

Selective Surface for efficient Solar Thermal Conversion

— Dr. Md. Golam Mowla Choudhury

Department of Physics, University of Rajshahi, Bangladesh

Introduction

Energy is the primary and most universal measure of all kinds of work by human being and nature. Every thing that happens in the world is the expression of flow of energy in one of its forms. If the question is asked as to what energy source will supply the enormous energy demand of the coming years, conventional thinking says, it is fossil fuel. But as the reserve of fossil fuels is gradually depleting, it is becoming a general belief that renewable source is going to be the answer to meet the ever increasing demand of the future energy supply.

To-day, there are two main challenges for the world energy industry. The first is to meet the expected exponential growth in demand for energy services, in particular, in the developing countries where billions of people do not have access to commercial energy. The second is to deal with the global, regional and local environmental impact resulting from the supply and use of energy. Considering these facts, fossil fuel will continue to dominate for some time; but renewable energy source will become more and more important with time.

Among the various renewable or non-conventional sources, wind, sea, geothermal and biomass solar energy are the most important and can be a major source of power supply. Sun's energy can be utilized as thermal and photovoltaic. The

simplest and most direct method of harnessing solar energy is to convert the incident solar radiation into heat (called solar thermal conversion).

Conversion of solar energy into thermal energy

The efficient utilization of solar energy for heating, cooling and other applications utilizes flat-plate collector or concentrator systems, which first capture as much as possible of the incoming solar radiation and then deliver a high fraction of the captured energy through a working fluid.

The conversion efficiency dependent on the properties of the absorber plate of the collector system is limited by the thermal losses due to conduction, convection and radiation. The efficiency can be expressed by the equation (Duffe and Beckman, 1991) as,

$$\eta = \frac{Q_u}{I A_c} = \frac{F_R [(a\tau)I - U_L(T_p - T_a)]}{I}$$

Where, Q_u = useful heat gain, I = incident solar radiation intensity, A_c = area of the collector, $(a\tau)$ = absorptivity-transmittivity factor, U_L = overall heat loss coefficient, T_p = temperature of the plate, T_a = ambient temperature and F_R = heat removal factor.

The exponent of the efficiency of the solar thermal conversion device is the absorbing surface and its optical and thermal characteristics. The efficiency can be increased by increasing the absorbed solar energy (α

close to unity) and by decreasing the thermal losses. Surfaces/coatings having selective response to solar spectrum are called selective surface/coating. Such surfaces offer a cost effective way to increase the efficiency of solar thermal collectors by providing high solar absorptance (α) in the visible and near infrared spectrum (0.3 – 2.5 μm) and low emittance (ϵ) in the infrared spectrum (2 – 20 μm) to reduce thermal losses. The economical and efficient utilization of solar thermal requires almost always the use of an efficient and low cost selective surface/coating.

Solar absorptance and emittance of selective surfaces

Figure 1a shows the difference between the solar radiation at ultraviolet, visible and near infrared spectrum and black body radiation at far infrared spectrum at two different temperatures. Unfortunately, materials that would behave optimally for solar heat conversion does not exist in nature. Virtually all black

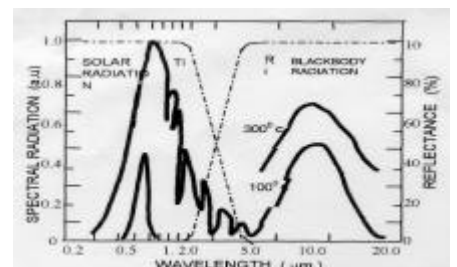


Figure 1a: Spectral distribution of solar terrestrial and black body radiation together with the ideal reflectance (R_i) and transmittance (T_i) curve for transparent heat mirror.

Selective Surface for efficient Solar Thermal Conversion

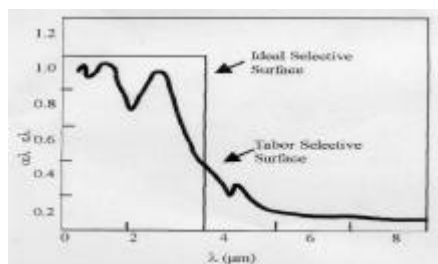


Figure 1b: Emissivity/absorptivity variation for an ideal selective surface and for a typical real surface by Tabor.

materials have high solar absorptance and also have high infrared emittance. Thus it is necessary to manufacture selective materials with ideal or very close to ideal optical properties. The surface/coating should have the following physical properties (Garg, 1997).

1. High absorptance for solar spectrum range 0.2-2.5 μm and low emittance for spectrum greater than 2.0 μm .
2. Spectral transition between the region of high absorptance and low emittance be as sharp as possible.
3. The opto-physical properties of the coating must remain stable under long term operation at elevated temperatures, repeated thermal cycling, air exposure, ultra-violet radiation, etc.
4. Adherence of coating to substrate must be good.
5. Coating should be easily applicable, and
6. Coating must be economical.

The characteristics desired for an ideal selective surface ($\alpha_\lambda = \epsilon_\lambda = 1$ for $\lambda < 4 \mu\text{m}$ and $\alpha_\lambda = \epsilon_\lambda = 0$ for $\lambda > 4 \mu\text{m}$) are shown in Fig

1b. For comparison, the variation obtained for one of the earliest surface synthesized by Tabor (1956) is shown in the figure.

Spectrally selective surfaces /coatings

Solar selective surfaces have been studied quite thoroughly in the late second half of the 20th century. Tabor (1955) introduced the use of spectrally selective surface for solar collectors and several types of selective surfaces have been developed since then. For energy applications, an ideal spectrally selective surface should have an abrupt transition between the low and high reflectance region around 2 μm , which is approximately the limit of the solar spectrum. Spectral reflectance behaviour of some selective coatings is shown in Fig 2. An ideal surface is also shown in the figure. However, it is impossible to prepare such an ideal coating in practice.

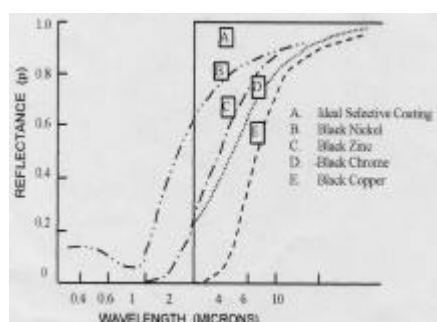


Fig 2: Reflectance behaviour of some selective coatings.

Selective surfaces with desired optical properties are usually deposited on metals or metalized substrates. Spectral selectivity can be achieved in a variety of ways. The various types of absorber surfaces are :

a) Intrinsic absorbers

- b) Particulate coatings
- c) Coating / metal tandem
- d) Semiconductor / metal tandem
- e) Optical trapping
- f) Multilayer thin films
- g) Transparent heat reflector / absorber tandem
- h) Transparent heat reflecting and conducting coatings.
- i) Quantum size effect.

Actual selective surface often utilizes the combined action of two or more mechanisms to obtain high selectivity. Since cost effectiveness is an important consideration in solar energy applications, a knowledge of various properties helps in the choice of a coating for a particular application. The recent development of semiconductor paints has provided a low cost large area process for large-scale applications in solar collector systems and has received particular attention.

Methods of preparation of selective coatings

Solar selective surface can be prepared by using the following techniques:

1. Vacuum evaporation
2. Vacuum sputtering
3. Ion exchange
4. Chemical vapour disposition
5. Chemical oxidation
6. Dipping in chemical baths
7. Electroplating
8. Spraying
9. Screen printing, and
10. Brass painting method, etc.

Selective Surface for efficient Solar Thermal Conversion

Surface layer of copper oxide and "nickel black" were first selective surfaces found to be suitable for practical use. The copper oxide layer was formed by chemical conversion, by treating a cleaned and polished copper plate in a hot solution of sodium hydroxide and sodium chloride for a specified time. Values of absorptivity $\alpha = 0.89$ and $\epsilon = 0.17$ were obtained.

The "Nickel black" surface was developed and commercialized by Tabor group (1964). Coating was prepared by electroplating method on galvanized iron sheet. Values of $\alpha = 0.81$ and $\epsilon = 0.16$ to 0.18 were obtained. Using the same method "Black nickel" was deposited on copper and mild steel by Cathro (1975) and values obtained were $\alpha = 0.89$ and $\epsilon = 0.09$ to 0.15 .

Cobalt oxide selective surface can be produced on bright nickel-plated steel substrates by electroplating techniques. The coating is obtained by immersing the substrate in an aqueous electrolytic bath at 400°C and using the substrate as a cathode. The solar absorptance of 0.87 and 0.92 , thermal emittance of 0.07 and $.08$ are observed in CoO and Fe-doped CoO selective coating respectively, deposited on nickel-plated steel substrate.

One of the most successful selective surfaces developed so far is "Black chrome". It has been extensively investigated and recommended even for very high temperature application. This coating is a metal-dielectric composite consisting of a Cr_2O_3 layer over a chromium particle/ Cr_2O_3 composite. It is prepared by electroplating on a nickel-

plated copper or steel base. McDonald (1975) reported values of $\alpha = 0.868$ and $\epsilon = 0.088$.

Properties of some of the important selective coatings are listed in Table 1.

Table 1: Properties of some important selective coatings

Coating	Substrate	Absorptivity	Emissivity
CuO	Cu	0.90	0.11
CuO	Al	0.93	0.11
CuO / ZnO	Zn / Al	0.88	0.20
CuO	Fe	0.90	0.16
Black nickel on bright nickel	Fe, Cu	0.96	0.07
Black nickel	Zn / Fe	0.94	0.09
Black chrome on bright nickel	Fe, Cu	0.95	0.09
	Zn / Al	0.95	0.12
	Ni / Al	0.95	0.5
	Zn / Fe	0.95	0.16
Co_2O	Zn / Fe	0.93	0.08
	Ni	0.92	0.08

Conclusion

One of the simplest and most direct methods of harnessing solar energy is to convert the incident solar radiation into heat, the solar thermal conversion. A key component in the solar thermal conversion device is the absorbing surface and its optical and thermal characteristics such as high absorption in the UV region and low thermal emittance in the infrared region. In quest for higher possible solar absorptance, lowest thermal emittance and stability to stay at high temperature in air, it is found that surface can be produced that gives desired characteristics for efficient conversion of solar thermal energy. Surfaces with desired properties can be obtained by adopting different effects of the materials and may be prepared by using different techniques. Applications, materials economics, energy inputs and desired system life would

determine the choice of techniques to be used for its preparation. Practical and efficient selective coatings are based on mixed tandem, gradient index and composite structure which are sensitively dependent on deposition and structural parameters, thus making the selective coating technology a high level technology.

Reference

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