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All-ceramic solar collector and all-ceramic solar roof

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ABSTRACT

A type of all-ceramic solar collector is introduced. These all-ceramic solar collectors are made from ceramics. The material of absorber coating is V–Ti black ceramic. The solar absorptance of absorber coatings with a reticular formation is in the range of 0.93–0.97, without the attenuation of solar absorptance. The fluid passages are integrated with the absorber plate, which naturally formed in the process of shaping. The integration between fluid passage and absorber plate is good to transfer heat from the absorber plate to the fluid. The thermal efficiency of all-ceramic solar system is more than 50%. The all-ceramic solar system can integrate well with building roof. All-ceramic collector and system are characterized by low cost and long lifetime. Such characteristics reduce the cost of solar energy utilization.

1. Introduction

Solar energy is considered one of the main promising alternative sources of energy to replace the dependency on the fossil energy resources, because of the shortage of fossil energy resources and the environmental pollution caused by the burning of the fossil fuels. It has been estimated that 30 min of solar radiation falling on earth is equal to the world energy demand for one year [1]. The greatest advantages of solar energy as compared with other forms of energy are clean and rich. The disadvantages of solar energy are scatter and difficult to collect. Therefore, the key point related to the wide and economical use of solar energy is the collection with a cost as low as possible. Solar collector, as a basic component for the use of solar energy, must be focused.

Nowadays, the significant progress of solar collectors is made by improving the conversion efficiencies and trying best to increase service life. Merely, we should not forget that the major production cost is the cost of materials. Therefore, the other move must be towards the cheaper materials. In fact, in the first Chemical Sciences and Society Symposium (CS3), scientists had 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' " [2]. It is, therefore, sought in the future researches on solar collectors to use, especially, many more might follow with the combined advantages of suitability, mass production, cheap raw materials, and long life insurance [3].

Ceramic is one of the cheapest and most used engineering materials. They have been widely used in electronic and structure areas. Ceramic also is a very interesting material for solar thermal collectors, 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 [4]. 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 characters, such as low cost, long lifetime, no attenuation of absorptance, and building integration.

2. All-ceramic solar collectors

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

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

600 × 600 mm^2, 800 × 800 mm^2, and 1000 × 1000 mm^2. The lowest value of the test-pressure of the all-ceramic solar collector is 2 bar. Moreover, the bursting pressure can be increased number of times by transforming the structure or the wall thickness.

2.1. Black ceramic absorber coatings

Absorber coating is one of the most important parts of the collectors. The coatings may be selective or non-selective. Selective absorber coatings mean high absorptance 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, researches state 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 absorptance as high as possible rather than emphasizes high selectivity at the expense of lower absorptance, through an analytical expression for the instantaneous efficiency [5]. In fact, the ideal absorber material should be "inexpensive, easy to form, stable, high absorptance without attenuation".

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. Slurries were transformed into droplets by the compressed air. As soon as droplets were sprayed on the surface of dried biscuits, the water 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. The solar absorptance of black ceramic absorber coatings with a reticular formation is in the range of 0.93–0.97. Usually, the calculated absorptance 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 [6]. The reticular formation is necessary for the black ceramic absorber coating. It has been tested that the solar absorptance of black ceramic absorber coatings with a smooth formation is lower than 0.85. There are no attenuations of solar absorptance in black ceramic absorber coatings, because of its unique manufacturing technology and good thermo-physical properties. There is no separation of absorber coatings either, because that the combination between absorbers and absorber coatings is ionic bond. It has been examined that the solar absorptance still remains unchangeableness, even if absorber coatings directly confront a hostile environment (e.g., acid rain, hot and cold switching).

2.2. Integration of fluid passages with absorber plates

Flat plate solar collectors are the most common for use in solar water heating systems in homes and in solar space heating. 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 [7]. Mechanical pressure, thermal cement, brazing, and ultrasonic welding had been tried to make the assembly. Fig. 2 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, comparing with metal. However, if the entire collector area is in contact with the heat transfer fluid, the thermal conductivity of the material is not important [8]. Therefore, more attention should be paid to other factors such as cost, health hazards, and durability when one is trying to select the type of absorber plate [9].

2.3. Costs of all-ceramic solar collectors

The ceramic manufacturing production process generally consists of the four basic stages: preparation of raw materials, shaping, drying and sintering. The energy costs associated with the various phases in the production cycle. The most recent consumption data indicate that in order to obtain 1 kg of ceramic floor or wall tile, overall around 5700 kJ of energy are necessary and this in turn, corresponds to around 6846 kJ of primary energy [10]. The production process of all-ceramic solar collectors is similar to ceramic floor and wall tile. The weight of