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Short communication

All-ceramic solar collectors

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Abstract

A type of all-ceramic solar flat plate collector is introduced. These all-ceramic solar collectors are made from ordinary ceramic and V–Ti black ceramic. The ordinary ceramic raw material mainly means porcelain clay, quartz, feldspar etc. The vanadium–titanium black ceramic is synthesized from recycled industrial wastes. This type of solar collector has some advantages, such as low cost, long lifetime, no attenuation of absorptivity, and building integration. As can be seen these all-ceramic collectors can be used for a wide range of applications and provide significant benefits.

Keywords: A. Sintering; B. Composites; C. Color; E. Functional applications

1. Introduction

Flat plate solar collectors normally incorporate an absorber, a transparent cover, and a back and side insulation. The main materials of absorbers are copper, aluminum and steel [1]. In addition, the absorber coatings were studied, such as black nickel [2], black chrome [3], CoCuMnOx spinels [4], copper oxide [5], carbon/nickel oxide [6], and so on. However, from an economical point of view, traditional flat plate collectors are characterized by high cost. Their high cost is due to the use of expensive materials and the required accurate manufacturing phases [7]. Meanwhile, their lifetimes are no more than 20 years, because of the corrosion of metal and the attenuation of solar absorptivity. In the first Chemical Sciences and Society Symposium (CS3), scientists stated that "too often the focus is on efficiency: much more effort needs to be given to 'develop new catalysts and materials from low-cost, earth-abundant elements that can be used to build affordable, sustainable solar energy'" [8]. In other words, materials of collectors should combine the advantages of suitability, mass production, cheap, and long life insurance.

Ceramic is one of the cheapest engineering materials and the most used materials for technical applications. Moreover, ceramic also is a very interesting material for solar thermal collector construction, because it combines good thermo-physical properties with a high workability and stability to thermal stresses. Ceramic honeycomb and foams have been used in concentrating solar power (CSP) systems because of their stability at high temperature [9]. Herein, we report a type of flat plate collector made from ceramics. Both absorbers and absorber coatings are made from ceramics. This type of solar collector has some advantages, such as low cost, long lifetime, no attenuation of absorptivity, and building integration.

2. Manufacture of the solar collectors

2.1. Materials

The absorber material of this type of all-ceramic solar collector is ordinary ceramic raw materials. The ordinary ceramic raw materials mainly mean porcelain clay, quartz, feldspar, etc. In fact, most ceramic products have a certain requirement of whiteness. However, all-ceramic solar collectors have black or fuscous color, without whiteness requirement. Therefore, raw materials with higher Fe content can be used. The chemical constitution of a typical raw material is shown in Table1. The material of absorber coating is V–Ti black

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ceramic. The V–Ti black ceramic is produced using tailings of vanadium extraction as one of the starting materials [10].

2.2. Manufacturing process

The all-ceramic collector manufacturing process generally consists of the four basic stages: preparation of raw materials, shaping, drying and sintering. Firstly, ordinary ceramic raw materials were mixed with a suitable amount of water and ground in a ball-mill to powders of finer than 120 mesh. Secondly, biscuits were shaped by plaster molds. Thirdly, biscuits were dried and sprayed with V–Ti black ceramic coatings. Fourthly, the biscuits were sintered in a roller kiln with a high temperature of 1210 °C.

3. Performance characteristics

3.1. Physical performance

Table 2 shows the physical performances of biscuits and ceramics. The breaking strength of biscuits has an important influence on the yield of final products. The biscuit is easy to break when the breaking strength is lower than 16 Kg/cm^2. The sintering temperature of absorber material should match with the V–Ti black ceramic. The extortionate sintering temperature will lead to the disappearance of reticular formation of black ceramic absorber coatings, which will lower the solar absorptivity. For the solar collectors, it is good to have a highest possible value of thermal conductivity. Enhancement of thermal conductivity of ceramic can be achieved by adding Al_2O_3 to the ceramic paste [11]. However, a higher content of Al_2O_3 in the ceramic paste usually means to the higher sintering temperature. Here, the reticular formation of black ceramic absorber coatings is more important than the higher thermal conductivity. Therefore, the sintering temperature should fit the black ceramic absorber coatings firstly. The influence of thermal conductivity on the all-ceramic solar collector will be discussed in Section 3.3. The lowest value of the test-pressure of the all-ceramic solar collector is 2 bar. Moreover, the bursting pressure can be increased a number of times by transforming the structure or the wall thickness.

Fig. 1 shows an all-ceramic solar collector with an area of 0.5 m^2. The dimension is 710×710 mm^2. It is easy to change the dimension of all-ceramic solar collectors if necessary. All-ceramic solar collectors with other dimensions have been manufactured, such as 600×600 mm^2, 800×800 mm^2, and 1000×1000 mm^2.

3.2. Black ceramic absorber coatings

Absorber coating is one of the most important parts of the collectors. The coatings may be selective or nonselective. Selective absorber coatings mean high absorptivity for the solar spectrum and low emissivity for the infrared heat radiation. Although the optical properties of absorber coatings are varying with time because of various degradation processes, researchers stated that selective absorber coatings mean high thermal efficiency of the solar collectors. However, Roberts and Forbes found that it is more important for hot water heaters to keep the absorptivity as high as possible rather than emphasizing high selectivity at the expense of lower absorptivity, through an analytical expression for the instantaneous efficiency [12]. In fact, the ideal absorber material should be "inexpensive, easy to form, strong (in terms of pressure and handling), stable at temperature of 205 °C, stable under long-term exposure to ultraviolet radiation, nonporous, lightweight and completely noncorrosive" [13].

In the production of all-ceramic collectors, the biscuits were manufactured and dried firstly. Then the black ceramic slurry was sprayed on the surface of dried biscuits. Through the compressed air, slurries were transformed into droplets. As soon as droplets were sprayed on the surface of dried biscuits, the water contained in droplets was absorbed. By this way, black ceramic slurries adhered to the surface of the biscuits. At last, they were sintered together at 1210 °C. The roughness and thickness of the solar absorber coatings can be controlled by adjusting the pressure of compressed air, the angle and time of spraying, the moisture content of black ceramic slurry, and so on. Fig. 2 shows an SEM image of the reticular black ceramic solar absorbing coating. The solar absorptivity of black ceramic absorber coatings with a reticular formation is in the range of 0.93–0.97. Usually, the calculated absorptivity of the selective absorbers (before degradation) falls in the range of 0.92–0.97 and after degradation falls in the range of 0.883–0.922 [14]. The reticular formation is necessary for the black ceramic absorber coating. It has been tested that the solar absorptivity of black ceramic absorber coatings with a smooth formation is lower than 0.85. There are no attenuations of absorptivity in black ceramic absorber coatings, because of the unique manufacturing technology and good thermo-physical properties. There is no separation of absorber coatings either, because the combination between absorbers and absorber coatings is an ionic bond. It has been examined that the solar

Table 1
The chemical constitution of a typical raw material (wt%).

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	Loss on ignition	Total
70.64	19.85	0.40	/	0.30	4.12	0.36	4.56	100.33

Table 2
The physical performances of biscuits and ceramics.

Biscuits	Breaking strength (Kg/cm^2)	18.9
	Percent of drying shrinkage (%)	4.1
	Percent of sintering shrinkage (%)	10.5
	Sintering temperature (°C)	1210
	Refractoriness (°C)	1530–1580
Ceramics	Radioactivity	
	I_{Ra}	0.44
	I_r	0.94
	Water absorption (%)	≦0.3%
	Breaking strength (Kg/cm^2)	1020
	Thermal conductivity (W/(m K))	1.1–1.7

Fig. 1. An all-ceramic solar collector with an area of 0.5 m^2.

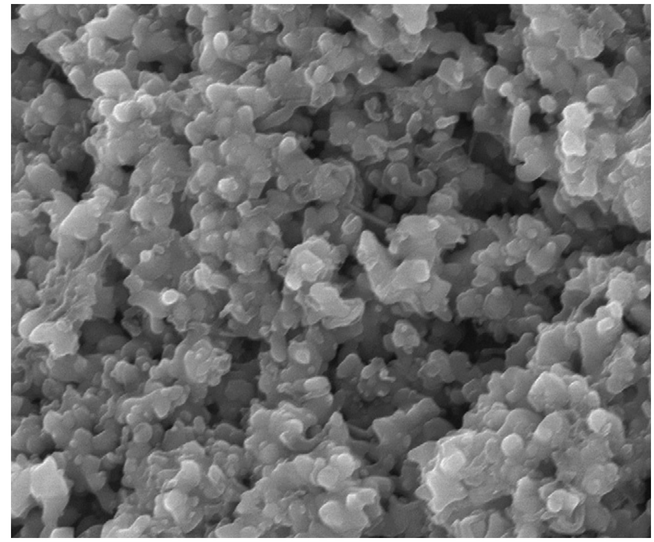

Fig. 2. An SEM image of the reticular black ceramic solar absorbing coating.

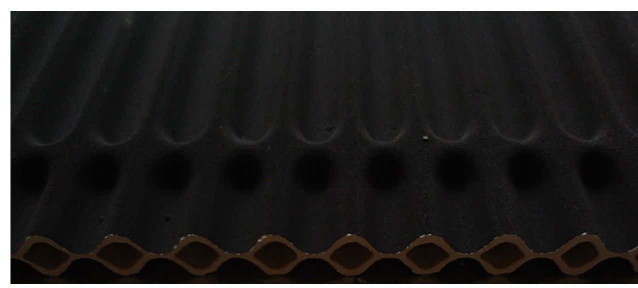

Fig. 3. The interior of an all-ceramic solar collector.

absorptivity still remains unchangeable, even if absorber coatings directly confront a hostile environment (e. g., acid rain, hot and cold switching).

The absorber coating may not be V–Ti black ceramic, but black pigments made from other materials [15–18]. Solar collectors with colored absorber coatings can also be used, although their thermal efficiency is lower than the collectors with black absorber coatings. Tripanagnostopoulos et al. have studied the difference of colored absorber coatings and black absorber coatings [19]. There are various pigments with different colors in ceramic industry, which can also be used in the production of all-ceramic solar collectors.

3.3. Integration of fluid passages with absorber plates

For flat plate collectors, a major problem is obtaining a good thermal bond between tubes and absorber plates without incurring excessive costs for labor or materials. Experimental work carried out by Whillier and Saluja shows that the efficiency factor of the collector is reduced from 0.89 for a soldered bond to 0.77 for an unsoldered bond with a 0.051 mm average thickness air gap between the tube and the plate [20]. Mechanical pressure, thermal cement, brazing, and ultrasonic welding have been used to make the assembly. Fig. 3 shows the interior of an all-ceramic solar collector. The fluid passages are integrated with the absorber plate, which ensure good thermal conductance between the fluid and the absorber plate. The integration was naturally formed in the process of shaping. The thermal conductivity of ceramic is lower, compared with the metal. However, if the entire collector area is in contact with the heat transfer fluid, the thermal conductivity of the material is not important [21]. In fact, more attention should be paid to other factors such as cost, health hazards, and durability when one is trying to select the type of the absorber plate.

3.4. Low costs of all-ceramic solar collectors

The complete costs for traditional metal collector production can be divided into three parts: the fixed costs per absorber area (for frame, glazing, insulation, supports, etc.), the costs per volume for the absorber plate, and the costs for the tubing (per unit length) [22]. However, the copper prices may raise an inevitable problem, as the resources are restricted. Therefore, the cost of metal plat flat collector will be more and more.

The ceramic manufacturing production process generally consists of the four basic stages: preparation of raw materials, shaping, drying and sintering. The energy costs are associated with the various phases in the production cycle. The most recent consumption data indicate that in order to obtain 1 Kg of final product of ceramic floor or wall tile, overall around 5700 kJ of energy is necessary and this in turn, corresponds to around 6846 kJ of primary energy [23]. The production process of all-ceramic plat flat collectors is similar to ceramic floor and wall tile. The weight of the all-ceramic plat flat collector is about 20 Kg/m^2. Accordingly, the consumption of primary energy is about 129.72 MJ/m^2. Base on these, the cost of energy consumption is no more than 15 Yuan RMB to obtain one square meter all-ceramic solar collector in China. It is estimated that the embedded cost is no more than 40 RMB to obtain one square meter all-ceramic plat flat collector in China.

4. Conclusion

Solar energy should be utilized instead of other alternative energy forms because of its massive potential. However, solar energy also is decentralized and intermittent. It is difficult to collect. Therefore, the key point related to the wide use of solar energy is the low cost of the solar collectors. The word ''low cost'' means not only low cost of solar collector materials, but also the longest lifetime. All-ceramic solar collectors have characteristics of low cost, long lifetime and good thermostability. Moreover, it can integrate well with buildings. The dream that conventional energy sources widely replaced by solar energy may become true, if all-ceramic solar collectors are used whenever possible.

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