. In other words, using one-ten-thousandth part of the incoming sunlight would cover the whole energy demand of mankind.

The most common way to use this energy source is by solar thermal collectors. These devices receive the sun radiation and convert it into heat. Previously, this kind of solar collector was painted with a black ink, which give a low efficient conversion. But, today, it's used the selective surfaces, which provide more efficient thermal collectors. Selective surfaces have an important role in absorption and reflection of sunlight, as well as in emission of thermal radiation, influencing on the solar collector efficiency. They work increasing the absorption of the solar radiation and decreasing the emission of infrared. There are many kinds of selective surface, as described in the next section.

This paper describes the obtainment of new kind of selective surface based on residue of granite, and the tests made by using a solar collector prototype. It was tested and compared four types of surface, one with granite and Araldite type A as a binder, one with a mixture of granite and CRFO also with Araldite type A, and with Araldite type B was obtained the two other surfaces, one with granite and the last one with a mixture of granite and CRFO.

The using of granite residue is an ecofriendly solution for solar collector designs and fabrication. Furthermore, it will allow a cost reduction in the collector production. According to Geosciences Institute of Federal University of Rio de Janeiro Yearbook (2005) it is estimated that granite industry produces about 200 thousand ton of residue.

1.1 Flat-plate solar collectors

According to Duffie (2006), a solar collector is a special type of heat exchanger that converts solar energy into heat. The difference is that most of the heat exchangers transfer heat between fluids, and radiation is not important in the process, while in the solar thermal collectors energy is transferred from a faraway source of radiation to a working fluid. They use both the solar radiation diffuse and direct, and need no auxiliary systems to change the angle of the plate relative to the incident radiation, in addition, require little maintenance. They have a simple mechanical structure compared to solar concentrators. And its application in most cases occurs in the water heating, building heating, air conditioning and industrial processes heating.

The main parts of a flat-plate solar collector are the absorber plate (selective surface), the glass cover, and insulation. The absorber plate containing the metallic substrate, typically of copper or aluminum, on which the substance or coating which provides selectivity to the surface is deposited. The absorber plate is the most important component of the solar collector, since the process of energy conversion takes place through it. The glass cover reduces convection and radiation losses to the atmosphere and the insulation reduces conduction losses.

1.2 Selective surface

According to McEnaney (2010), the solar thermal electricity plants, domestic hot water and process heat systems, solar heating and absorption chilling systems, and solar thermoelectric and thermionic generators all begin utilizing solar power by converting the sun's rays into heat, and to be efficient, they must absorb as much of the sun's rays as possible while limiting the radiative heat loss from the absorbing surface. To do this, the solar absorbtance must be increased and infrared emittance must be decreased. This is possible by using selective surface on absorber plates. There are many kinds of selective surface, or many ways to obtain selectivity. This paper will describe a selective surface new technology, based on granite powder.

According to Grangvist (1990) selective surfaces fall into six broad categories: a) intrinsic, b) semiconductor-metal tandems, c) multilayer absorbers, d) metal-dielectric composite coatings, e) textured surfaces, and f) selectively solar-transmitting coatings on a blackbody-like absorber. These categories will be described below.

Intrinsic materials are naturally selective bulk materials. Such materials include borides, carbides, and silicides, but even the best of these materials are not excellent selective surfaces: ZrB2 has a solar absorbtance of only 77% while having an emittance of 8% at 100 C (Handich, 1981).

Semiconductor-metal tandems are selective surfaces in which the semiconductor absorbs at wavelengths smaller than the bandgap, while the metal substrate has low IR emittance.

Multilayer absorbers rely on interference effects between different layers of materials. Two examples of multilayer absorbers are an Al2O3-Mo stack, which can achieve a solar absorptance of 91% and an emittance of 16% at 538 ºC, and a MgF2- Mo-CeO2 stack, which can achieve a solar absorptance of 85% and an emittance of 6.2% at 538 ºC (Schimidt, 1965).

Metal-dielectric composite coatings, can be deposited on top of a metal substrate to make an effective selective surface. The composite coatings are frequently cermets, which are metal particles in a ceramic (or dielectric) host. The properties of cermets can be tuned via host material choice, particle material choice, particle density, particle shape, particle size, particle structure, particle orientation, and coating thickness.

Textured surfaces are also a kind of a selective absorber. These surfaces rely on geometric, porous, or dendritic structures, which have features small enough so that they appear rough to short-wavelength radiation and smooth to long-wavelength radiation. The short-wavelength light is more effectively absorbed by the multiple reflections created by the structures, while the long-wavelength radiation is essentially unaffected by the surface features.

The last category of selective surfaces is selectively solar-transmitting coatings on blackbody substrates. These systems allow the solar radiation to transmit through the coating and be absorbed by the blackbody, while preventing the emission of IR losses from the blackbody. Examples include gold films on glass, where the gold film is encapsulated by titanium dioxide short-wavelength antireflection coatings, and doped oxide-semiconductor coatings.

1.3 Literature review

There are several paper, thesis and works that investigate the selectivity of coatings and materials, furthermore they study the different methods to obtain, deposit and evaluate these coatings. Shuler, *et al.*, (2000), obtained selective surfaces, with titanium containing amorphous hydrogenated carbon films, using a combined process with PDV (Physical Vapor Deposition) and PECVD (Plasma Enhanced Vapor Deposition). In order to fabricate a multilayer selective surface, they used an a-C:H/Ti layer overcoated with pure a-C:H layer. And, to ensure good adhesion, a titanium layer with thickness of about 10 nm was deposited previously onto the aluminum substrate. The composition of the deposited films was measured by XPS (X-ray Photoelectron Spectroscopy). The results shown an absorbtance α of 0,876 and an emittance ε of 0,061 and an optical selectivity s = α/ ε of 14,4.

Barshilia, et al., (2007), obtained TiAlN/TiAlON/Si_3N_4 tandem absorber by deposition on 3 different substrates, copper, stainless steel, and Nimonic (trade mark, nickel-chrome alloy), using a reactive direct current magnetron sputtering system. The composition and the thickness of each set was optimized during the tests in order to achieve high absorbtance (0,958) and low emittance (0,07) at a temperature of 82 ºC, these results was achieved with copper substrate. They

Madhukeshwara and Prakash (2012), studied the performance characteristics of a solar flat plate collector with 3 different coatings, solchrome, matt black, and black chrome deposited on copper substrate. The purpose of the paper was to compare the results between the different coatings. In the results, was observed that the highest temperature was achieved by the black chrome coating, and the highest thermal efficiency either. They also investigate three different tilt angles (30º, 45º and 60º) and the best configuration was that with an angle of 30º.

Vieira (2011), obtained selective surfaces with $Cr_{0,75}Fe_{1,25}O_3$ (CRFO) e Fe0,5 $Cu_{0,75}Ti_{0,75}O_3$ (FCTO) due to screen printing deposition method. The coatings were compared with a commercial surface. In order to investigate the coatings

ISSN 2176-5480

composition was utilized Raman spectroscopy. Furthermore, the apparatus was submitted to field tests, what means that the surfaces were exposed to sunlight. The data was collected due to a data logger, and was used to calculate absorbtance and emittance of the obtained surfaces. The commercial surface data was get from the catalogue. An absorbtance of 0,80 was achieve, and the commercial surface achieve an absorbtance of 0,95. Since the method used by the author is quite simple, he concludes that it can be used for low cost collectors.

2. METHODOLOGY

This section will describe the obtainment of the selective surface and the temperature tests.

2.1 Selective surface obtainment

The granite used in this work was the "verde ubatuba" as it is commercially known. For obtainment of the compound to be deposited on the substrate was initially performed the granite powder production. After grinding the granite, granite powder was mixed with a flux (B_2O_3/Bi_2O_3) and a binder. It was used 2 types of binder, Araldite type A and Araldite type B. One of the compounds was only obtained with the powder of granite. Other selective surface compound was obtained by mixing the granite powder with CRFO.

After obtaining the compound, this was deposited on the copper substrate through the process known as screen printing in which a spatula is used to perform the spreading of the compound on the substrate. This process was entirely manual, so that was almost impossible to obtain a perfect homogeneous surface, which influences the results. The commercial surfaces takes great advantage in this aspect, since the process is 100% automated and techniques are well mastered. The plate with the coating was putted in the resistive oven to sintering. The sintering parameters are shown in the fig. 1 below.

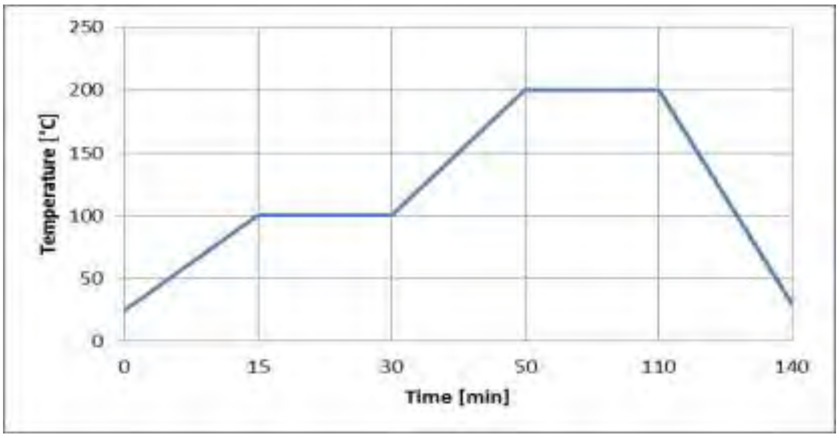

Figure 1. Sintering parameters chart

The compounds deposited on the substrate are the absorber plate with a selective surface. The tab. 1 below shows the mass percent composition of each compounds in each plate.

Table 1. Compound mass percent composition

Components	Plate 1	Plate 2	Plate 3	Plate 4
Granite powder [%]	64,2	64,2	32,2	32,2
CRFO [%]	-	-	32,2	32,2
Araldite type A [%]	32,3	-	32,1	-
Araldite type B [%]	-	32,3	-	32,1
Flux [%]	3,5	3,5	3,5	3,5
Total mass [g]	0,63	0,63	0,63	0,63

The absorber plate substrate was copper plates 40 x 40 x 1 mm, and they are shown in the fig. 2 below.

a) 
b) 

c) 
d) 

Figure 2. Absorber plates. a) plate 1; b) plate 2; c) plate 3; and d) plate 4.

The plates 1 and 2 were synthetized with granite powder; plates 3 and 4 were synthetized with the powder and CRFO mixture. Plates 1 and 3 had Araldite type A as binder, and plates 2 and 4 had Araldite type B as binder.

2.2 Solar collector prototype and experimental apparatus

A solar collector prototype was used to test the selective surfaces. It was wood made. The external structure of wood had these dimensions, 220 x 465 x 100 mm, 15 mm thickness and has three slots, where the copper plates coated with compounds of granite and a mixture of CRFO and granite was posted. The glass cover had a thickness of 5mm and dimensions of 210 x 445 mm. Its transmissivity τ = 0,885. This prototype was used in a master degree thesis, so to avoid loose time, it was decided to use the same apparatus for this paper. Figure 3 below shows the dimensions and parts of the solar collector prototype.

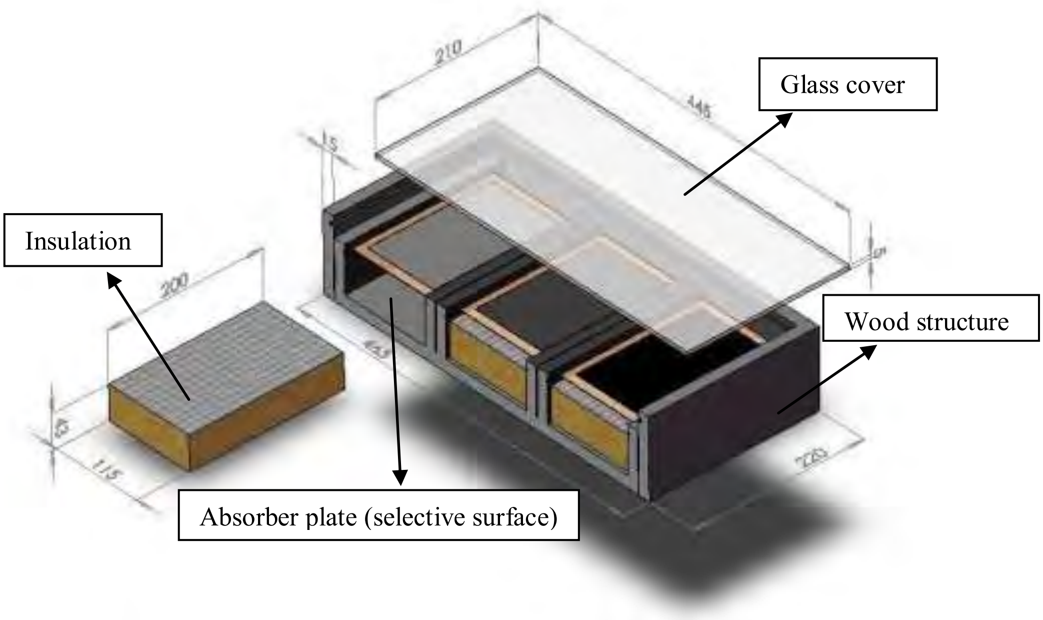

Figure 3. Solar collector prototype dimensions and parts

ISSN 2176-5480

Figure 4 below show the real solar collector prototype used for the tests.

Figure 4. Solar Collector Prototype

The testing equipment also had thermocouples type K for temperature measurements. The data were collected by a data logger Hyperlogger Portable Data Logging System and stored in a computer. It was also used a pyranometer to take the sun radiation measurement for future calculations of global collector efficient and some properties, like absorptance and emittance, but this isn't the scope of this paper.

2.3 Tests

The experimental apparatus was exposed to sun light during 6 days, from 01 June to 07 June 2013. It had been exposed to solar irradiance about 8 hours per day. The thermocouples were placed at the bottom of the absorber plates. Temperatures were taken in an interval of 1 min. The experimental procedures are described below:

1- put the experimental apparatus under sun radiation exposure;
2- turn on data logger and to registering temperatures;
3- take the measurement data by a computer; and
4- turn off the equipment.

3. RESULTS AND DISCUSSIONS

Firstly, it was shown that the selective surfaces based on granite powder were successfully obtained through screen printing and sintering processes, with good homogeneity and adhesion. The temperature tests results are described below. Figure 5 to fig. 10 shows the plates temperatures comparison chart of each day and the solar irradiance.

ISSN 2176-5480

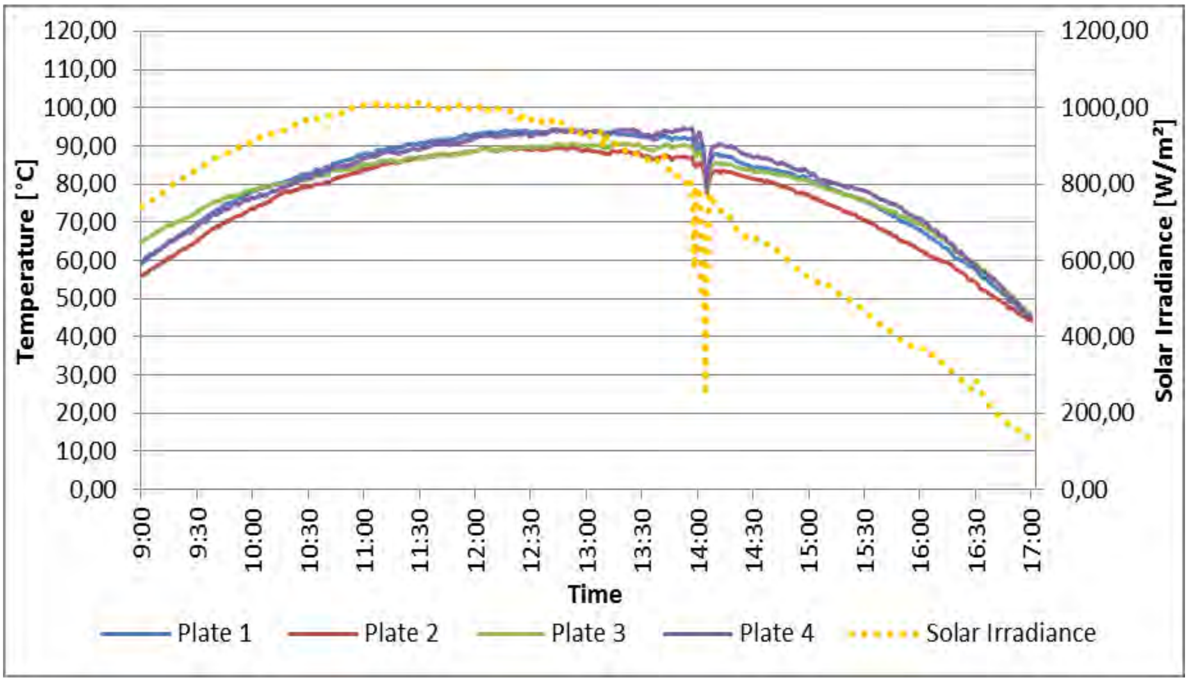

Figure 5. Plates temperarures comparison on 01 July 2013.

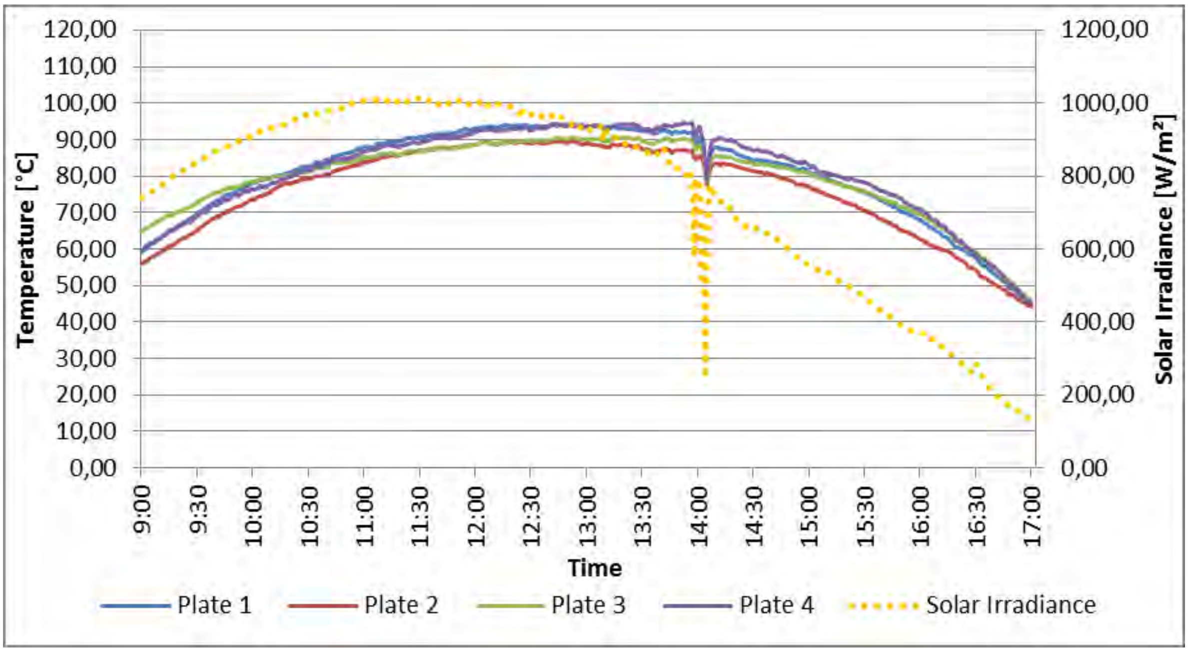

Figure 6. Plates temperarures comparison on 03 July 2013

ISSN 2176-5480

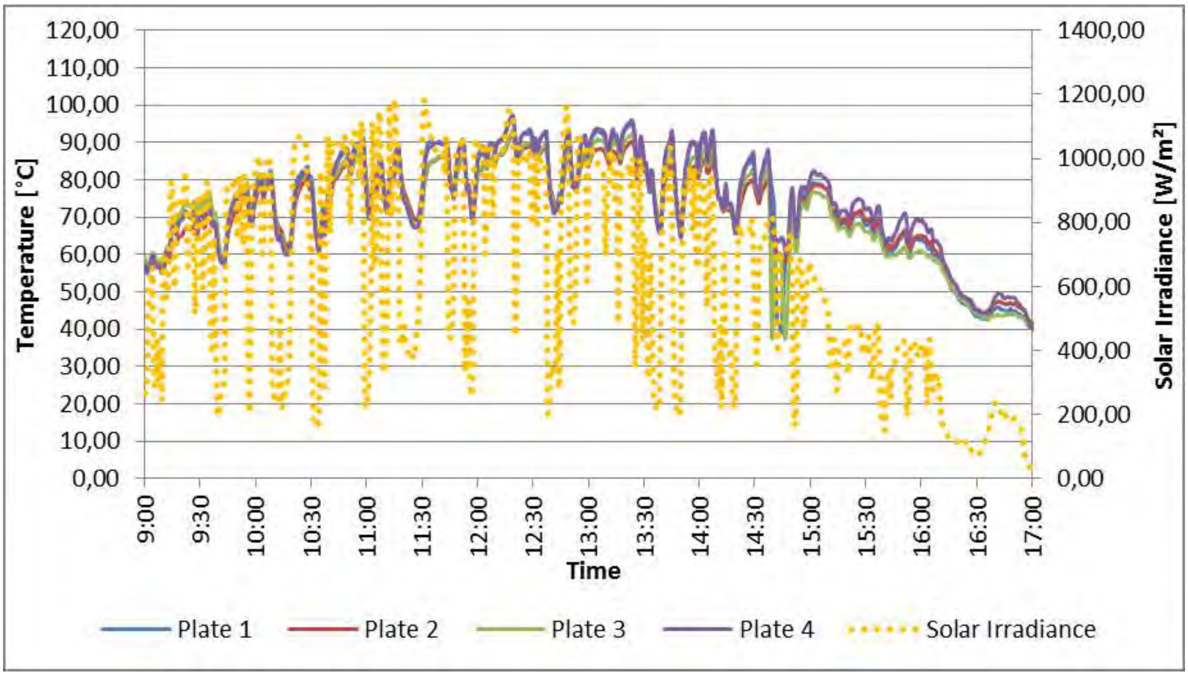

Figure 7. Plates temperarures comparison on 04 July 2013

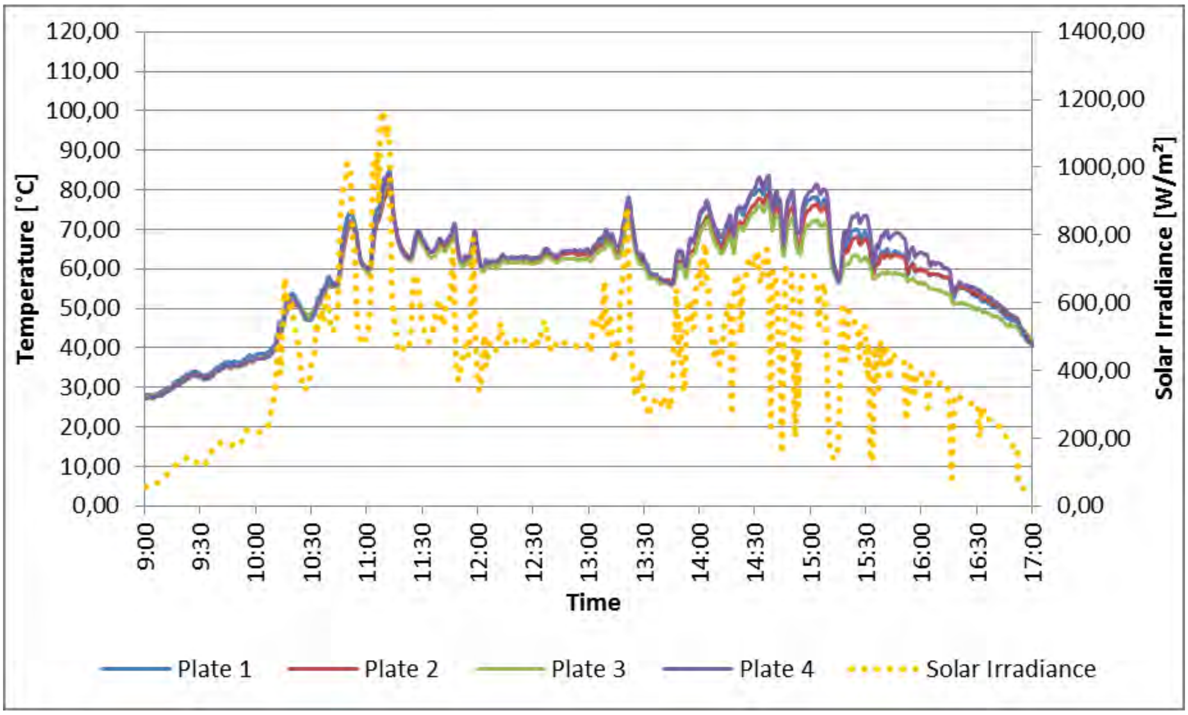

Figure 8. Plates temperarures comparison on 05 July 2013

Figure 9. Plates temperarures comparison on 06 July 2013

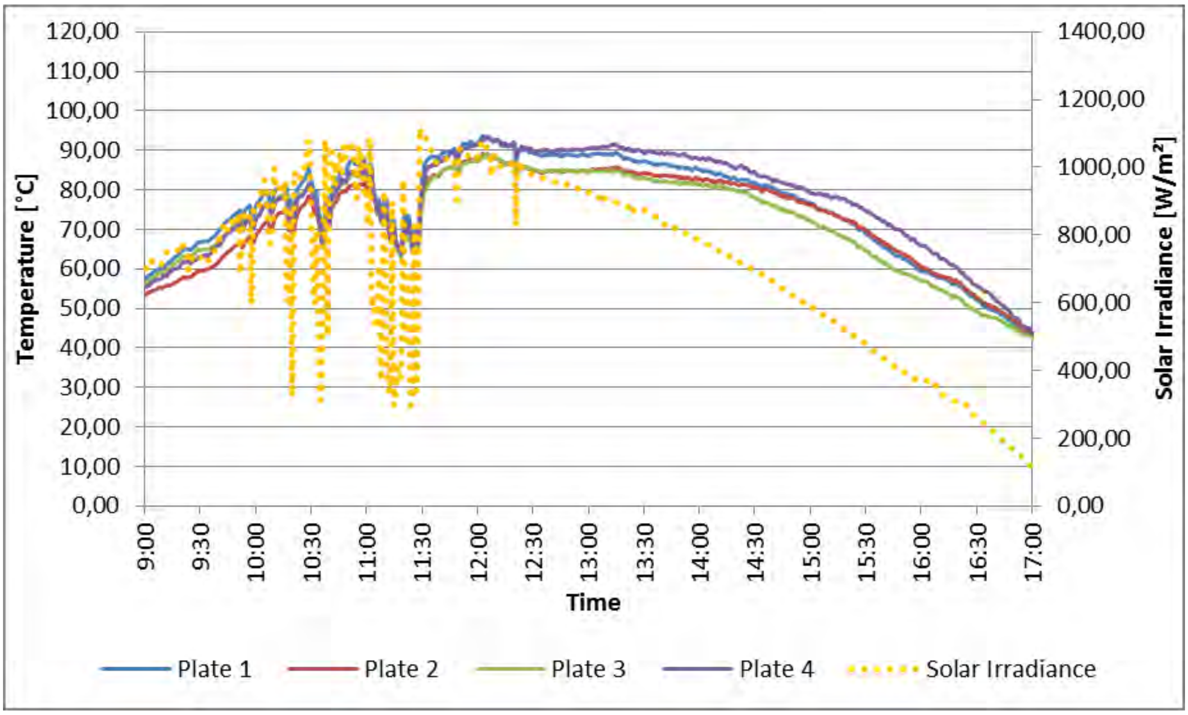

Figure 10. Plates temperarures comparison on 07 July 2013

As it is shown in the figures above the plates reached temperature about 90 °C. For example, in the fig. 5 when the mean solar irradiance was about 970 W/m² the plate 4 mean temperature was about 90 °C. All figures show that the plate 4 reached highest temperatures and the plate 3 the lowest. The plate 4 was made with a mixture of granite powder and CRFO, as well as plate 3, the difference between these two plate is only the binder, plate 4 uses Araldite type B while plate 3 uses Araldite type A. It’s also possible to see the thermal inertia of all plates, since even there was a great fluctuation in the solar irradiance almost all days, there is a delay on the surfaces temperatures oscilation. In the figure 5 and 6, this phenomenon is more clear, even the solar irradiance started to decrease about 12h30, the surfaces temperatures continued to increase.

ISSN 2176-5480

Vieira (2011) made experimental tests with selective surfaces based on CRFO and FCTO and comparated it to a commercial surface (known as TiNOX). In his results it is shown that TiNOX reachs temperatures about 110 °C when the solar irradiance was about 950 W/m². As was mentioned, TiNOX is a commercial selective surface, made through a automated manufacturing process, so it has a great advantage on the surfaces obtained for this paper.

4. CONCLUSIONS

In this paper, 4 different selective surfaces for low cost thermal sollar collector were obtained and tested in field. These 4 coatings can be deposited by screen printing process, with good adhesion and homogeneity. The analysis was made considering the surfaces temperatures and solar irradiance recorded data. Based on this, it was shown that the temperatures reached by the obtained surfaces allow its commercial use, if compared with results of commercial surface, shown by Vieira (2011). The binder has a significative influence on surface temperature, as well as its combination with CRFO. Therefore, it can be concluded that selective surfaces based on granite powder could be a good option in a soon future, considering its low cost and ecofriendly features.

5. REFERENCES

Barshilia, H. C., Selvakumar, N. and Rajam, K.S., 2007. “Thermal stability of TiAlN/TiAlON/Si3N4 tandem absorbers prepared by reactive direct current magnetron sputtering”. Journal of Vacuum Science and Technology A 25, p. 383-390.

Duffie, J.A. and Beckman W. A., 2006. *Solar Engineering of Thermal Processes.* John Wiley & Sons, New Jersey, 3rd edition.

Grangvist, C. G., 1991. “Solar Energy Materials – overview and some examples”. *Applied Physics. A – Solids and Surfaces,* 52, p. 83-93.

Handich, E. and Pettit, R.B., 1981. “Solar selective properties and high temperature stability of CVD ZrB2”. *Solar Energy Materials 5*, p. 425-435.

IGEO-UFRJ, 2005. “Geosciences Institute of Federal University of Rio de Janeiro Yearbook”. p. 139-151.

Madhukeshwara, N. and Prakash, E. S., 2012. “An investigation on the performance characteristics of solar flat plate collector with different selective surface coatings”. International Journal of Energy and Environment, Vol. 3, Issue 1, p. 99-108.

McEnaney, Kenneth, 2010. *Modeling of Solar Thermal Selective Surfaces and Thermoeletric Generators.* M.Sc. thesis, Massachusetts Institute of Technology, Massachusetts.

Quaschining, V., 2005. *Understanding Renewable Energy Systems.* Earthscan, London and Starling.

Schimidt, R.N. and Park, K.C., 1965. “High-temperature space-stable selective solar absorber coatings”. *Applied Optics,* Vol. 4, p. 917-927.

Shuler, A., Geng, J., Oelhafen, P., Brunold, S., Gantenbein, P. and Frei, U., 2000. “Application of titanium containing amorphous hydrogenated carbon "lms (a-C : H/Ti) as optical selective solar absorber coatings”. Solar Energy Materials & Solar Cells 60, p. 295-307.

Vieira, S.G., 2011. *Obtenção, Caracterização e Aplicação de uma nova Superfície Seletiva para Coletores Solares Térmicos.* M.Sc. thesis, Universidade Federal do Ceará, Ceará.

6. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.