Thermal Efficiency Development of Solar Selective Absorber Surface for Hot Air in Solar Drying

Chanon Bunmephiphit

Energy and Environmental, Rattanakosin College for Sustainable Energy and Environment, Rajamangala University of Technology Rattanakosin, Nakhonpathom 73170, Thailand
Corresponding author's email: chanon.bun@rmutr.ac.th
Received: 15 August 2023, Revised: 21 December 2023, Accepted: 30 December 2023

Abstract

Solar selective absorbers are the most commonly used in solar water heaters and heat sources to produce hot air for drying. Normally, solar selective absorber surfaces are produced by a chemical method with a complex process. Also, developing the solar selective absorber surface without the complex process for application use will be important. This work focuses on designing the solar selective absorber surface for producing hot air in solar drying by using material residue from a coffee aluminum can. The aluminum can was coated with Ni-Al powder using the spray method to increase the efficiency of absorption. The result of coating sprayed with the BOSANY Hi-Temp Spray Paint (Black) code 1039 had a wavelength in the range of 300–2,500 nm, and the absorptance efficiency was 0.98. The characteristic of the selective absorber surface was similar to that of the sugar crystals, which is the uniformity of the mountains affected by the anti-reflection. In addition, the coating is able to be used in special thermal applications by maintaining the thermal conductivity of materials over the operational temperature range (50–650 °C) due to thermal efficiency of 0.81 and heat extraction factor coefficient or heat loss (-FRUL) of -18.38 W/m2•ºC. It can be used for producing hot air in solar drying, which has a low cost and high thermal efficiency.

Keywords:

Aluminum Can; Solar Selective Absorber Surface; Solar Absorptance; Thermal Efficiency

1. Introduction

Solar energy is one of the primary energy sources on Earth and has high efficiency in converting it into thermal energy for photo-thermal conversion applications. [1], [2]. Photothermal conversion, which produces hot fluid or hot air, takes place in solar collectors. Efficient conversion requires that a solar-absorbing surface be in thermal contact with the fluid or gas and that thermal losses to the environment are minimized. The absorber is positioned under a transparent cover, and a transparent thermal insulation material is also used [3]. The photothermal conversion performance of a photoexcited material is mainly determined by two properties: the light-harvesting ability and the light-to-heat conversion efficiency.

The solar collector should be well insulated using conventional techniques. The most critical part of the photothermal conversion is the actual solar absorber surface. The present development of solar selective absorbers used chemical methods with complex processes such as coating, sputtering, deposition, and anodization [4]. H. Liu et al., 2021 [5] present that the absorption of solar spectral radiation using Ni-Al_2O_3 can have a conversion efficiency as high as 96.45%. R. A. X. Nunesa et al. (2018) [6] show a selective surface composed of black chromium (Cr/Cr_2O_3) with an absorptance efficiency of 95.3%. R. N. Abed et al. (2021) [7] applied a nanocomposite thin film coating comprising

Co_3O_4:Cr_2O_3 and carbon with an absorption efficiency in the range of 88–93.2%. This research aims to design a solar selective surface for producing hot air in solar drying by using material residue from coffee aluminum cans. Aluminum is an excellent heat and electricity conductor, and in relation to its weight, it is almost twice as good a conductor as copper [8]. It is a great process. However, if it wasn't carefully or mistakenly processed, it would impact the environment. Then, the knowledge and techniques of this process are limited to producing heat and are not popular for use in food. The preparation process involved coating with the spray method and increasing the efficiency of absorption by Ni-Al powder on solar selective surfaces due to its high heat absorption capability among the Al-based metallic composites [9]. Which is easy preparation process, good thermal, shorter processing time, low toxicity in environment, and less equipment needed without the complex process.

2. Experimental detail

2.1. Preparing material of the solar selective absorber surface

The solar selective surface was prepared on an aluminum can, and increased absorption was achieved with a spray black color combined with Ni-Al powder. Preparing the solar selective absorber surface was as follows:

(1) Preparing the aluminum can cylinder from coffee can have a diameter of 4-5 cm and a thickness of 0.11-0.16 mm. It was cut on top and below the bottom of the can, and after that, it was washed until clear.

(2) Cleaning the surface of the aluminum can before spraying color on the solar selective absorber surface. It was sprayed with sand to remove the original color and scrubbed with sandpaper for a rough surface.

(3) The aluminum can was attached to a long tube with chemical glue before coating the surface.

(4) The coating surface of the aluminum can was sprayed flat black with Ni-Al powder. This experiment compared the solar absorptance properties of a flat black sample from a market in Thailand Table 1. The brands of color with high solar absorptance were applied to the surface of the solar selective.

(5) The condition design of the solar selective absorber has a width of 0.9 m, a length of 2 m, and uses cover glass on top to protect heat loss (Fig. 1).

Table 1 The flat-black color of this experiment.

Type of color	Code
BOSANY Hi-Temp Spray Paint (Black)	1039
BOSANY Hi-Temp Spray Paint (Flat Black)	1200
SWAN Hi-Temp (Black)	HT310
KOBE (Flat Black)	912
LAZER (Flat Black)	L212(C)
Nippon paint PYLAC1000 (Flat Black)	229
Swan Spray (Flat Black)	212
TOA Spray (Flat Black)	021
TOA Spray 3000 Heat-Resistant (Flat Black)	051

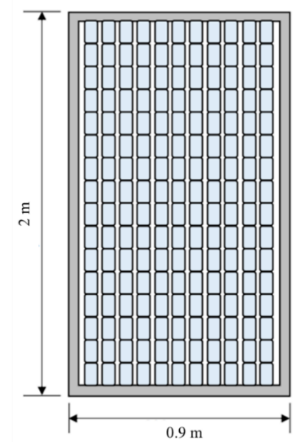

Fig. 1 Characteristic of Solar Selective Absorber Surface.

2.2. Properties analysis of the solar selective absorber surface

Properties analysis of the solar selective absorber surface was tested, including solar absorptance, morphology surface, and thermal efficiency, as follows:

(1) The solar absorptance (α) is the ratio of radiation absorbed by a solid to the radiation incident on that solid. It was analyzed by an ultraviolet-visible-near spectrophotometer (UV-vis) in the wavelength spectrum range of 300–2,500 nm according to the standard value of ASTM G1073 for air mass 1.5 [10] using equation (1).

$$\alpha_{sol} = \frac{\int_{0.3\mu m}^{2.5\mu m} I_s(\lambda)[1\text{-}R(\lambda)]d\lambda}{\int_{0.3\mu m}^{2.5\mu m} I_s(\lambda)d\lambda} \quad (1)$$

Where α_{sol} is the spectral absorptance of the solid, I_s is the spectral distribution of the solar irradiation, λ is the total hemispherical absorptance, and R is the spectral reflectance of the solid.

(2) The morphology of the solar selective absorber surface was assessed using a scanning electron microscope (SEM).

(3) The thermal efficiency was tested for converting solar radiation into heat energy when working substances have not changed state or non-energy accumulation. The experiment with thermal efficiency is shown in Fig. 2. It was carried out by hot air by feeding a hot air inlet temperature of 30–50 °C from the temperature control and blower. Each temperature was kept for 7 minutes. And then they were taken out of the air by blower [11]. The condition of the thermal efficiency experiment is observed in Table 2.

Table 2 The condition of thermal efficiency experiment.

Condition	Properties	Notice
Aperture area	1.8 m^2	
Working fluid	Water	
Flow rate ($\dot{m}$)	0.036 kg/s	0.02 kg/(s.m^2)
Inlet temperature	10-50 ºC	T_{fi}-T_a
Solar irradiance	790±50 W/m^2	

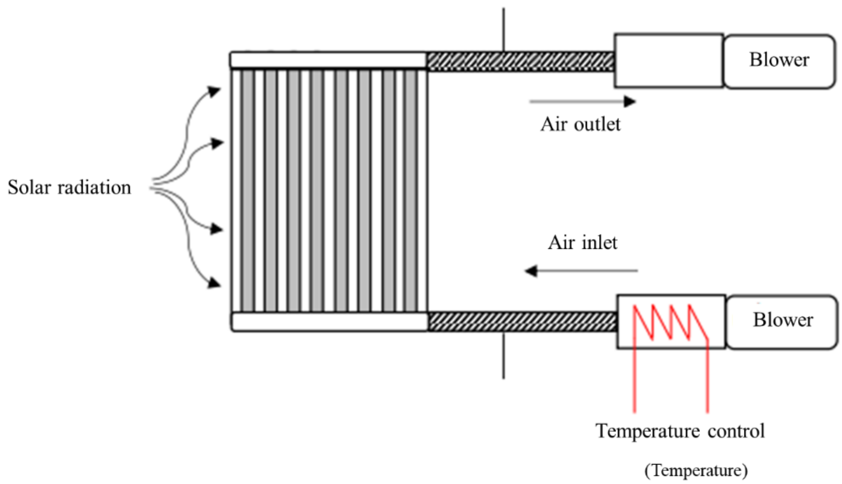

Fig. 2 The experiment of the thermal efficiency.

3. Results and Discussion

3.1. The solar absorptance of the solar selective absorber surface

Fig. 3 shows the solar absorptance efficiency of the solar selective absorber surface. It was found that the wavelength in the range 300–2,500 nm, which is the sprayed surface of the BOSANY Hi-Temp Spray Paint (Black) code 1039, had the highest absorptance efficiency of 0.98 by the UV-vis. Then, comparing other research, it was found that solar absorptance was 0.85-0.95 [4, 5, 6, 9, 10]. The characteristic of the BOSANY Hi-Temp Spray Paint (Black) code 1039 is a flat-black color. Normally, the flat-black, dark-colored group has higher absorption [12]. I. D. M. Medeiros et al. (2019) [10] made solar selective coating by black chromium with the electrodeposition technique that obtained the highest level of absorption maximum of 96%. Moreover, it has no reflection and is shiny, resulting in the highest solar absorptance efficiency. According to theory, the reflection when comparing solar density has low reflection ($R = 0$) and high solar absorptance ($\alpha = 1$). The absorptance of the wavelength was compared to the solar density, which has an air mass of 1.5 AM and has a value near the solar density. Also, the coating is able to be used in special thermal applications by maintaining the thermal conductivity of materials over the operational temperature range (50–650 °C).

3.2. The morphology surface of the solar selective absorber surface

Fig. 5 shows the morphology surface of the solar selective absorber surface with the coating by the BOSANY Hi-Temp Spray Paint (Black) code 1039 from the SEM of magnification 100X. It was found that the selective absorber surface characteristic has a black surface similar to the sugar crystals or the uniform height of the mountains, which is a more uniform surface with the micro-fissured region in prominence, similar to I. D. M. Medeiros et al. (2019) [10]. It can be seen clearly in the image. It had affected the anti-reflection, according to Fig. 6.

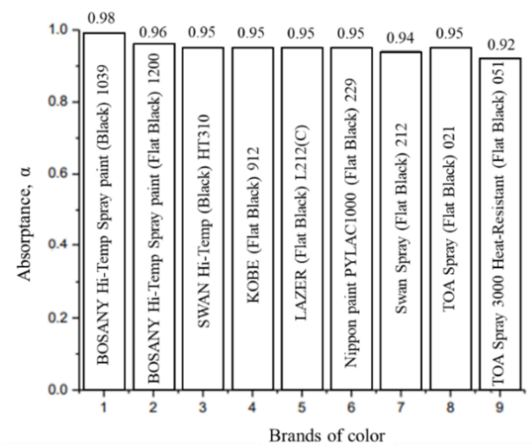

Fig. 3 The solar absorptance of the solar selective absorber surface.

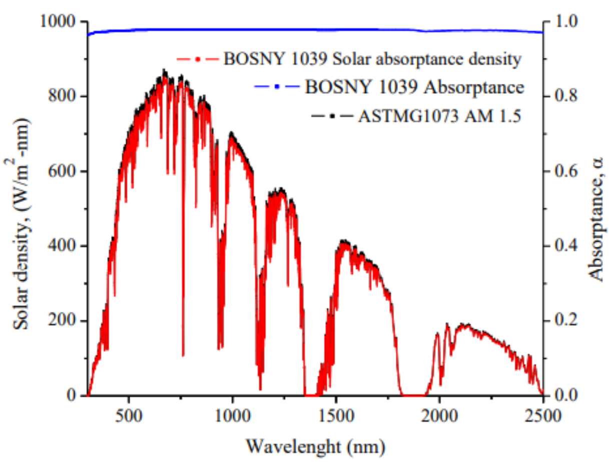

Fig. 4 Comparing the solar absorptance density of solar selective absorber surface with ASTM G1073 AM 1.5.

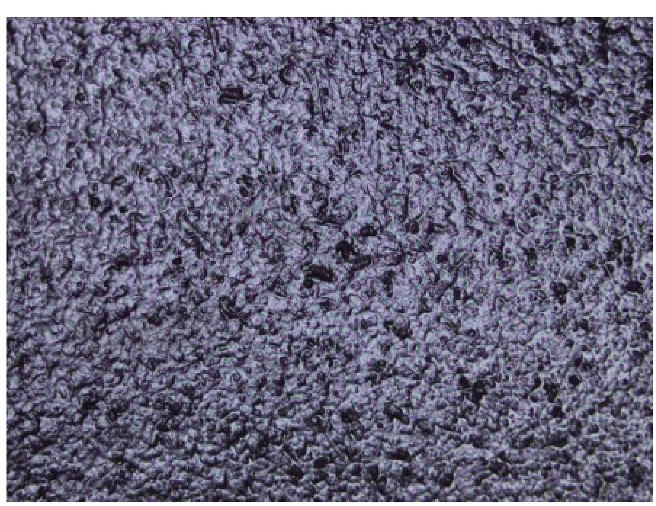

Fig. 5 Morphology surface of the BOSANY Hi-Temp Spray paint (Black) 1039.

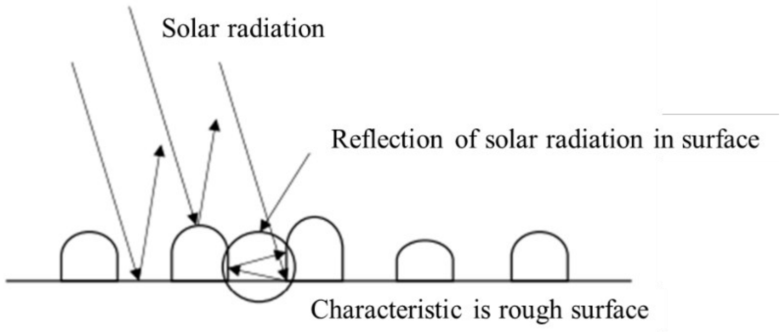

Fig. 6 Reflection of solar radiation in rough surface.

3.3. The thermal efficiency of the solar selective absorber surface

Fig. 7 shows the thermal efficiency of the solar selective absorber surface. It was found that the coating by the BOSANY Hi-Temp Spray Paint (Black) code 1039 had a thermal efficiency of 0.81 at solar irradiance 790±50 W/m^2 and a heat extraction factor coefficient, or heat loss (-FRUL), of -18.38 W/m^2 °C, as observed from the slope of the graph.

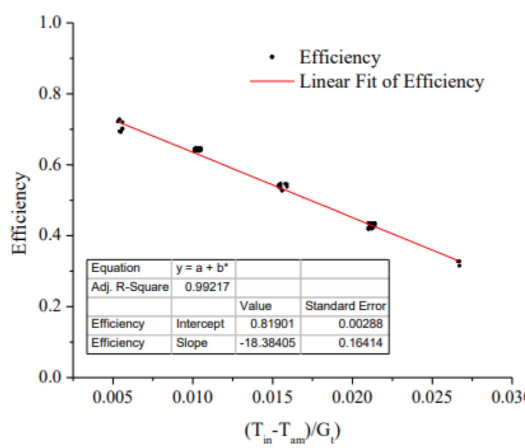

Fig. 7 The thermal efficiency of the solar selective absorber surface.

4. Conclusion

The solar selective absorber surface with coating sprayed with the BOSANY Hi-Temp Spray Paint (Black) code 1039 had a wavelength in the range 300–2,500 nm, and the absorptance efficiency was 0.98. When comparing solar density, it has low reflection (R = 0) and high solar absorptance (α = 1) as a value theory. The solar density has an air mass of 1.5 AM, which has a value near the solar density. The selective absorber surface characteristic has a black surface similar to the sugar crystals or the uniform height of the mountains affected by the anti-reflection. In addition, the coating is able to be used in special thermal applications by maintaining the thermal conductivity of materials over the operational temperature range (50–650 °C). due to thermal efficiency of 0.81 and heat extraction factor coefficient or heat loss (-FRUL) of -18.38 W/m^2•°C. It can be used for producing hot air in solar drying, which is low cost and high thermal efficiency.

Acknowledgements

The authors would like to acknowledge the support from the National Research Council of Thailand (NRCT). Energy and Environmental, Rattanakosin College for Sustainable Energy and Environment, Rajamangala University of Technology Rattanakosin, Nakhonpathom, Thailand. We would like to thanks for providing facilities and equipment in this experiment.

References

[1] Ning, Y., Wang, C., Wang, W., Tomasella, E., Sun, Y., Song, P., Hao, W., & Bousquet, A. (2020). Improvement of thermal stability of ZrSiON based solar selective absorbing coating. *Journal of Materiomics*, *6*(4), 760-767.

[2] Menezes, V. L., Gomes, K. C., & Carvalho, M. (2022). Evaluation of the manufacturing processes for solar selective surfaces based on Cr_xO_y from a carbon footprint perspective. *Cleaner Materials*, *3*, 100035.

[3] Granqvist, C. G. (1st Edition). (2004). *Encyclopedia of Energy*. Colorado, USA: Elsevier Inc.

[4] Xu, K., Du, M., Hao, L., Mi, J., Yu, Q., & Li., S. (2020). A review of high-temperature selective absorbing coatings for solar thermal applications. *Journal of Materiomics*, *6*(1), 167-182.

[5] Liu, H., Xie, M., Ai, Q., & Yu., Z. (2021). Ultra-broadband selective absorber for near-perfect harvesting of solar energy. *Journal of Quantitative Spectroscopy and Radiative Transfer, 266*, 107575. from https://doi.org/10.1016/j.jqsrt.2021.107575

[6] Nunesa, R. A. X., Costa, V. C., Sade, W., Araújo, F. R., & Silva., G. M. (2018). Selective Surfaces of Black Chromium for Use in Solar Absorbers. *Materials Research, 21*(1). from http://dx.doi.org/10.1590/1980-5373-MR-2017-0556

[7] Abed, R. N., Abed, A. R. N., & Yousif., E. (2021). Carbon Surfaces Doped with (Co3O4-Cr2O3) Nanocomposite for HighTemperature Photo Thermal Solar Energy Conversion Via Spectrally Selective Surfaces. *Prog. Color Colorants Coat*, *14*(2021), 301-315.

[8] Azonetwork. (2002). Aluminum - Advantages and Properties of Aluminum. Retrieved December 14, 2022, from https://www.azom.com/article.aspx?ArticleID=1446

[9] Zhou, Q., Hu, Q., Wang, B., Zhou, B., Chen, P., & Liu., R. (2020). Fabrication and characterization of the Ni–Al energetic structural material with high energy density and mechanical properties. *Journal of Alloys and Compounds*, *832*, 154894.

[10] Medeiros, I. D. M., Gomes, K. C., Gonçalves, R. P. N., & Galvão., G. O. (2019). Selective Solar Surface Solar Based on Black Chromium: Influence of Electrodeposition Parameters in the Absorption of Surfaces. *Materials Research*. *22*(2), e20180625. from http://dx.doi.org/10.1590/1980-5373-MR-2018-0625

[11] Cui, X., Ruan, Q., Zhua, X., Xiz, X., Hu, J., Fu, R., Li, Y., Wang, J., & Xu., H. (2023). Photo thermal Nanomaterials: A Powerful Light-to-Heat Converter. *Chem. Rev*. *123*(11), 6891-6952. from https://pubs.acs.org/doi/epdf/10.1021/acs.chemrev.3c00159

[12] Gebretinsae, H. G., Tsegay, M. G., Welegergs, G. G., Maaza, M., & Nuru., Z. Y. (2022). Effect of Rotational Speed on the Structural, Morphological, and Optical Properties of Biosynthesized Nickel Oxide Thin Films for Selective Solar Absorber Nanocoatings. *Energies*, *15*(23), 8960. from https://doi.org/10.3390/en15238960