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Highly efficient collectors of solar energy using nanocarbon coatings based on vegetable raw materials

N.G. Prikhodko[a,c,*], N.B. Rakhimzhan[a], G.T. Smagulova[a,b], B.T. Lesbayev[a,b], A.B. Lesbayev[a,b], M. Nazhipkyzy[a,b], T.S. Temirgaliyeva[a,b], Z.A. Mansurov[a,b]

[a]*Institute of Combustion Problems, 172, Bogenbay Batyr St., 050012, Almaty, Kazakhstan*
[b]*Al-Farabi Kazakh National University, 71 al-Farabi Ave., 050040, Almaty, Kazakhstan*
[c]*Almaty University of Energetics and Communications, 126, Baytursinova St., 050013, Almaty, Kazakhstan*

Abstract

In this work we present the results of a study of model samples of solar collectors with an absorption material based on carbonized vegetable raw materials from apricot stones, rice husks and their combination with carbon nanotubes. These studies have shown the possibility and prospects of the use of carbon structures based on carbonized vegetable raw materials for the absorbing layers of solar collectors. Experimentally, on the basis of a comparative study of the absorption capacity of the coatings from carbonized rice husk, apricot stones, and their combination with the carbon nanotubes, it was found that the maximum absorption capacity was observed for a coating based on carbonized rice husks.

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Keywords: collector of solar energy; carbonized carbon material; absorber.

1. Introduction

As is well known, the solar collector efficiency is largely determined by the losses associated with the reflection of solar energy from the glass tubes (to 7.5 %), the absorber (to 6.3 %), and the loss of radiation of heat energy in the infrared range (up to 4.4 %). At present, the efficiency of vacuum solar collectors is in the range of 70-80 %. By

* Corresponding author. Tel.: +7-705-174-74-09
E-mail address: nik99951@mail.ru

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using, an absorbent material with an efficiency of 98 % and the absence of reflections from it and with the maximum heat insulation in the infrared range is possible to increase the efficiency of the solar collector to a value above 80 %.

A number of teams have developed different methods to improve the efficiency of absorption by solar energy collectors. For example, a known collector with a selective highly absorbent coating, but weakly emitting in a certain area of spectrum, which correspond to certain semiconductors [1, 2]. However, currently used semiconductors exhibit a low mechanical strength and low thermal conductivity together with a high cost, which makes them less suitable for the manufacture of a total solar radiation receiver. To compensate for these negative properties of semiconductors, we can apply a thin layer on a metal substrate, which has toughness, good thermal conductivity, but low absorption capacity [3].

The use of carbon composite materials based on carbon nanotubes is a new direction in terms of increasing the absorption efficiency of solar collectors. It is known that carbon nanotubes behave like an ideal black body, absorbing a wide spectral range of more than 98 % of the energy of incident sunlight [3-5]. Carbon nanotubes have high strength, flexibility and high thermal conductivity and can be fabricated in to continuous tape with an extended submicron thickness, which can be wound onto the solar receiver with any configuration made of any material [6, 7].

The development of new materials for solar absorbers is quite a challenge. The purpose of such searches is to obtain coatings with a higher coefficient of absorption of solar energy at the lowest loss to radiation in the infrared range in combination with the low cost of their production. One of the new directions in the field of new materials for coating solar collectors, is the use of the carbonized material from vegetable raw materials and their combination with various additives as an absorber for a solar collector.

1.1. Experimental

Glass tubes were coated with a layer of sodium silicate mixed with a powder of carbonized vegetable raw material from apricot pits (AP) or rice husk (RH). The coating thickness does not exceed 0.8 mm. Samples were prepared in duplicate. A second instance was coated with 10 layers of films from carbon nanotubes (CNTs). Synthesis of a CNTs "forest" was carried out in the NanoTech Institute, University of Texas at Dallas (USA) headed by Professor A.A. Zakhidov, who is a foreign partner for the implementation of this work. The height of the synthesized CNT "forest" is an average of 300-350 μm and with CNT diameters ranging from 18 to 30 nm. A general view of the model solar collector tubes and the method of coating of CNTs are shown in Fig. 1.

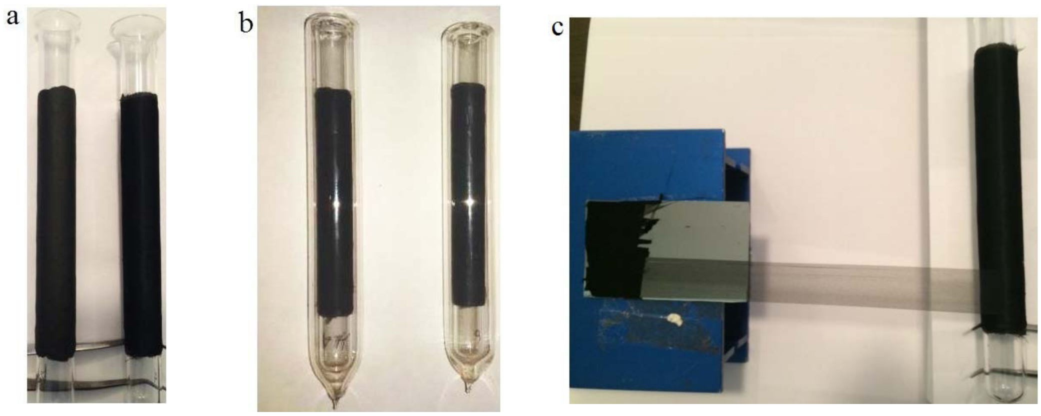


Fig. 1. General view of the collector tubes with coating (a, b) and the method of coatings of CNTs on the tube with a pre-coated RH or AP (c)

The coated tube was placed inside a tube of larger diameter and hermetically heat sealed. This assembly was evacuated to a pressure of $5x10^{-3}$ Pa and sealed. A general view of the finished evacuated tube of the solar collector model is shown in Fig. 1 (b).

The efficiency of solar energy absorption by the coatings was evaluated from the temperature rise in the water in the tube. For this purpose the inner tube of the solar collector contained distilled water with volumes of 15, 100 and 400 ml. The tube was closed with a rubber stopper and the water temperature was measured using a chromel-alumel thermocouple. The experiments were carried out on the street on a sunny day with a stable solar radiation. A general view of the devices and the instruments in the experimental study of solar collectors models are shown in Fig. 2.

Fig. 2. General view of devices and instruments in the experimental study of solar collectors models: 1 – thermometer, temperature fixing air, 2 – thermometers, temperature fixing water 3 – a device for measuring the intensity of solar radiation, 4 – samples of solar collectors with different absorbing coating, 5 – ChA thermocouple

The intensity of solar radiation (W/m^2) were measured device PL-110SM (Solar Radiation Measuring Instrument). The water temperature was measured by a digital thermometer (type TC-KO1), the display of which is fixed simultaneously four temperature values.

Efficiency ratio η heat absorption surface under study was calculated using the formula:

$$\eta = q/q_{max} \cdot 100, \% \tag{1}$$

where q - value of specific heat absorption within 30 minutes of the experiment, kJ/cm^2, q_{max} - the maximum possible value of the specific heat absorption within 30 minutes of the experiment, which was adopted on the climatologically average value of the directory on the intensity of solar radiation values kJ/cm^2.

The values of the heat absorption efficiency factor depends on the maximum value of the solar radiation and the outside air temperature. With an increase in the intensity of solar radiation the value, even for the same coating is increased, which practically does not allow to make a comparative assessment of different coatings. Therefore, the specific heat absorption efficiency ratio was introduced, which defined by the formula:

$$\eta_{sp} = \eta/q_{max} \tag{2}$$

1.2. Results and Discussion

Fig. 3 shows plots of the temperature change in the water collectors with different coatings in the experiment. The graph shows (Fig. 3, Curve 4), that the at the beginning temperature of the water in the tubes with coatings of RH and RH-CNT exceeds the temperature of the water in all the other tubes. The tubes with triple glazed water heating temperature (Fig. 3, curve 5 and 6), lower than the temperature of heating water in all other coatings. After 30 minutes of the experiment the heating temperature of water is practically equalized in all tubes. For exact estimation of efficiency the coatings of heat absorption was calculated. Analysis of the experimental values for the efficiency of absorption of solar radiation with various coatings showed that the most effective is a coating on the basis of carbonized rice husk (85.53 %). It was supposed that the combined coating based on RH-CNT and CNT-AP can increase the absorption capacity of solar radiation. However, experiments have not confirmed this assumption. In this case small increase solar radiation absorption efficiency was observed on samples with a combined coating AP-CNT (84.04 %) as compared to pure coated of the AP (81.16 %).

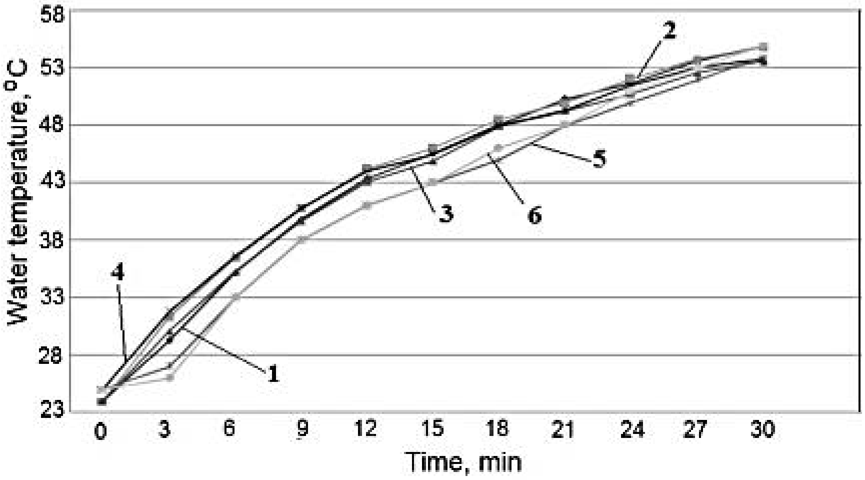


Fig. 3. Graph changes in water temperature for different coatings depending on the time at the maximum heat absorption q_{max}=127,92 J/cm^2: 1 – coating AP-CNT (10 layers), 2 – RH (pure), 3 – AP (pure), 4 – RH-CNT (10 layers), 5 – RH (pure with triple glazed), 6 – AP (pure with triple glazed)

Structural and morphological properties analysis of the carbonized powders of RH and AP was carried out. Carbonized RH and AP for Raman spectrometer were examined (NTEGRA Spectra Raman, λ = 473 nm, the signal area with a diameter of 80 nm). Figure 4 shows the optical picture and Raman-spectra of the powder of carbonized rice husk. The particle size of the carbonized rice husk after milling and sieving on a vibrating sieve in the range from 1 to 12 μm (Fig. 4 a). As shown by Raman spectrum, carbonized RH predominantly have amorphous structure.

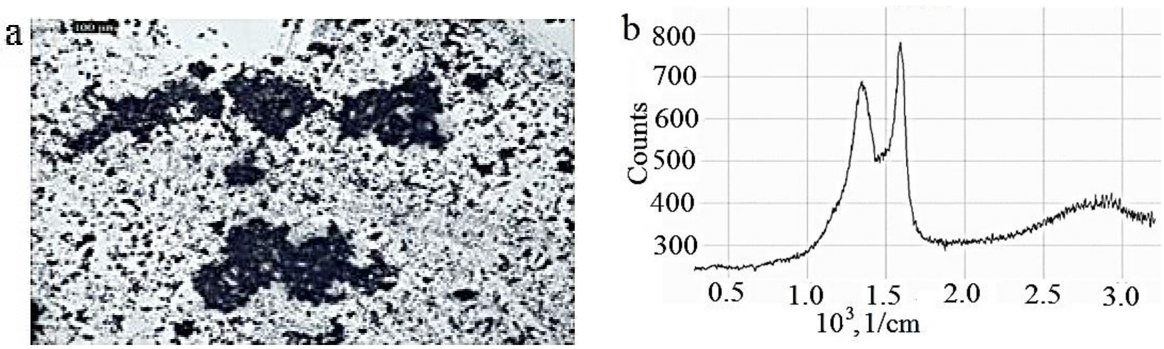
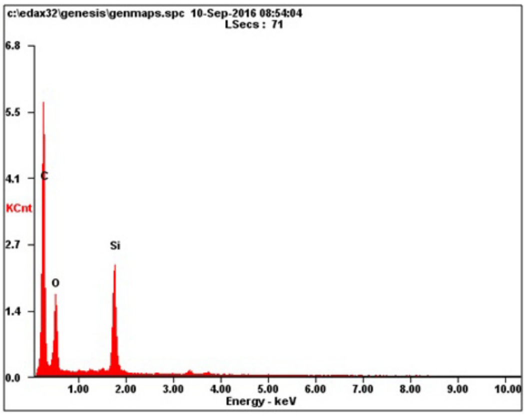


Fig. 4. The optical picture (a) and Raman-spectra (b) of the powder of carbonized rice husk

The elemental composition of RH was determined at the energy-dispersive X-ray spectroscopy (EDAX). Fig. 5 shows the spectrum of percentage and the elemental composition of RH.

a


b

Element	Wt%	At%
CK	68.78	78.54
OK	16.83	14.43
SiK	14.39	7.03
Matrix	Correction	ZAF

Fig. 5. Spectrum (a) and percentage elemental composition carbonized RH (b)

Comparative experimental study of a sample of the solar collector coated with carbonized rice husk and coated of industrial production (China) showed its higher solar energy absorbing properties (Table 1).

Table 1. Comparative assessment of the effectiveness of heat absorption.

Coating type	RH (not evacuated)	Industrial model (China, evacuated)
Heat absorption of coating, q, J/cm^2	118.97	115.57
Maximum heat absorption, q_{max} , J/cm^2	139.83	139.83
Efficiency, η, %	85.08	82.65
Specific efficiency, $\eta_{sp}\cdot 10^{-2}$	60.85	59.11

Analysis of the results (Table 1) showed that the solar collector with a coating from the RH has an efficiency of absorption of solar energy - 85.08 %, and the industrial model of solar collector (China) has an efficiency of absorption of solar energy - 82.65 %.

Carbonized RH and AP for scanning electron microscopy (SEM) were examined (Quanta 200i 3D, USA). Figure 6 shows the SEM images of carbonized RH and AP.

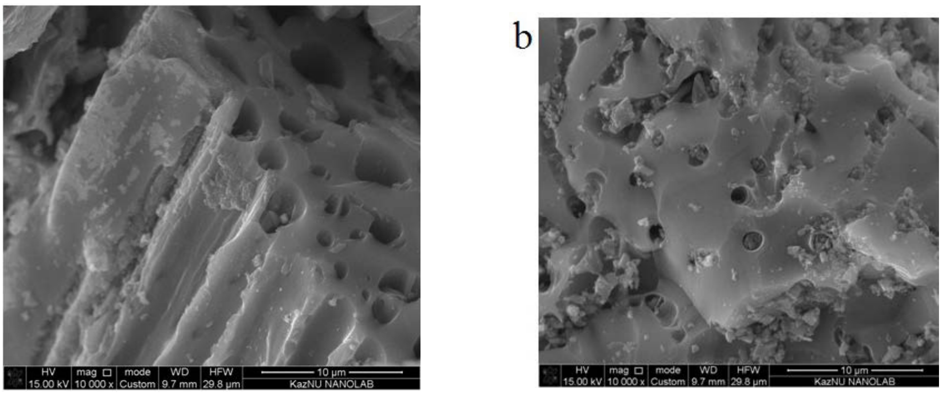
a b


Fig. 6. SEM images of carbonized RH (a) and AP (b)

Analysis of the SEM photographs of carbonized samples of RH and AP (Fig. 6) shows that the structure is porous and has large specific surface area. The specific surface area of RH is 134.11 m^2/g and specific pore volume is 0.095 cm^3/g. The specific surface area of AP is 26.44 m^2/g and specific pore volume is 0.011 cm^3/g. Advantage of considered carbon materials based on vegetable raw materials, compared to existing coatings is their porous structure. Wherein the dimensions of pores are in the nanometer range. The average pore size of RH is equal to 2.84 nm, and 3.72 nm for AP. The porous structure of the carbonized RH and AP, and nanometer pore size increases the scattering of light within the absorbing coat and increase the degree of absorption of solar energy. The specific surface area, the specific volume of pores and pore size of RH and AP were analyzed on the specific surface area analyzer "Sorbtometer-M" (Russia).

1.3. Conclusion

It is found that the coating from carbonized rice husk (RH) has the highest absorption capacity compared to the coatings of other carbon materials. It is shown that the carbonized rice husk has a good surface area (134.11 m^2/g) and a higher specific porosity (0.095 cm^3/g) compared with apricot pits (26.44 m^2/g and 0.011 cm^3/g, respectively) which may be the determining factor to improve the absorption of solar energy capacity. It is found that the coating from carbonized rice husk has a higher efficiency of absorption of solar energy (85.08 %) compared with industrial model (82.65 %).

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