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Using of Cement Bypass for Making Solar Absorbers

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Abstract

This study discusses the issue of absorbent surfaces used in the field of solar thermal energy and the method of manufacturing an absorbent surface from only one component instead of the traditional method that depends on the presence of a substrate and selective coating. This will be achieved using the wastes of cement factories. The samples were made from glass, which consists of cement factories waste (25 %) and silica sand with additives (75%). After manufacturing the basic sample of glass, free of any additives, it turned out to be a very transparent sample, which makes it not suitable to work as an absorbent surface. Therefore, some components had to be added to make the sample completely opaque. Accordingly, cobalt (0.2 and 0.4%) and basalt (10, 20, 30, and 40%) were added to the glass composition. The samples were investigated using XRF and tested for absorption in wavelengths from (280 to, 2400 nm). The best absorption sample was investigated using DTA to know the ability to do heat treatment.

Keywords: glass, cement bypass, solar absorbers, cobalt, basalt, absorbance

1. Introduction

Solar electricity represents between 5 to10 times the cost of electricity from fossil fuels, providing only 0.015% of global electricity demand. Solar heat provides 0.3% of the energy used to heat water. Global electricity demand is expected to double by 2030 and demand for fuel and heat will increase by 60%. The usage gap between the potential and use of solar energy can be overcome by increasing the efficiency of conversion processes.[1]

Solar thermal power plants produce high heat that is converted into electricity by conventional energy cycles.[2] Major solar thermal companies have already overcome the price of PV and natural gas, and have plans to beat the price of coal in the near future[3]. The issue will still be how to develop solar thermal technology to make it more economical. Now, there are two ways to collect solar heat; the first is the focus line group and the second is the focus point. Focusing on the line is less expensive, technically easier, but less efficient than focusing on points. Focus line technology consists of parabolic-shaped mirrors, which rotate on a single axis throughout the day,

tracking sunlight. The focus point technique consists of a series of mirrors surrounding the central tower. Mirrors focus sunlight on a point on the tower, which increases the heat of usable energy. The temperature of the mirror array with a focus can reach 250 °C. This is a sufficient temperature to operate the steam turbine, but at 500 °C and higher temperatures, the extra effort and cost balance through its capacity is more efficient. High efficiency is important because it reduces land use and the effective cost per kilowatt-hour of the plant. [3]

All solar thermal systems need solar absorbers to transform solar radiation into heat. The solar radiation spectrum is based on electromagnetic radiation which consists of many forms of energy such as visible light, infrared, ultraviolet, X-ray, etc. They are all parts of electromagnetic radiation that differ from each other in "energy.". Infrared and visible energy are the part of the sun's spectrum responsible for heating the Earth.[4]

Solar absorbers are materials with high absorption in the UV solar range but with low heat emissions in the IR range. They are called selective surfaces and are

extremely useful because they increase the absorption of solar energy and can inhibit re-heat radiation.[5] The spectral selective surfaces are the most costly component of a solar thermal collector.[6] The basic principle in the quality of any surface absorber is that it has a low associated heat emission (e) in the near-infrared (NIR) and far-infrared (FIR) wavelength ranges and high absorption (A) in the UV solar wavelength range. To obtain this condition, a material with a reflection of less than 10% in the UV range and more than 90% in the infrared range must be selected. The selectivity factor can be defined by the absorption / emission ratio (a / e); the higher the selectivity ratio, the more promising the material is for these solar applications.[7] Improving the overall efficiency of parabolic-trough solar power plants and increasing the operating temperature in solar energy to more than 400 °C aims to reduce the cost of solar electricity.[8] The next generation of power towers is designed to operate at temperatures of ≥ 650 °C. Cermet insulators currently used in water heaters have excellent optical properties, but are not suitable for power tower applications: they are sensitive to oxidation and suffer performance degradation at temperatures above 500 °C. Enhanced selective receivers must also be stable in the air , can be easily applied to large ranges, cost-effective, and saving thousands of dollars in the process of heating and cooling.[9]

The selective surfaces are mainly prepared by coating a substrate with a selective layer, which is facing some problems. The factors affecting coating quality include the method of deposition, solution pH, solution temperature, solution concentration, current types (ac, DC), current time, and current density. Initial cleaning of substrates plays an important role in the surface quality and the final optical coating. [10] Solar collectors (which rely mainly on selective coatings) must be designed to work for many years. Surfaces are usually exposed to oxidative and corrosive atmospheres, and operate at fairly high temperatures.[**11,**12] Methods of deposition include Chemical etching, electroplating, Chemical Vapor Deposition, RF and DC magnetron sputtering, sol-gel, and spray-painting.[13] Each method of deposition has its own advantages, and each method has a number of disadvantages. It is to be noted, that most of the problems will disappear if the absorbent surface is made of one material and does not consist of more than one layer. Selective surface roughening is a common technique used to obtain the highest absorption of matter through optical trapping of energy. It is possible to produce a surface that looks rough and absorbs visible energy and emits that energy badly in infrared radiation. [14]

A short summary of the selective surfaces is presented and discussed in the following. The surface of the stainless steel-aluminum nitride selective coating is generally uniform and measure absorption 0.9033 and emission 0.1317 by spectrum before annealing. After annealing below 500 °C for 1 hour, the sample had a higher absorption and less emission than the untreated sample. Stainless steel-aluminum nitride samples that were annealed above 500 °C were damaged and can no longer work. [15] Titanium-oxide cermet paint / aluminum showed an average absorbance was 93% before heating and an average emission was 9% before heating. The mean absorbance after heating was 93%, and the average emission after heating was 10%, confirm that there is no change in optical properties after heating. [16] Tests indicated that the maximum air exposure temperature was 600 K for TiB2 and 800 K for ZrB_2. Both substances exhibited spectral selectivity with an emission at 375 K ranging from 6% to 9%, solar absorption of ZrB_2 ranged from 67% to 77% while solar absorption of TiB_2 from 46% to 59%. Therefore, ZrB_2 was coated with Si_3N_4 anti-reflective material to increase absorption from 77% to 93%. [17] The individual layers of Cu-Co-Mn-O on the stainless steel substrate were first considered, and resulted in solar absorption of 86% $\pm$ 1% and thermal emissivity of 11% $\pm$ 1%, which is well suited for one coated layer.[18] To improve the solar absorption of the coating, an anti-reflective layer of silicon oxide (SiOx) was added. In this double-layer configuration, the solar absorption reached 94% $\pm$ 1% and heat emissivity of 11% $\pm$ 1% [18]**.** Using thermal hydrolysis succeeded in making MnCuFe-oxide spinels. Consequently, improvement of the spectral selectivity of the coatings was reached due to the lower emission values (<10%). [19] Black-nickel coating was measured after raising its temperature to 200 °C for 800 hours on a number of different substrates, and the result was: copper substrate α=95% ε= 9%, brass substrate α=94% ε= 11%, stainless steel substrate α=94% ε= 14%, aluminum substrate α=94% ε= 13%, metalized glass substrate α=91% ε= 11%.[20] Black-chrome coatings showed slightly lower solar absorption in comparison with black-nickel ($\alpha \approx 90\%$: 92%; $\varepsilon \approx 10\%$: 15%), but they stayed stable up to 300∘C. However, a relevant disadvantage related to chrome electrodeposition is represented by pollution

resulting from Cr+6 ions.[21] To make a good coating by black chrome, an initial deposition layer made from nickel on the substrate was required to ensure better chrome adhesion to the surface and improved corrosion and wear resistance.[22]

Optical properties were tested and the solar absorption of black ceramic coating ranged from 93% to 97%. The process of manufacturing a ceramic collector generally consists of four basic stages. First, ordinary ceramic raw materials are mixed with an appropriate amount of water and ground in a ball mill to powders of more than 120 meshes. Second, the biscuits were formed by plaster molds. Third, the biscuits were dried and sprayed with black porcelain paint V-Ti. Fourth, the biscuits were roasted in a cylindrical oven at a high temperature of, 1210 °C.[23] Pt-Al$_2$O$_3$ coatings are suitable for high temperature applications due to their high absorption and low emission at high operating temperatures, but their application remains difficult due to the high cost of platinum. Mo-Al$_2$O$_3$ cermet coatings were used in Luz receiver tubes that were used for solar thermal power plants. Although these coatings have good thermal stability in a vacuum, they have low thermal stability (≤ 300 °C) in the air. Siemens, Germany, modified the Mo-Al$_2$O$_3$ Cermet coating for higher thermal stability. W-Al$_2$O$_3$-based Cermet insulators are also commercially produced, which have been reported to be stable up to 500 °C in a vacuum. Mo - SiO2 and SS-AlN cermet coatings were successfully marketed to the receiving tubes by ENEA and TurboSun.[24] Single-layer black selective coatings were produced by low-cost sol-gel dip-coating, spin-coating, and coil-coating methods. For the deposition, a colorant dispersion was prepared by grinding a mixture of a black spinel (FeMnO$_4$) pigment. The prepared Nano-composite dispersion served as the deposition of coil absorber coatings (800 m) on aluminum coil. They gave excellent homogeneity and solar absorbance of 90.5% and thermal emittance of 12%. The stability of the coatings at 400 °C was brilliant, but corrosion resistance was moderate (5 days in salt spray). High Power (HIPO) solar coatings deposited on stainless-steel (AISI 316) served 1216 h at 460 °C and 400 h at 500 °C without change of selectivity, while after temperature 500 °C for 1216 h, thermal emittance greater than before to 5–7% but solar absorbance remained unchanged.[25]

Since the present research depends on the preparation of absorbent surfaces from the wastes resulting from cement factories, in order to be able to prepare absorbent surfaces at a cheap price, and to contribute greatly to the disposal of one of the important industrial pollution factors, so we will show some information about cement bypass. Cement bypass is present in various manufacturing processes such as stone extraction, raw material processing, and clinker grinding, mixing, packing and shipping of finished products. Cement is an adhesive such as powder, consisting of calcium oxide (CaO), aluminum trioxide (Al$_2$O$_3$), ferric oxide (Fe$_2$O$_3$), silicon oxide (SiO$_2$), magnesium oxide (MgO), selenium, shale, clay, Thallium, sand and other impurities .[26] Cement affects not only humans, but also directly affects the quality of the soil, adding a number of harmful substances to it. It produces toxic, carcinogenic and mutagenic substances, such as molecular materials, sulfur dioxide, nitrogen dioxide, volatile compounds, long-lived dioxins and heavy metals .[27] The burning and production of cement produce toxic gases that cause injuries to plants and animals. Cement dust causes many threats to the biological environment, which have harmful effects and toxic risks to plants and animal health.[28] The most important cause of industrial air pollution in Egypt is the presence of 26000 factories with old facilities, so the fuel was upgraded from diesel to compressed natural gas, and accordingly, a project supported by the Canadian International Development Agency established 50 factories using compressed natural gas near the CNG distribution facility and cement factories that is a major source of air pollutants. [29] Vitrification is a technique that involves the conversion of industrial waste into a stable and harmonious silicate glass through the process of smelting waste, with some modifications to the atch to reach a specific composition. Vitrification can accept wastes of different compositions and shapes, such as liquids, mud, solids or their mixtures. The only disadvantage of this technology is the cost of treatment, as the cost of disposal of industrial waste by burying it is still much cheaper than reprocessing.[30] Cement dust is made up of about 70% of the components of the glass batch, depending on the composition. The composition of cement kiln dust is adjusted by additives of other components such as silica sand, granite and magnesium. Batches are melted and then poured into glass that can be subjected to heat treatment to induce crystallization.

The glass produced before and after crystallization is characterized by extremely high hardness and high corrosion resistance.[31] Most glass products use the

Soda-Lime Silicate glass produced from sand (SiO_2), soda ash (Na_2CO_3), and dolomite ($CaMg(CO_3)_2$)) with the addition of alumina (Al_2O_3). They are usually used in many products such as tableware, glass sheet, and containers. The glass smelting process is developed to save energy by applying the concepts of standard glass fusion and separating the three basic processes: melting of components, thermal grain disintegration, and removal of bubbles. The advantage of the standard glass fusion concept is to reduce the residence time of the glass melting process by avoiding seeds and bubbles.[32]

As no previous work was found in the literature dealing with the fabrication of absorbers from cement bypass, the purpose of this work is to prepare glass based on the cement by-pass with cobalt and basalt addition in order to prepare solar absorber material. Samples will be investigated for their optical properties and characterization will be made using XRF and DTA.

2. Experimental Work

Two groups of samples were prepared; the first group is the cobalt group and the second group is the basalt group.

The cement bypass, basalt and silica sand were analyzed by x-ray fluorescence (XRF) on (Axios PAnalytical 2005 Sequential WD_XRF Spectrometer) to determine the chemical composition of the raw materials.

According to this analysis, the samples were prepared by mixing the glass forming raw materials, cement bypass and silica ore such that the silica

content reaches approximately 70 at%. Then, the additives (cobalt and basalt) were added according to Table 1.

Every batch was crushed and milled for 20–30 min in an agate mill (SD series rapid laboratory mill). Then melted in a crucible made of platinum that was cleaned before working with sodium carbonate Na2Co3 and then sterilized with hydrochloric acid Hcl for 20 minutes to ensure the results then melted in an oven model (Carbolite HTF - High Temperature Laboratory Chamber Furnaces) at 1400–1450 °C for about 1:2 hours. During the melting process, sampling molds should be prepared by heating them before casting in an oven model (Wisd FP-14) at a temperature of 600 °C to prevent the thermal shock of the resulting glass. Then the glass was poured onto the molds and left to solidify, then transferred to a preheated muffle furnace (Wisd FP-14) at 550 °C for about 8 hours. After the preparation of the required glass, the samples were cut and the upper surface was polished to be suitable for the necessary measurements and tests.

Sample characterization:

To achieve a successful solar harvest, it is recommended to increase absorption in the UV range. Reflection spectra were collected in the UV-NIR range by a wavelength range between 200-2400 nm. For measuring the absorbance in UV range a UV-Visible-NIR Spectrometer model UV-3600, UV-VIS-NIR Spectrophotometer from **Shimadzu Co**., Japan was used.

$$\alpha = \frac{\int_{.28}^{2} I_{sol}(\lambda)(1-R(\lambda))d(\lambda)}{\int_{.28}^{2} I_{sol}(\lambda)d(\lambda)} \quad \text{.............. (1)}$$

Table 1. Chemical composition of batch mixtures (note that these contents are in g, and they will result in 100g of glass after LOI)

Group	Group (1)			Group (2)			
Sample designation	Base	Cobalt 0.2%	Cobalt 0.4%	Basalt 10%	Basalt 20%	Basalt 30%	Basalt 40%
Symbol	Bs	C2	C4	B 10	B 20	B 30	B 40
Bypass	23.58	23.58	23.58	21.22	18.86	16.51	14.15
Silica Sand	67.88	67.88	67.88	61.09	54.3	47.52	40.73
Al_2O_3	0.63	0.63	0.63	0.57	0.5	0.44	0.38
Na_2CO_3	23.94	23.94	23.94	21.55	19.12	16.76	14.36
$MgCO_3$	0.67	0.67	0.67	0.6	0.54	0.47	0,4
Co_2O_3	-	0.2	0.4	-	-	-	-
Basalt	-	-	-	10	20	30	40

Equation (1) that used to obtain the absorption for opaque materials was modified to include transmission and calculated with equation:

$$\alpha = \frac{\int_{.28}^{2.4} I_{sol}(\lambda)\big(1-R(\lambda)-T(\lambda)\big)d(\lambda)}{\int_{.28}^{2.4} I_{sol}(\lambda)d(\lambda)} \quad \ldots\ldots\ldots\ldots \quad (2)$$

Where: α Average Absorptivity, I_{sol} Solar irradiance, λ Wavelength, R Measured reflectance and T measured transmission.

Differential thermal analysis DTA for samples B30 and B40 was made because they have achieved the best optical properties in the basalt series, and we will not do DTA test for the series of cobalt because it is still Amorphous where it does not contain metals that are responsible for convert the glass to crystalline after heat treatment. The DTA scans of the glasses were carried out using a Perkin-Elmer Micro differential Thermo-analyser.

Visual Observation: It is noted that the dimensions of the samples were unequal due to several reasons, including: the difference in the amount of liquid glass resulting from the melting process, the difference in the number of bubbles in each batch, the difference in the size of the crucible during which the smelting, the difference of human skill during the casting of samples in the mold, a slight difference It results in changing the dimensions of the casting mold each time and the speed of casting the samples in the mold.

It was noticed that in the base sample, the resulting glass is of a light amber color and not pure glass, because of the impurities present in the cement bypass, which always varies in proportions and does not have

4. Results and Discussion:

specific proportions for each process of collecting cement bypass.

It was found that the cobalt samples were fragile and easy to break during casting. It was also found that they contained internal bubbles that hindered the process of cutting and levelling the surface. Therefore, the samples with cobalt were smaller than the samples with basalt due to the attempt to select the best part of the basalt during cutting and levelling the surface.

Optical Properties on UV Range: The optical properties of all samples were measured in the UV range (reflection - absorption - transmittance) due to the fact that the samples are glass and most of the samples have transmittance. This is in order to determine the best absorbance among all tested samples.

Reflection: The reflection was measured for the first group as shown in Figure 1 and for the second group as shown in Figure 2.
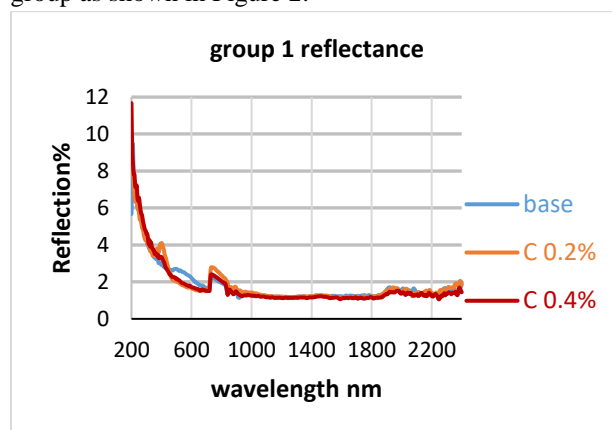

Fig.1 Group1 reflection (base- .2% cobalt- .4% cobalt)

X-ray fluorescence (XRF): The cement bypass, basalt and silica sand were analyzed by x-ray fluorescence (XRF) to determine the chemical composition of the raw materials. The results are listed in table 2.

Table 2.**The XRF analysis of cement bypass, basalt, and silica sand**

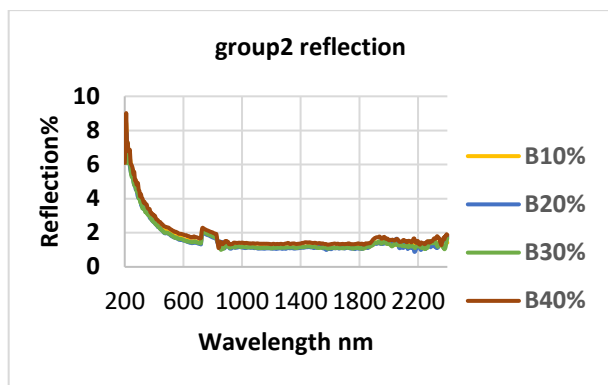| Elements (%)	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	Na_2O	K_2O	LOI
W. Basaltic rock	37.85	11.51	23.93	2.37	11.85	4.37	2.05	1.11	4.96
By-pass cement	19.03	4.97	3.37	2.23	48.77	0.78	1.67	4.52	14.66
Standard sand	71.7	1.8	0.04	-	11.5	0.5	14	0.2	0.86

Fig.2 Group2 reflection (10% basalt-20% basalt-30% basalt-40% basalt)

It is noted from both figures that Cobalt and Basalt additives did not affect noticeably the reflectivity of the glass, as the reflection results of the samples are very close to each other. It is to be noted that most reflection values range between 1 and 2%. For a good absorber, the reflection should be as low as possible. These results are promising as they indicate a low reflectivity (<2%).

Transmittance: The Transmittance was measured for the first group as shown in Figure 3 and for the second group as shown in Figure 4.
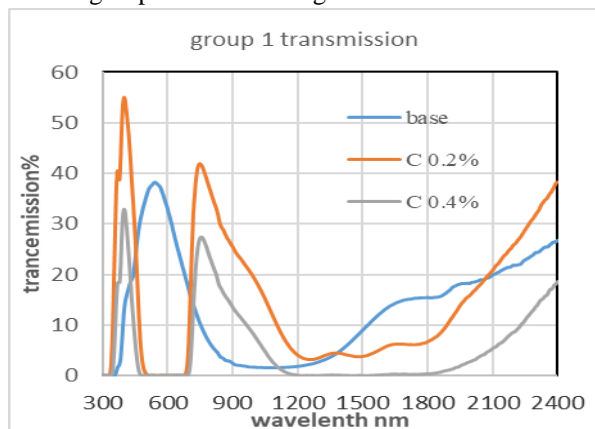

Fig.3 Group1 transmittance (base- .2% cobalt- .4% cobalt)

From figure 3, we notice that all Group 1 samples are characterized by high transmittance despite the addition of cobalt and an increase in its percentage. It reaches 47% in the case of the basic sample at the wavelength 500 and up to 32% in the case of 0.4% cobalt at the wavelength 350, due to the samples became darker. But in case of figure 4 notice that the results of add basalt are completely different from add cobalt, due to basalt is black compound. Note that the sample basalt10% was still transparent, so it considers the highest transmittance in group2, while the other three samples have close transmittance between 0 and 1%.
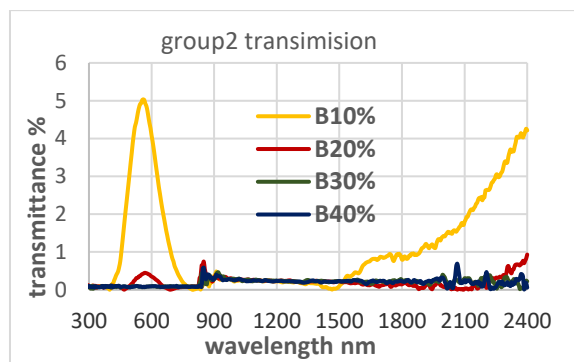

Fig.4 Group2 transmittance (10% basalt-20% basalt-30% basalt-40% basalt)

Absorbance: The absorbance was calculated based on the fact that A + R + T = 1 where: A is absorbance, R is reflection, and T is transmittance. The absorbance first group as shown in Figure 5 and for the second group as shown in Figure 6.
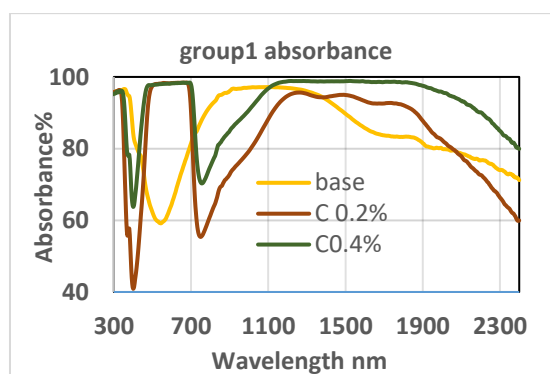

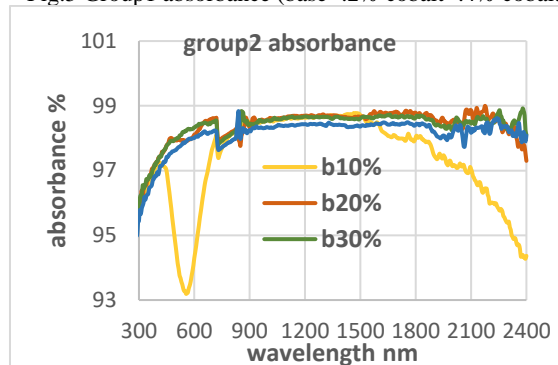Fig.5 Group1 absorbance (base- .2% cobalt- .4% cobalt)

Fig.6 Group2 absorbance (10% basalt-20% basalt-30% basalt-40% basalt)

From **figure 5** note that the sample cobalt 0.4% is the best sample absorbance in group 1 while from **figure 6** note that basalt 10% is the less absorbance percentage and the other three sample are almost identical.

After having the three main terms of optical properties and using the equation 1, we obtained the samples absorbance as illustrate in **table 3**.

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Table 3: **The absorbance result in UV range between 200-2400 nm wavelengths**:

sample	Base	Cobalt 0.2%	Cobalt 0.4%	Basalt 10%	Basalt 20%	Basalt 30%	Basalt 40%
absorbance	82.5	82.8	91.2	96.9	98.1	98.2	97.9

Differential Thermal Analysis (DTA): Differential thermal analysis (DTA) was done to know the temperature required for the conversion of both samples of amorphous glass to the crystalline phase (exothermic) and we can analyze the DTA to identify the temperature at which the glass begins to convert to crystal (endothermic) and **Figure 7** shows the temperatures of the sample 30% basalt where it shows that the temperature of the endothermic is 697 °C and the exothermic temperature is 880 °C. As for the sample 40% basalt, the temperature of the endothermic is 706 °C and the temperature of the exothermic is 850 °C.
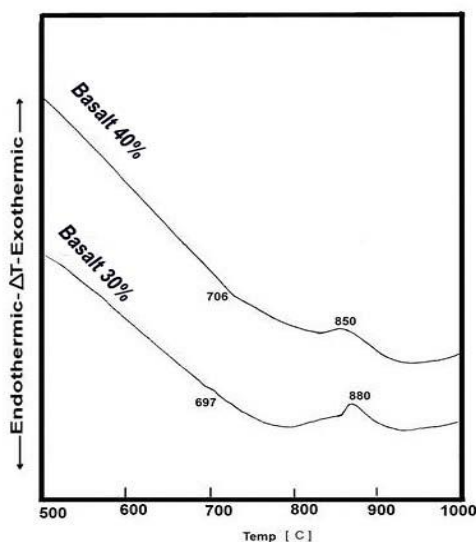

Fig. 7 Differential thermal analysis (DTA) for B30 and B40 samples

Notice that there is increase of the temperature in the sample B40, which means that the sample is able to withstand a higher temperature without any changes, which gives us great hope that this sample is suitable for high temperature solar thermal applications (> 500).

5. Conclusions:

In this paper, the possibility of manufacturing absorbent surfaces from only one material was studied, instead of manufacturing absorbent surfaces from substrates and coatings. Cement bypass was used to turn it into glass used for made absorbent surfaces, as cement dust is considered a very dangerous substance to the environment and is disposed of for

free. For this purpose, the glass samples were prepared and divided into two groups with two different additives, cobalt and basalt. The first group consists of the main sample, cobalt 0.2% and cobalt 0.4%, and the second group is made up of basalt 10%, basalt 20%, basalt 30% and basalt 40%.

The absorbance was measured for all samples, and it was found that the first group gave low absorbance, where absorbance for base sample is (82.5), absorbance for 0.2% cobalt sample is (82.8), and absorbance for 0.4% cobalt sample is (91.2) while the second group gave excellent results, especially samples basalt 20% (98.1% absorbance), basalt 30% (98.1% absorbance) and basalt 40% (97.9% absorbance).

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