SELECTIVE BLACK SURFACES FOR PHOTO-THERMAL CONVERSION OF SOLAR ENERGY

BY

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ABSTRACT

A detailed study of the optical, thermal and surface-microstructural properties of black nickel, black chrome, black copper and black iron prepared by electroplating/chemical conversion on galvanized steel, tin coated steel, copper, aluminium, stainless steel and nickel plated steel has been undertaken to investigate (i) the dependence of the properties on the deposition parameters like: bath composition, temperature, pH and current density, (ii) effect of substrate surface roughness on the coatings, and (iii) the thermal performance. Efforts have been made to obtain high solar absorptance ($\alpha_s \sim 0.94$) and low thermal emittance ($\epsilon \sim 0.08$).

An optical model to describe the optical absorption behaviour of the coatings is developed using Maxwell-Garnett theory and an interesting possibility of tailoring them through the optical properties of the composite film (small metal particles embedded in a dielectric) is established in case of black chrome, black nickel and black copper. A graphical analysis has been carried out to select a particular selective absorber depending on its operating conditions (temperature and insolation). Theoretical studies have shown that through the use of selective absorber over non-selective, the performance of a flat plate collector operating at $\sim 100^{\circ}C$ is increased by $\sim 20\%$. Results have been verified experimentally in case of black nickel flat plate collector.

Radiometric, calorimetric and heat balance techniques have been developed to measure the α_s and ϵ values of the coatings. Calorimetric and heat balance measurements have been carried out in vacuum ($\sim 10^{-5}$ torr). A mini-collector has been constructed to study the stagnation temperature and to conduct the sun exposure tests. A test facility has been fabricated to carry out the thermal performance measurements.

Black nickel coatings have been prepared with $\alpha_s = 0.92$ to 0.94 and $\epsilon = 0.08$ to 0.1 on galvanized steel by electroplating and chemical conversion. Stagnation temperature of $\sim 132^{\circ}C$ is obtained under one glass cover at insolation $\sim$ 810 W/m^2. Black nickel coatings prepared on galvanized steel could withstand the accelerated thermal test at 200°C for 50 hours and sun exposure test for six months. Coatings degraded from $\alpha_s = 0.94$ to 0.88 after carrying accelerated humidity tests (at 70°C and 95% relative humidity) for 30 hours.

Black chrome coatings electroplated on galvanized steel and tin coated steel have been prepared with $\alpha_s \sim 0.92$-0.94 and $\epsilon = 0.08$-0.16. These coatings have been found to be stable against sun exposure test for six months and 180 hours for thermal test at 200°C. Coatings withstand the accelerated humidity test (at 70°C and 95% relative humidity) over a period of 50 hours.

Black nickel and black chrome coatings prepared by electroplating on nickel plated steel substrates exhibit α_s = 0.92-0.94 and ϵ = 0.08 to 0.12. Stagnation temperatures of $\sim$ 135°C and $\sim$ 145°C are obtained under one and two glass covers, respectively. Black nickel and black chrome withstand the accelerated humidity test for 40 hours and 60 hours, respectively.

Coatings of black copper on copper and black iron on stainless steel have been obtained by chemical conversion with α_s = 0.86-0.92 and ϵ = 0.08-0.16. These coatings are stable under sun exposure test for six months and thermal cycling at 180°C for 80 hours. Coatings withstand the accelerated humidity test for a period of 20 hours.

An improvement of 2-4% in α_s has been achieved for coatings deposited on surfaces with roughness 2-3 μm (rms). The scanning electron micrographs support the results on optical scattering. Composition and its gradient have been studied by Auger depth profile studies conducted on black nickel and black chrome.

A thermal efficiency $\sim$ 28% has been measured for electroplated and chemically converted black nickel coatings on galvanized steel at an operating temperature $\sim$ 100°C, ambient temperature $\sim$ 38°C and insolation $\sim$ 1000 W/m^2. The thermal efficiency in case of flat black painted collector (α_s = 0.96, ϵ = 0.9) under identical conditions was found to be $\sim$ 10%.

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