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Investigation of Solar Air Heating Collector Integrated with a Nanocomposite Solar Absorbers

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ABSTRACT

Solar air heating collector are widely used in many solar thermal applications, to enhance its capability to harvest solar radiation, the solar selective coating should be used. In this connection, in the present research, the nano carbon and chromium carbide based coating was affected on zinc substrate and the solar absorber was developed. The prepared absorber was characterized through XRD and UV. The prepared absorber was deployed in solar air heating collector and it was thermally analyzed. The research outcomes related to characterization of solar absorber showed that the presence of nanosized crystallites, influence of mixing of nano particles and good absorption in UV and visible regions. The research outcomes related to thermal analysis on solar absorber in outdoor and stagnant environment showed that the average increase in temperature was 23.7°C and 108.8°C.As the solar absorber had desirable optical and thermal properties, it could be concluded that nano carbon and chromium carbide coated solar absorbers would be used in photo thermal appliances due to their positive impact on thermal performances.

Keywords: *Preparation-Characterization- Utilization-Thermal Analyses-Thermal Performance*

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INTRODUCTION

Solar air heater is a device to produce the green energy by heating the air which can be used for the various household and industrial applications like building heating, crop drying and space heating etc [1]. The low coefficient of heat transfer between air and absorber plate, the solar air heater always suffers from poor thermal efficiency. Researchers have been used different techniques and methods to improve heat energy transfer from the absorbers. The nano material coating over the absorber plate is most commonly used approach of all these methods for improving the efficiency of the solar air heater [2]. Katumba *et al.* (2008) carried out research on the optical characteristics of solar absorptive coatings with the chemical composition of nano carbon and metal oxides. The research result revealed that the solar absorptance of nano carbon and nickel oxide coating deposited on metal substrate was 84% [3]. Vasantha Malliga et al. (2017) carried out research on nano graphite and CuO coated absorber and evaluated the thermal performance of solar air heating collector integrated with the same nanographite and CuO coated absorber. The research outcome revealed that the sizes of graphite and CuO crystallites in absorptive coating were in nano ranges that were confirmed through XRD analysis. The research outcome also revealed that the maximum temperature of working fluid was 59.4ºC and the maximum thermal performance of solar collector integrated with absorber that had nano graphite and CuO mixed absorptive coating on aluminium substrate was 68.0% [4]. Liu et al. studied the effect of CrAlO nanocomposite coating on the absorber plate. The four-layers structured coating consists of a pure chromium layer, low Cr–Al–O (LOCL) content of oxygen, a central Cr–Al–O(MOCL) oxygen content and a high Cr–Al–O(HOCL) oxygen content. The results show that LOCL and MOCL had a relatively large absorptive value of 0.924 and a relative low emittance of 0.21 as well as an excellent thermal stability of 0.919/0.225 selectively even after annealing at7000 C in the air during 2 hours [5]. Jeong et al. investigated the CuO nanostructure as a absorber coating for solar absorption. The experiment was examined by both indoor and outdoor condition for the performance of solar absorber.

Results showed that the sharp morphology and a random distribution of the CuO structure permit enhanced optical broadband absorption, with the corresponding results calculated at about 95% and 97% of the existing state-of-the-art TiNOX absorber for both single-and two-glazing situations. Thermal stability and life of service are important high-temperature parameters for solar absorber applications. The absorber coatings are exposed to extremely intense solar intensity and experience high thermal shocks during the day and night. This is one of the main factors of ageing, since the alternation between night and day and cloud spells may create sharp changes in solar intensity, leading to thermal heat shocks to the absorber coats [6]. In the present research work has been carried out with the objectives such as (i) preparation of nano carbon and chromium carbide coated solar absorber (ii) characterization of coating effected on solar absorber and (iii) thermal analysis on small and large scale solar absorber, (iv) thermal performance on solar air heating collector integrated with solar absorber that had nano carbon and chromium carbide coating on zinc substrate. The preparation, characterization and thermal analyses have been presented and the research outcomes have been elaborately discussed in this research paper.

MATERIAL AND METHODS

In the current research, the bituminous coal blocks were collected. They were powdered in nano sizes by using planetary ball mill. There were four stainless steel mill jars in ball mill and 20 g of bituminous coal was loaded in each of these jars. The demineralised water of 20 ml was added in mill jars. There were 54 steel balls and each ball size was 20 mm. The angular velocity of mill jar was fixed to be 350 rpm. The milling was carried out for two hours with suitable period of breaks. The powdered samples were collected and they were dried at 600°C for two hours. The dried samples were stored and the stored samples were used for further studies in this research [7]. The prepared carbon powder was mixed with nano sized chromium carbide in different proportions. The mixed carbon and nano sized chromium carbide powder was stirred by using mechanical stirrer in solar emulsion used in solar industries [8]. The prepared solar absorptive solution was used for coating on solar absorbers. The metal sheets were commercially procured. They were properly cleaned and pre-treated by adhering standard procedures. The prepared absorptive solution was sprayed on these cleaned and pre-treated metal plates. While the spray rate was 10 $mlmin^{-1}$ with compressed air as carrier gas, the distance between spray head and metal plate was kept to be 15cm. The coated metal sheets were cured and they could serve as solar absorbers. The prepared solar absorbers were thermally analyzed so as to know their thermal durability in photo thermal collectors. In this connection, they were kept in hot air oven. After the test tenure of four hours in hot conditions in hot air oven, the heated solar absorbers were taken out. They were cooled in outdoor conditions as per Bureau of Indian Standards (BIS) specifications [9]. The peeling of coating, if any, was manually checked. In addition, the fading of coating, if any, was visually inspected. The coatings on solar absorbers were characterized through XRD and UV analyses and the structural, reflectance spectra outcomes were obtained. It is to be noted that all the characterization techniques were carried out at room temperature [10]. The crystalline nature of the carbon or bituminous coal (BC) powder, chromium carbide nano particles and various ratio composites of BC:Cr_3C_2-NPs (70:30, 60:40 and 50:50) was explored by powder X-Ray diffraction patterns recorded in the 2θ range from 10^0 to 80^0 using the XPERT-PRO diffractometer with the wave length of 1.5406 Å [11]. The diffuse reflectance spectra of the bituminous coal powder, Cr_3C_2-NPs and various ratio composites of BC: Cr_3C_2-NPs (75:25, 60:40 and 50:50) was recorded in the range of 400 and 2400 nm using UV-Vis (SHIMADZU-2400) spectrophotometer with BaSO4 as a non-absorbing standard reference [12]. In the current research, the cleaned and pre treated metal sheets were cut into small scale (400 mm x 200 mm) and large scale (2000mm and 1000mm) metal substrates. The metal substrates were coated with the prepared absorptive solution by spray coating method and they were cured before utilizing them as solar absorbers. It is to be noted that the length of the large scale absorber, breadth of the large scale absorber and thickness of the absorber were fixed as per BIS specifications [9]. The prepared small scale solar absorbers were thermally analyzed in outdoor environment so as to know thermal enhancements on them with varied meteorological conditions. In this connection, the solar absorbers were fixed on the specially fabricated test stands so as to be free from dusts, shadows and other influencing materials during the experimental tenure [10]. As these solar absorbers were kept in suitable test stands in outdoor conditions, there was a significant increase in temperature on these black coated solar absorbers. The increase in temperature on these solar absorbers was periodically measured. In addition, the levels of influencing parameters such as solar radiation, ambient temperature and wind speed were systematically measured during experimental tenure [13].

RESULTS AND DISCUSSION

In the present research, the objectives were to prepare a solar absorber, characterization of coating on solar absorber and thermal analyses on solar absorbers and solar air heating collector, they were separately materialized by adopting standard methodology and the experimental outcomes of the current research have been individually documented [14][15]. While the specifications of the solar absorber have been recorded in Table 1, the level of thermal enhancements on solar absorbers with variations in different levels of incident solar radiation have been recorded in Table 2. At the same time, the characterization outcomes with reference to XRD and UV analyses have been recorded in figure 1 and figure 2. In the present research, the material zinc was used as substrates of solar absorbers. The nano carbon and chromium carbide mixed absorptive coating was deposited on zinc substrates and solar absorbers were prepared. The thermal durability test on solar absorbers showed that the outside layer could endure neither fading of coating nor peeling of coating in stagnant and operative conditions. It also showed that the coating on solar absorbers could withstand the degree of temperature in stagnant and operative conditions of solar air heating collectors.

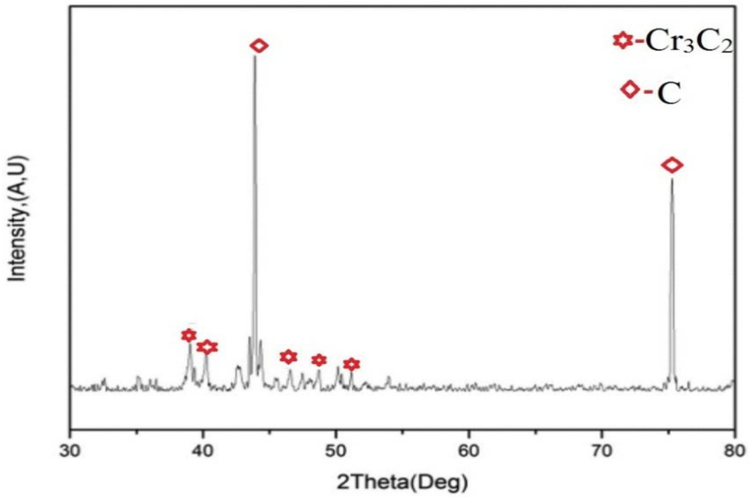

Fig. 1 XRD pattern of the BC: Cr_3C_2-NPs

The XRD pattern for BC: Cr_3C_2 is shown in Fig. 1 with all the Cr–C phases. In the diffractogram, the bituminous coal (BC) and chromium carbide (Cr3C2) in 70:30 ratio exhibited an intense XRD peak at 44.10º (0 0 2) that would correspond to the graphitic carbon structure. The analytical results showed that the BC: Cr_3C_2-NPs had orthorhombic structure (JCPDS No-00-035-0483). The Debye-Scherer formula has been used to find the crystallite size and it was found that the crystallite size was 55nm. The XRD pattern could exhibit the peaks of all BC: Cr_3C_2-NPs composites and so it was confirmed that the BC: Cr_3C_2-NPs composites have been formed.

Fig. 2. shows the absorbance spectra of the Cr_3C_2-NPs, and different ratios composites of the BC: Cr_3C_2-NPs.

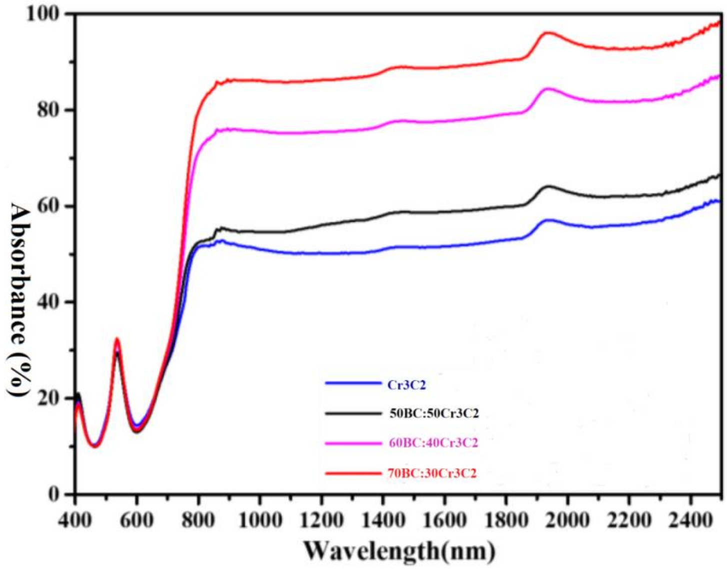

Fig. 2 Absorbance spectra of Cr_3C_2 and composite of BC: Cr_3C_2-NPs

The absorbance spectra showed that there was an excellent absorption in the entire UV and also visible region. Hence, the UV outcomes showed that the BC:Cr_3C_2-NPs composite might be acting as good absorber material for the solar spectrum.

Table 1 Specifications of solar absorber

Description of solar absorber	Materials and dimensions of solar absorber
Material	Zinc
Thickness of material	0.30 mm
Width of material (Small scale)	20 mm
Length of material (Small scale)	40 mm
Breadth of material (Large scale)	1000 mm
Length of material (Large scale)	2000 mm
Coating on solar absorber	Nano carbon and chromium carbide coating

Table 2 Temperature enhancements on BC: Cr_3C_2-NPs composite coated solar absorber in outdoor conditions

Solar radiations (W/m^2)	Temperature enhancement (oC)		
	solar absorber with BC: Cr_3C_2-NPs in the mass ratio of 70:30	solar absorber with BC: Cr_3C_2-NPs in the mass ratio of 60:40	solar absorber with BC: Cr_3C_2-NPs in the mass ratio of 50:50
350-400	5.9	5.5	5.0
450-700	8.0	7.7	6.9
700-755	9.6	9.2	8.6

The research result related to thermal analysis in outdoor environment revealed that the enhancements of temperature on solar absorbers coated with carbon and chromium carbide nano composite in the mass ratio of 70:30, 60:40 and 50:50 were 25.4^{o}C, 24.5^{o}C and 21.2^{o}C respectively. The research result related to thermal analysis in stagnation environment also revealed that the enhancements of temperature on glass cover, carbon and chromium carbide nano composite coated absorber and working fluid were 108.8^{o}C, 104.6^{o}C and 96.0^{o}C respectively. Based on the obtained results on solar air heating collector and solar absorber, the main factors could be the intensities of incident solar radiation, the influence of meteorological parameters, and the persistence of stagnant conditions in solar air heating collectors.

CONCLUSION

Due to their desired optical and thermal properties, nano carbon and chromium carbide coated solar absorbers were suggested for solar thermal applications based on results from research. Additionally it could be concluded that nano carbon and chromium carbide coated solar absorbers would be used in photo thermal appliances due to their positive impacts on thermal performance.

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