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Research Article

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Study of surfaces, produced with the use of granite and titanium, for applications with solar thermal collectors

Abstract: The present work consisted in obtaining and studying selective surfaces for applications in low-cost flat plate solar collectors, using residues from the granite industry. Five different surfaces were studied, varying the percentage by weight: 100% granite powder, 75% granite powder + 25% titanium oxide, 50% granite powder + 50% titanium oxide, 25% granite powder + 75% titanium oxide and 100% titanium oxide.

For the tests, an experimental wooden bench was built, and it was possible to simulate the conditions of a flat plate solar collector. For characterization of the surfaces, SEM techniques, infrared analysis and UV-VIS absorbance determination were used, as well as graphs with surface temperatures and with radiation in the sun tests.

The efficiency of the surfaces was determined by the ratio of the absorptivity through the emissivity, as well as the trademark **MR**TiNOX. An efficiency of 23.58 was obtained for this, while for the 50% granite - 50% titanium surface the value of 23.30 (closest to the trade mark) was calculated. Therefore, replacing the traditional components of selective surfaces with granite proved to be a satisfactory solution, contributing to the reduction of costs with solar energy.

Keywords: selective surface; efficiency; granite; titanium

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1 Introduction

The increase in the lack of fossil energy sources, as well as the damage caused to the stratospheric ozone by the emission of carbon dioxide with the option of this type of energy source, has made the option for renewable energy more plausible.

In Brazil, in 2016, 43.5% of all energy produced came from renewable sources, and the energy generated in hydroelectric plants represented 29%, which is reflected in 68.1% of the electric energy produced. Wind and solar energy make up only 5.4% of the electricity produced in the country and does not have significant representation in the total percentage of energy (which includes electric, thermal and chemical energy). With regard to fossil fuels, these are responsible for almost 55% of all energy generated [1].

Solar energy can be used in the form of photovoltaic energy and solar thermal energy, which are non-polluting energy sources, unlike the vast majority of energy sources that pollute and harm the planet [2].

It is possible to find several types of solar collectors in Brazil, with national or imported manufacturing. With regard to flat collectors, there are models with and without cover. National thermally insulated glass cover collectors with black matte metal absorber range from R$500 to R$700, with areas of 1.5 to 2 m^2 [2].

Several solar thermal collectors are being researched and commercialized over the last few decades. One of the major problems with collectors is the coating stability on the receiver and the reflector [3].

The study of selective surfaces of solar thermal collectors is carried out by means of electromagnetic radiation. Thermodynamically, the ideal surface would absorb all the radiation, there being no reflection or transmission (black body) [4]. An ideal selective surface on the absorber plate of a solar thermal collector, consists of a material that has high absorption in the solar radiation band and high reflection in the emission band, which means low emissivity at the operating temperature. As no material has these char-

acteristics, it is sought to get as close to the ideal condition as possible.

In 2000, [5] deposited, through the processes of PVD (Physical Vapor Deposition) and PECVD (Plasma Enhanced Chemical Vapor Deposition), titanium films on aluminum substrate, for use in flat plate solar collectors. At first, only pure titanium was deposited on the substrate. Subsequently, a layer containing hydrogenated amorphous carbon (a-C: H/Ti) and titanium was applied, and another layer containing only pure a-C: H. With the XPS technique (X-ray Photoelectron Spectroscopy), it was possible to determine the compositions of the films used. Absorbance (α) values of 0.876, emission (ϵ) of 0.061 and selectivity s (α/ϵ) of 14.4 were reached. The estimated lifetime of the films produced was more than 25 years.

Selective surfaces on copper and on glass, using Cr-Cr_2O_3 and Mo-Al_2O_3 cermet, by means of magnetron sputtering deposition, were produced by [6] in 2001. By varying the oxygen flow during the deposition procedure, there were obtained multilayer surfaces with Cr-Cr_2O_3 cermet, which contributed to the improvement of optical performance. With this deposition technique, absorbance of 0.94 and emittance of 0.04 were verified using Cr-Cr_2O_3 on copper substrate. With Mo-Al_2O_3, although the absorbance was the same as 0.94, the emittance value increased to 0.09.

In 2005, [7] carried out experimental studies on silicon-carbon dissolved in aqueous media and deposited by spin-coating on a glass substrate of different thicknesses, and then passed through a heat treatment. The objective was to evaluate the emissivity and the absorbance of the surfaces, and the best results were found for films with a thickness of 1000 nm, which presented absorbance of 0.94 and emissivity of 0.15.

In 2007, [8] worked with TiAlN / TiAlON / Si_3N_4 in the production of selective surfaces, having the first two layers absorbing characteristics, and the third acting as an anti-reflective layer. Through the deposition technique known as reactive magnetron sputtering DC, the multilayer surface was applied to four different substrates: stainless steel, nickel, copper and **MR**Nimonic. Among the different applications of multilayers, the one that gave the best results reached, at a temperature of 82°C, absorbance of 0.958 and emittance of 0.07, for deposition on copper substrates.

In 2011, [9] used the screen-printing technique to obtain new selective surfaces based on chromium, iron and titanium. These surfaces could be compared with existing commercial surfaces and characterized by Raman and Infrared spectroscopy. He obtained absorptivity values around 0.79 for his CRFO cell and, for his FCTO cell, around 0.74, both very close to the cells obtained by [7], who, for a silicon-carbon film, obtained an absorptivity value of 0.84.

In 2013, [10] worked with CrMoN (H) / CrMoN (L) / CrON in the production of selective surfaces, making use of magnetron sputtering deposition DC reactive technique. For work at low temperatures, the surfaces applied on aluminum substrate were used, and at medium temperatures the stainless-steel substrate was chosen. At a temperature of 82°C, the CrMoN / CrON layers reached absorbance values of 0.90 and emittance of 0.08, when applied on aluminum substrate. On the other hand, with average temperatures, absorbance values of 0.92 and emittance of 0.13 were obtained with the multilayer surfaces applied on stainless steel.

In 2016, [11] evaluated through tests the potential use of sugarcane bagasse ash as raw material for the production of absorbent films. Two deposition techniques were used on three types of substrates, and it was concluded that the sugarcane bagasse ash presented intrinsic selectivity, with potential use for the production of solar absorber films. The best results of the set (film and substrate) showed peak and average absorption of, respectively, 0.88 and 0.65.

The objectives of this work are to synthesize and to study selective surfaces for applications in low-cost flat plate solar collectors using titanium oxide and waste from the granite industry. It is intended to achieve a similar or even higher efficiency than the selective surfaces already on the market, thus making the process of manufacturing solar collectors more efficient, since reducing costs and manufacturing time is directly linked to the current import requirement of these surfaces.

2 Experimental

2.1 Surfaces preparation

The granite used in the present work is the green-ubatuba, as it is known commercially. Firstly, to obtain the compound to be deposited on the substrate, the granite was macerated. The procedure consisted in first breaking an entire block into smaller pieces with the use of a sledgehammer, obtaining granite grains. These were powdered through the use of a planetary mill, by inserting in the tech pots 97 g of zirconium balls for every 10 g of granite grains. The milling occurred for one hour, with rotation of 360 rpm.

With the granite powder, it was necessary to perform a separation according to the granulometry, since the diameters were not homogeneous. For this, sieves with different MESH numbers were arranged, collecting the contents retained in the MESH 200, that has aperture of 0.075 mm.

Table 1: Composition of selective surfaces.

COMPONENTS	SURFACE 1	SURFACE 2	SURFACE 3	SURFACE 4	SURFACE 5
Granite powder [%]	62,0	-	20,7	31,0	41,3
Titanium oxide [%]	-	62,0	41,3	31,0	20,7
MRNauticola B [%]	35,0	35,0	35,0	35,0	35,0
Flux [%]	3,0	3,0	3,0	3,0	3,0
Total mass [g]	1,6	1,6	1,6	1,6	1,6
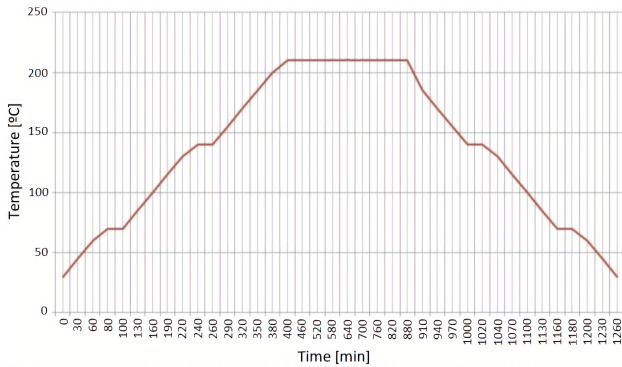
Figure 1: Sintering parameters of selective surfaces.

The composites were produced with the use of granite powder and titanium oxide, being combined in the following proportions: 25% − 75%, 50% − 50% and 75% − 25%. Two other surfaces were also synthesized: one with 100% granite and the other with 100% titanium.

As the samples produced were in the form of powder, the use of binders was necessary to make adhesion to the base material, transforming them into elements with viscous characteristics and adhering to metallic surfaces. In this work, the binder brand **MR**Nauticola B was chosen to perform the adhesion to the copper plates (substrate). To complete the deposited compound, the amount of 3%, by weight of the total amount of the samples, of B_2O_3 / Bi_2O_3 flux (a mixture of boron-bismuth in a 1: 1 molar ratio) was added to facilitate the fusion of the surface with the copper substrate. Without it, the surface would be brittle when handling the substrate. The compositions of each selective surface produced are set forth in Table 1.

After obtaining the compounds, the deposition was made on a copper substrate (4cm × 2cm plate, approximately 0.3mm thick), by means of the process known as "screen printing", in which a spatula is used to perform the scattering of those on this. Subsequently, the surfaces were heat treated (sintering) in a resistive kiln, following the parameters shown in Figure 1, so that the binder evaporated and, thus, the sintering process of the deposited compounds was completed. The heating rate was 0.5°C/min,

and the cooling of the copper plates occurred inside the kiln.

2.2 Test bench

To perform the field tests, an experimental bench in a box format was used. The structure was constructed from 2.5 cm thick muiracatiara wood with a colorless, tempered, and a 1 m × 12.6 cm and thickness of 4 mm **MR**Vivix float type glass cover. The workbench was divided into nine equal compartments, being covered in the lower part by rectangular pieces of glass wool, 11.5 cm × 8.5 cm and a thickness of 5 cm. The copper plates, with the selective surfaces deposited, were placed in each of these compartments, above the glass wool insulation, for testing in the sun. In Figure 2, there is the bench on one of the days of tests performed with exposure to solar radiation.

The bench was also composed of k-type thermocouples, for measuring the temperatures of the selective surfaces, the environment, the glass and the insulation, of an **MR**Eppley Horizontal Pyranometer, for the measurement of solar radiation, and of a datalogger, in order to register the obtained values.

Figure 2: Experimental bench for tests in the sun.

2.3 Performed tests

To characterize and verify the performance of the new selective surfaces obtained, the following tests were performed:

1. Verification of the morphological structure and chemical composition resulting from the synthetization of the material by means of EDX micro scanning electron microscopy (SEM), at the Analytical Center of the Federal University of Ceará (UFC);

2. Infrared analysis, with KBr inserts, in the Shimadzu apparatus, IRTracer-100 model, in the range of 400 to $4000cm^{-1}$, in order to determine if any composites were formed after the surfaces preparation in the resistive kiln;

3. Absorbance graphs, in the range of 185 nm to 1000 nm, obtained by analyzing the selective surfaces deposited in glass on Shimadzu's Uv-vis Spectrophotometer, Uv-2600;

4. Comparison between the performances of the surfaces, by means of tests carried out on the manufactured bench, in real ambient conditions, with temperature measurements and with calculations of absorbance and emittance.

3 Results

This section covers all the results obtained, being: average temperature and radiation graphs for tests in the sun, on April 23, 25 and 27, 2018, from 10:30 a.m. to 4:30 p.m.; absorbance graphs of the selective surfaces produced, mainly observing the visible light range (400 nm to 750 nm); graph of infrared analysis, comparing the peaks found; morphological characteristics and composition of selective surfaces produced and commercial, from images obtained in the SEM.

3.1 Field tests

Some tests in the sun were performed during the month of April 2018. Those that occurred in the presence of many clouds or even rain were excluded, taking into account only the data obtained on days 23, 25 and 27. Temperatures of six selective surfaces were saved every two minutes: granite; granite 75% – 25% titanium; 50% granite – 50% titanium; 25% granite – 75% titanium; titanium; **MR**TiNOX. Also the temperatures of the glass cover, the insulation and the environment were measured. The temperature averages, when the system reached the permanent regime, measured from 11 h to 12:30 h, are in Table 2.

The average radiation for the three days, in the steady state period (11:00 a.m. to 12:30 p.m.), was 978.7 W/m^2. The graph for the entire operating time range, from 10:45 a.m. to 4:10 p.m., with average temperatures and radiation, is shown in Figure 3.
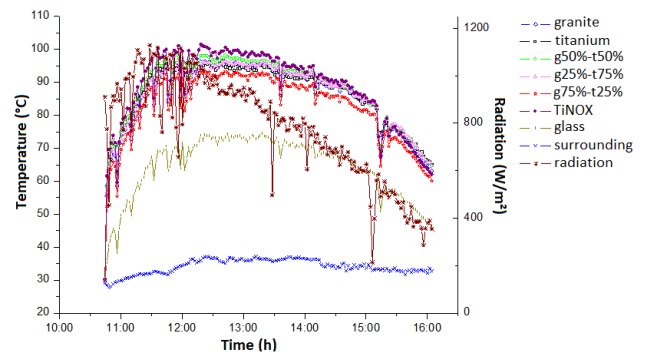

Figure 3: Comparison between average temperatures of selective surfaces.

Table 2: Average temperatures for steady state operation for selective surfaces, for the environment, for glass and for experimental bench's insulation.

MEASURED ELEMENTS	AVERAGE TEMPERATURE (°C)
Surface 100% granite	92,5
Surface granite 75% – titanium 25%	89,6
Surface granite 50% – titanium 50%	94,5
Surface granite 25% – titanium 75%	92,4
Surface 100% titanium	91,5
MRTiNOX	95,7
Glass cover	69,7
Insulation	42,5
Environment	34,7

3.2 Absorbance graphs of surfaces

One of the most important factors to consider in choosing a selective surface is the absorbance of each of them. Using Shimadzu's UV-VIS Spectrophotometer, Uv-2600, it was possible to plot the graphs in the wavelength range from 185 nm to 1000 nm, as shown in Figure 4.
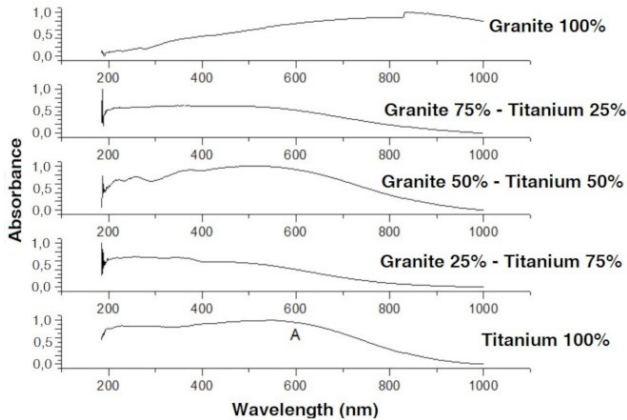

Figure 4: Absorbance graphs of selective surfaces produced.

It is observed that, on surfaces containing titanium, the absorbance has a maximum value of approximately 600 nm. The behavior of the surface graphs granite 75% – titanium 25%, granite 25% – titanium 75% and titanium 100% are similar: a constant value up to approximately 600 nm, beginning to show a sharp drop to 1000nm. The 50% granite – titanium 50% graph shows an increase in absorbance of 180 nm to 600 nm, when it also begins to fall to 1000 nm. Considering that the maximum absorbance is in the range of visible light (400 nm to 750 nm), there is a positive factor for better capture of solar energy. In the graph of the surface only with granite, there is a tendency of growth of the absorption in the range of 185 nm to, approximately, 830 nm. From there, the curve of the graph begins to show a decay.

3.3 Analyzes in the SEM

Electron microscopes are those that work by means of a beam of electrons, having capacity of magnification superior to the light's microscopes. They are basically divided into two main types: Electronic Transmission Electron Microscope (MET) and Scanning Electron Microscope (SEM).

According to [12], MET is recommended for the study of finer details of a cellular structure or of a molecular organization of viruses or subcellular constituents. This type of microscope has the disadvantages of being relatively complex, the specimens must be quite thin and, working with structures in three dimensions, the necessary information are more difficult to obtain. The SEM is the most used when studying the topography of surfaces of solid objects, although it does not provide (or provides very little) information about internal structures.

The SEM is a device with high resolution capability, through which it is possible to obtain images with great clarity with, for example, 10,000 times of magnification. The use of SEM with microprobe EDX (Energy Dispersive X-ray) is very useful in the investigation of microstructures, allowing elemental chemical analysis [13].

The micrographs, obtained through SEM, revealed the disposition of selective surfaces on the copper substrate. In Figures 5 to 8, morphological characteristics of the surfaces produced, according to the data of Table 1, are revealed.

In Figure 5, white particles, identified as the bismuth of the flux added in the preparation of the surfaces, are dispersed in a more compact layer of titanium oxide. There is little unfilled space, being the copper substrate almost completely occupied. Through 10,000 times of magnification, it is possible to identify, at some points, titanium oxide layer differences, which may be the result of the deposition method employed.

In Figure 6, particles composed basically of titanium, carbon, oxygen, silicon, iron and aluminum appear to be leaving the composition of the selective surface, being possible to observe a dispersion of their grains. There is considerable unfilled space, the copper substrate being uncovered by the non-uniform selective surface. A difference in grain size can also be seen in the same figure.

In the reference surface (**MR**TiNOX), it can be seen from Figure 7 that almost all of the copper substrate was filled. It is also possible to note a preferential direction of application of the selective surface, as a function of diagonal lines present in practically all the material. With greater approximation, dispersed grains of the main matrix are visualized, being identified oxygen, nickel, aluminum and chrome.

From the selective surfaces produced, the one that most approached visually of the commercial was 100% granite, according to Figure 8. Although the screen-printing technique was also used for all materials, only the granite not mixed with chrome was capable of filling the copper plate in a compact way. As in Figure 7, lines indicating a preferred direction of surface application are present, although with a smaller slope relative to the vertical direction.
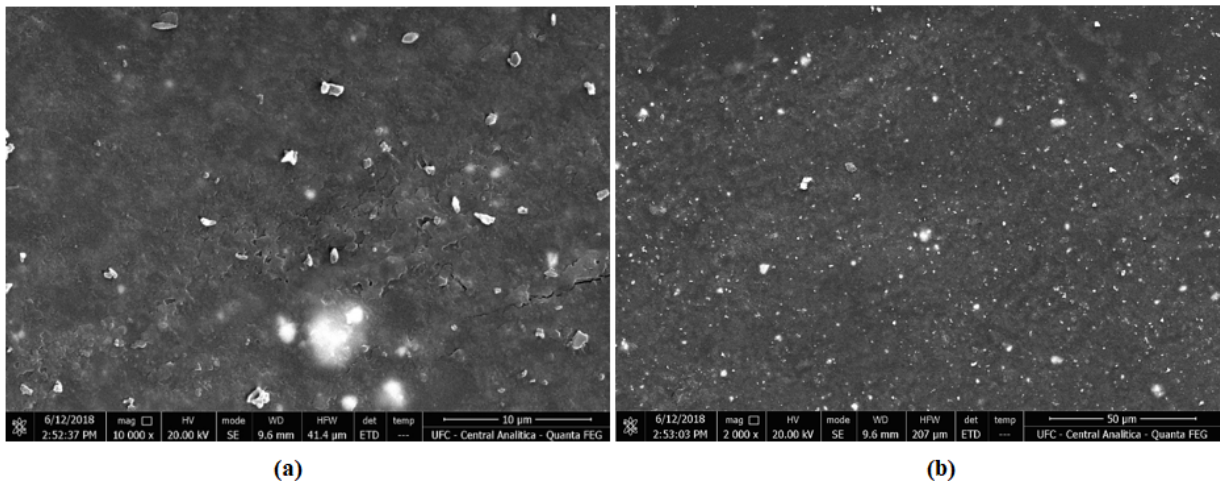
Figure 5: Micrograph of the selective surface sample of 100% titanium oxide, with magnification factor of: (a) 10000x and (b) 2000x.
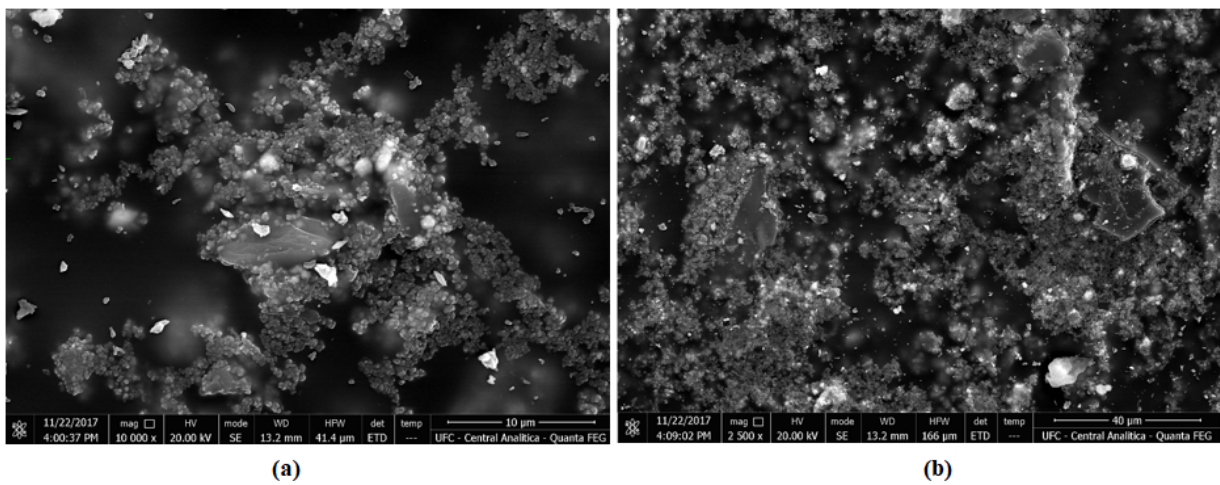

Figure 6: Micrograph of the selective surface sample of 50% titanium oxide – 50% granite powder, with magnification factor of: (a) 10000x and (b) 2500x.
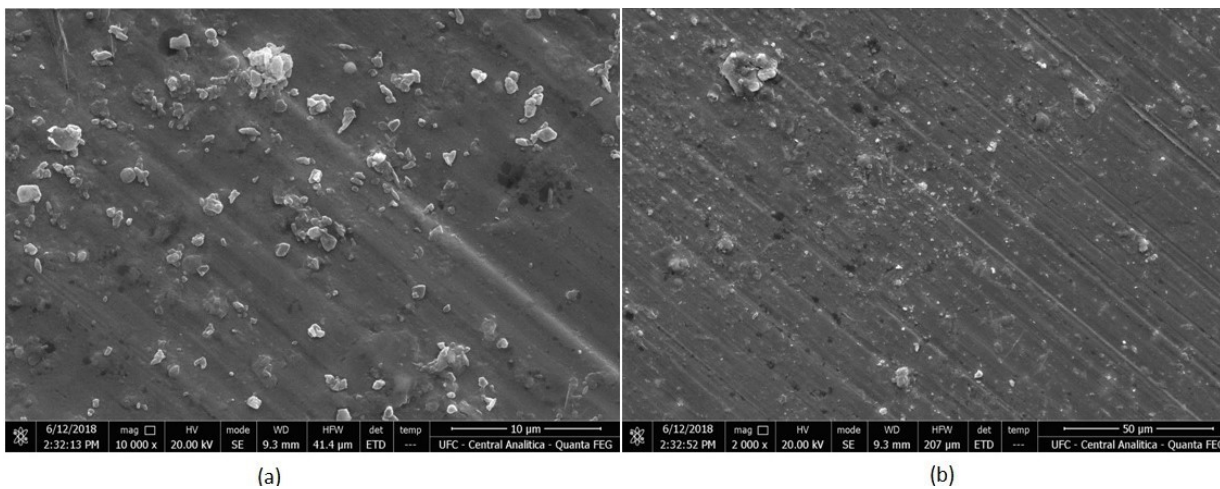

Figure 7: Micrograph of the **MR**TiNOX selective surface sample, with magnification factor of: (a) 10000x and (b) 2000x.
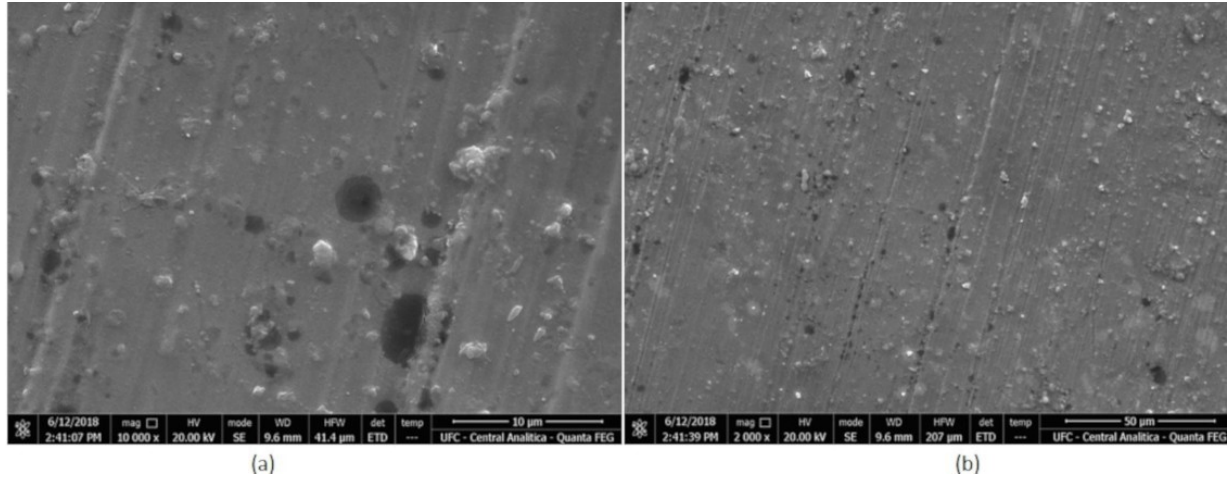
Figure 8: Micrograph of the 100% granite selective surface sample, with magnification factor of: (a) 10000x and (b) 2000x.

3.4 Infrared Analysis

The first spectrophotometers to emerge were the dispersive, of the analog type, that used monochromatic light to obtain the spectrum. Its main characteristics are: low sensitivity and scanning time of approximately fifteen minutes per sample [14] and [15].

With the development of the microcomputers, the IV spectra was estimated using the Fourier transform. With this, it was possible to perform the spectrum scanning faster when compared to the dispersive spectrophotometer. Another advantage of this evolution is to work with a more precise and reproducible wave number scale [15] and [16].

The absorption spectrum is reached as the continuous spectrum of light passes through a substance. Atoms and molecules generally absorb electromagnetic radiation at the same frequencies as they emit them, so it is said that both emission and absorption spectra are equivalent. This is due to the fact that, in the absorption, there is the inverse transition from the one observed in the emission spectrum [17].

The objective of this characterization was to identify the appearance of some component after the heating of the selective surfaces in a resistive kiln. Thus, analysis for only the titanium oxide, for only the granite powder and for the selective surface produced with 50% titanium – 50% granite was performed. The generated graph is shown in Figure 9.

Four major peaks are observed in Figure 9, in the following frequency regions: 3500 cm^{-1}, 3000 cm^{-1}, 1500 cm^{-1} and 1000 cm^{-1}, approximately. In all of them, the shape of the peaks coincides, differing only by the intensity, and no new components are obtained after the heating process.
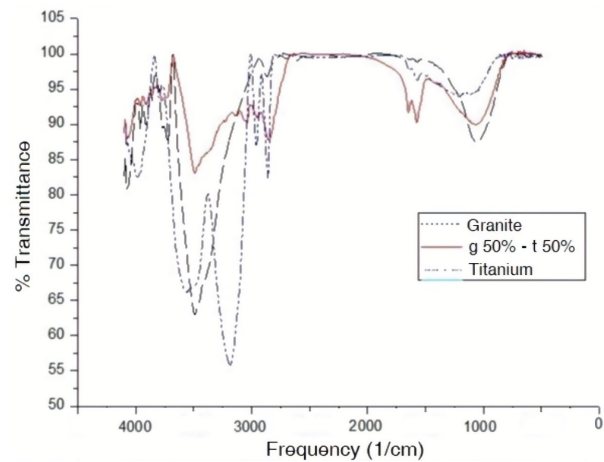

Figure 9: Sample transmittance graph with 50% granite powder + 50% titanium oxide, compared to the peaks with samples of 100% titanium oxide and 100% granite powder.

3.5 Surfaces' Efficiency

In order to compare the efficiency of the selective surfaces, it is necessary to perform an energy balance in the test bench with sun exposure. For this, the control volume around the copper substrate will be taken into account, as shown in Figure 10.

The incoming energy (Qin) is related to the solar radiation Rsol (W/m^2), with the transmissivity of the glass τ_V and with the absorptivity α_S and the area of the plate Ap (m^2) of the selective surface. Equation (1) represents the energy that arrives at the selective surfaces.

$$Qin = Rsol \times \tau_V \times \alpha_S \times Ap \qquad (1)$$

The losses involve the heat exchanged by convection, by conduction, by radiation and by reflection. Due to the

Table 3: Emissivity and absorptivity of selective surfaces to achieve efficiency.

SURFACE	ABSORPTIVITY	EMISSIVITY	EFFICIENCY
Surface 100% granite	0.90	0.039	22.90
Surface granite 75% – titanium 25%	0.86	0.038	22.52
Surface granite 50% – titanium 50%	0.93	0.040	23.30
Surface granite 25% – titanium 75%	0.90	0.039	22.88
Surface 100% titanium	0.88	0.039	22.73
MRTiNOX	0.95	0.040	23.58
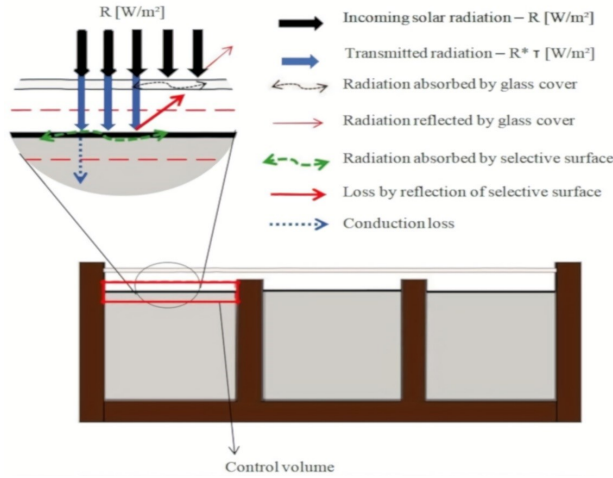
Figure 10: Test bench energy balance for operation of selective surfaces in the sun [9].

glass protection, only the natural convection between the selective surface and the glass cover is considered. The conduction loss occurs by thermal insulation, which has a thickness L of 5cm and thermal conductivity K of 0.04 W/mK. The Stefan-Boltzmann constant ($\sigma = 5{,}67 \times 10^{-8}$ W/m^{2}K^4) is used for radiation-related energy calculations. The energy lost by reflection represents the solar radiation reflected by the surface of the copper plates. Each of these parts is represented in equations (2) to (5).

$$Qconv = h \times Ap \times (Tp - Tcg) \qquad (2)$$

$$Qcond = \frac{K}{L} \times Ap \times (Tp - Tb) \qquad (3)$$

$$Qrad = \epsilon \times Ap \times \sigma \times (Tp^4 - Tcg^4) \qquad (4)$$

$$Qref = (1 - \alpha_S) \times Rsol \times Ap \qquad (5)$$

Where: Tp is the plate temperature; Tcg is the temperature of the glass cover; h is the coefficient of heat transmission by convection; Tb is the temperature near the outer

wall of the structure; ϵ is the emissivity of the selective surface.

For the control volume of Figure 10, the energy balance is indicated in equation (6). The transformed heat rate is zero because no power generation occurs.

$$Qaccumulated = Qin - Qout + Qtransformed \qquad (6)$$

In steady state, with temperature stabilization, the accumulated energy rate becomes zero. Thus, by inserting equations (1) to (5) in equation (6), the energy balance can be expressed by:

$$Rsol \times \tau_V \times \alpha_S \times Ap = \epsilon \times Ap \times \sigma \times (Tp^4 - Tcg^4) + h \qquad (7)$$
$$\times Ap \times (Tp - Tcg) + \frac{K}{L} \times Ap \times (Tp - Tb) + (1 - \alpha_S) \times Rsol$$
$$\times Ap$$

As the selective surfaces produced are not commercially available, their absorptivity and emissivity properties are not known, and it is needed to be calculated by equation (7). To do so, it is used equation (8), which represents the useful energy supplied by a solar collector to the fluid of work [18].

$$Quseful = Ap[Rsol \times \tau_V \times \alpha_S - Ul(Tp - Ta)] \qquad (8)$$

The overall coefficient of heat loss (Ul) is the same for all surfaces, since the operating conditions were identical. For the situation in question, since there is no use of thermal fluid, Quseful = 0. Thus, equation (9) is obtained, which is the adaptation of equation (8) for this study, considering Ta the ambient temperature.

$$Ul = Rsol \times \tau_V \times \alpha_S / (Tp - Ta) \qquad (9)$$

The commercial selective surface (**MR**TiNOX) has absorbance $\alpha_S = 0.95$ and emissivity $\epsilon = 0.04$, according to the manufacturer's data [19]. The transmissivity of the glass used is 0.87. Considering that the average radiation, for the interval from 11h to 12:30h, according to the graph of Figure 3, was 978.7 W/m^2, and that the commercial plate

and ambient temperatures were 95.7°C and 34.7°C, respectively, according to Table 2, the calculated global heat loss coefficient was Ul = 13.26.

Applying equation (7) to the commercial surface, knowing that the area of the plate used was Ap = 8×10^{-4} m^2, a coefficient of convection heat transfer h = 27.18 W/m^{2}K was found. Based on a range of 5 to 30 W/m^{2}K for this coefficient, in natural convection applications [20], the result calculated is assumed as plausible.

For the selective surfaces produced, and using the result for calculated Ul, the absorbance values are obtained by equation (9). Then, by equation (7), the emissivity of each surface is found. In order to compare the efficiency (f) of all selective surfaces, the absorptivity is divided by emissivity. For values f > 18, the absorber surface is considered highly selective [19]. All data obtained are summarized in Table 3.

Although no selective surface produced has exceeded the efficiency value of the commercial product, the emissivities found of those were equal to or less than the emissivity of this, and all of them can be considered highly selective.

One of the factors that also contributed to the fact that the obtained results did not reach the same standard of commercial surface quality was the way in which the deposition of the selective surface was made in the copper substrate. As it was worked with the granite, it was not possible to make the electro deposition, method of application used commercially and that provides a more uniform surface.

In a study of energy efficiency of solar heat concentrators using glass coated Al doped ZnO (AZO) transparent conducting oxide as selective absorber, the absorbance of the AZO films was calculated by varying their thickness from 100 nm to 1000 nm. As a result, an increasing absorbance pattern was observed with the reduction of the thickness, reaching a difference of approximately 23% between 100 nm (0.86) and 1000 nm (0.66) films [21].

According to the manufacturer's data [18], the **MR**TiNOX surface has a thickness of 250 nm, while the average thickness of the surfaces produced was eight times greater than the commercial surface (2000nm). Therefore, this was a factor that may also have contributed to the failure to obtain higher absorbance results for the selective surfaces produced.

Selective surfaces of titanium containing amorphous hydrogenated carbon films (a-C : H/Ti), for use in solar absorbers, were also obtained and tested [5]. A solar absorptance of 88% was found, being this result equal to that obtained with the surface of 100% titanium, according to Table 3.

4 Conclusion

Although none of the selective surfaces produced have exceeded the efficiency of the trademark **MR**TiNOX, they can all be considered highly selective, which represents a major step towards reducing the cost of solar collectors. The surface produced with granite 50% – titanium oxide 50% was the one that presented the closest efficiency to the commercial.

The main difference between the analyzed surfaces occurred in the absorptivity, varying from 0.86 to 0.95. The values of emissivity found were very close, and some selective surfaces produced reached numbers even smaller than the commercial product.

One of the ways to try to obtain better values for the efficiencies is to change the technique of applying the selective surfaces on the copper substrate. The process used in this work was the *screen printing*, but other forms of deposition, such as *spin coating*, could be tested.

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