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ORIGINAL ARTICLE

Nanoparticles Ni electroplating and black paint for solar collector applications

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Abstract A nanoparticles layer of bright nickel base was deposited on copper substrates using electrodeposition technique before spraying the paint. IR reflectance of the paint was found to be around 0.4 without bright nickel layer and the reflectance increased to 0.6 at a Ni layer thickness of 750 nm. The efficiency of the constructed solar collectors using black paint and black paint combined with bright nickel was found to be better than black paint individually. After aging tests under high temperature, Bright nickel improved the stability of the absorber paint. The collector optical gain $F_R(\tau\alpha)$ was lowered by 24.7% for the commercial paint and lowered by 19.3% for the commercial paint combined with bright nickel. The overall heat loss $F_R(U_L)$ was increased by 3.3% for the commercial paint and increased by 2.7% for the commercial paint combined with bright nickel after the temperature aging test.

1. Introduction

Due to increasing interest in the exploitation of renewable energy sources, absorbers for solar thermal applications are becoming increasingly important. The efficiency of the photothermal energy conversion is strongly dependent on the optical properties of the absorber [1]. The absorber consists of an absorber plate (the substrate) which is coated with the paint coating. The absorber substrate must be made of a material with good thermal conductivity to transfer the heat to fluid. Copper is the most metal used as substrate as it has high thermal conductivity. The absorber coating is responsible for the conversion of UV and VIS radiation to heat [2]. A selective paint that has a minimum reflection in the solar spectrum (high absorptance) and maximum reflection in the thermal spectrum (low emittance) can achieve this objective [3].

Because of the generally high emittance, the main selection criterion of non-selective paint coatings has high absorptance, good durability and low cost [4]. For solar thermal applications, the paint material and substrate should not greatly change their physical and chemical properties within operation. This may has adverse affect on the solar absorptance and thermal emittance. Thin metal base layer is deposited onto absorber metal substrates to avoid the diffusion into the composite film during accelerated aging tests, which decreases the optical performance of the coatings [5]. Coating material

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selection is the key to find the acceptable solution to overcome the inter diffusion and higher emittance problems in solar selective coatings [6].

The performance of the flat-plate collector with an absorber for photothermal conversion can be described by the conversion efficiency (η) [7,8]

$$\eta = F_R\tau\alpha - F_R U_L\left(\frac{T_i - T_a}{I}\right) \tag{1}$$

where η is the instantaneous efficiency of solar collector, F_R is the collector heat removal factor, α is the solar absorptance, τ is the solar transmission, U_L is the heat transfer coefficient, T_i is the inlet temperature of the transfer medium flowing into the collector, T_a is the ambient temperature, and I is the total irradiance onto the collector plane.

Thickness insensitive spectrally selective (TISS) paint coatings were prepared according to Orel et al. [9]. Pigments were dispersed in silicone resin binder imparting the TISS paint coatings high-temperature tolerance, excellent adhesion, UV resistance, flexibility and weather-durability, which make them suitable coatings for glazed or unglazed solar absorbers. Spectrally selective surfaces can be prepared on three different substrates using siloxane and epoxy/silicone resins as binders according to Orel et al. [10]. The method of application of paint influenced the final spectral selectivity. Better results were obtained when the paint was applied by draw bar coater due to the more homogeneous distribution of the applied over the substrate. It was found that the thermal emittance decreased by the decreasing the thickness of the applied paint.

This paper deals with the following: first, the deposition and optical characterization of a commercial black paint delivered by the manufacture (Al Gammal Gp., Egypt) will be investigated; this paint is based on siloxane resin binder and is appropriate for high temperature applications above 200 °C. Then the impact of electrodeposited nanoparticles bright Ni base layer on the optical properties of the commercial paint also will be investigated. Solar collector instantaneous efficiency testing will be covered in detail. The efficiency tests are accomplished according to ASHRAE 93 standard (American Society of Heating, Refrigerating and Air conditioning Engineers, INC.) [11]. Finally, aging tests will be conducted on the whole collector. The impact of temperature aging test on the optical properties of the absorber coatings and its effect on the efficiency of the collector will be discussed.

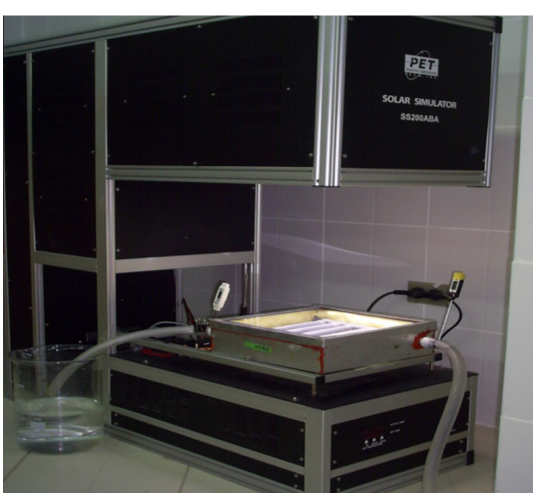

Figure 1 Setup for instantaneous efficiency measurement of the collector under illumination.

2. Materials and methods

Two prototypes of solar collectors: one with the black paint and the other with the black paint combined with the electroplated bright nickel base layer as absorbers are constructed. The gross area of the prototype is 27 × 27 cm^2, and the aperture area is 20 × 20 cm^2. The instantaneous efficiency measurements applied on the collector prototypes are performed using sun simulator (PET Photo Emission Tech., Inc. USA), with exposure area 20 × 20 cm^2 as shown in Fig. 1.

2.1. Sample preparation

Commercial black paint as received from Al Gammal Gp Company is applied on copper substrates and bright Ni base layer by spray deposition technique (Voylet H2000 spray gun, China). After spraying, the samples are cured at 180 °C for 45 min. to attain coating adequate thermal, weathering and mechanical resistance [10]. For Ni electroplating, DC regulated power supply as the power source and the copper substrate as cathode are used and a nickel sheet with a purity of 99.9% as anode is used. The composition of the electrolyte is shown in Table 1. Current density of 2 A/dm^2 and deposition time of 3 min are used. Nickel sulfate, low cost, commercially available material, is used as a source of nickel ions for deposition. For improving the brightness, cobalt sulfate is used. Boric acid serves as a weak buffer controlling PH of the solution. Ammonium chloride is used to improve both the cathode efficiency and the electrical conductivity of the solution [12].

2.2. Optical measurements of absorber material

The near-normal spectral reflectance of the samples was measured in the 0.2–0.9 μm wavelength range with (UV–visible evolution 600, Thermo). The specular reflectance is measured using varying angle specular reflectance accessory. Fourier Transform Infrared spectrophotometer (FTIR, Berkin Elmer) is used to measure near normal reflectance in the 2.5–29 μm wavelength range. From these measurements of specular reflectance, the solar absorptance (α) and thermal emittance (ε) behavior could be evaluated [13]. The main contents of the paint coating are investigated in the range from 400 to 4000 cm^{-1} using (Shimadzu FTIR-8400 S, Japan).

Table 1 Chemical composition for bright Ni deposition (at room temperature).

Material	Condition (g/l)
$NiSO_4 \cdot 7H_2O$	124
H_3BO_3	30
$CoSO_4 \cdot 7H_2O$	15
NH_4Cl	37