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Optimization of Thermal and Economic Performance of a PTSC System through Material Selectivity: A Comparative Study for Efficient Solar Thermal Conversion

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***Abstract*— Solar-thermal power generation is based on the transformation of solar radiation into heat andusing that heat in a thermo-mechanical process. The solar radiation is concentrated by meansof mirrors to achieve a higher energy density in the focus of the mirrors and therefore be ableto force higher temperatures on a heat transfer medium. There are several geometrical optionsfor the realization of the concentrators. 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. This paper is mainly emphasized on the selection of the optimize parameters (like absorber material properties, reflective surface material, material emissivity properties etc.) for the efficient solar thermal conversion through selective material property in order to reduce the loss of heat through conduction, convection and radiation and make a system economic.**

***Keywords*—Absorptivity,Emissivity,Intercept actor,Particulate coating, Reflectivity, Thermal efficiency, Transmissivity.**

I. INTRODUCTION

Energy is the prime and most universal measure of all kinds of work by human being and nature. Everything that happens in the world is the expression of flow of energy in one of its forms.This combination of technology and energy provides important synergies that improve human life. Today, there are two main challenges for the world energy industry. The first is to meet the expected exponential growth in demand ad 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. 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 in to heat (called solar thermal conversion).Parabolic trough collectors concentrate the sunlight before it strikes the absorber. Mirrored surfaces curved in a parabolic shape linearly extended into trough shape focus sunlight on an absorber tube running the length of the trough. A heat transfer fluid is pumped through the absorber tube of the collector where the solar flux is transformed to heat. Parabolic troughs are collectors designed to reach temperatures over 100ºC and up to 450ºC and still maintain high collector efficiency by having a large solar energy collecting area (aperture area) but a small surface where the heat is lost to the environment (absorber surface).Energy balance, describing the collector performance, indicates the distribution of incident solar radiations into the useful energy gain and losses. The so-called optical efficiency of parabolic trough collectors (efficiency if the operating temperature is equal to the ambient temperature) is always lower than that of flat-plate or evacuated tube collectors. The reason for this is that the shape of the parabola can never be perfect (due to manufacturing tolerances) and that the reflectivity of the mirrors is always less than 100%. On that score, parabolic trough collectors have a disadvantage compared to flat-plate or evacuated tube collectors at low temperatures. However, their advantage is that heat losses are reduced because of the small surface of the receiver. This advantage becomes predominant if the collector is operated at temperatures higher than approximately 100°. The main advantages of using parabolic concentrator over Flat-plate collectors are that (i) reflecting material requires less material (ii) the absorber of concentrator systems is smaller than that of flat-plate system for same solar energy radiations (iii) insolation intensity is greater (iv) area of heat loss is small than that of flat-plate collectors, and foremost, owing to the small area of absorber per unit of solar energy collecting area, selective surface treatment and/or vacuum insulation, to reduce heat loss and improves collector efficiency are economically feasible with parabolic concentrating systems.

II. CONVERSION OF SOLAR ENERGY INTO THERMAL ENERGY

For efficient utilization of solar energy in heating, cooling and other applications through the use of concentrating parabolic trough, first capture as much as possible of the incoming solar radiation and thendeliver 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 energy balance equation, shown below, indicates the distribution of incident solar radiation into useful energy gain and various losses.

In – Out = Rate of accumulation

The term 'rate of accumulation' denotes the change in the capacity or energy of the system. Under steady state condition, useful heat delivered by a solar collector is equal to the energy absorbed in metal surface minus heat losses from the surface directly and indirectly to the surroundings.

$$A_c HR(\tau.\alpha)_e - A_C U_L(t_p - t_a) = Q_u$$

Where; Q_u is the useful energy delivered, $A_c HR(\tau.\alpha)_e$ defines the overall energy absorbed in metal surface and $A_C U_L(t_p - t_a)$ is the heat loss from metal surface to surroundings, A_c is collector area, H is the rate of incident beam on unit area of metal surface, R is the factor to convert solar incident beam to that on plane of collector, τ is transmissivity, α is absorptivity. $(\tau.\alpha)_e$ is termed as effective transmittance-absorptance product, U_L is the overall heat loss coefficient, t_p is the average temperature of upper surface of absorber plate (°C) and t_a is the atmospheric temperature (°C). The term 'HR' defines the solar energy received on upper surface of the collector, and is given by:

$$HR = (H_b . R_b + H_d . R_d)$$

Where; H_b & R_b are defined for beam radiations and $H_d . R_d$ are defined for diffused radiations.

In order that the performance of a solar collector be as high as economically practical design, the possible efforts be made, such that to either increase the value of $HR(\tau.\alpha)_e$ or to reduce the value of $U_L(t_p - t_a)$. Greater the energy absorption in metal surface and lower the heat loss from surface, higher is energy recovery. In order to reduce the rate of radiation and convection losses, one or more transparent surfaces are placed above the absorber surface. The efficiency can be increased by increasing the absorbed solar energy $(\alpha \; close \; to \; unity)$. 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 (0.3–2.5mm) and low emittance in the infrared spectrum (2–20 mm) 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.

III. Selective Surface Properties of Reflector

The most complex parameter involved in determining the optical efficiency of a parabolic trough collector is the intercept factor. This is defined as the ratio of the energy intercepted by the receiver tot eh energy reflected by the focusing parabola. The value of intercept factor is largely depended on the size of the receiver, the surface angle errors of the concentrator and the beam spread by it. For efficient conversion of solar radiations into useful thermal energy, it should have high absorptance for solar spectrum range 0.2-2.5 mm and low emittance for spectrum greater than 2.0 mm. Variety of reflector materials are available in the global market, which possess the same or nearby properties to be act as good reflector. Here in this paper different kind of reflector materials are compared based upon their *Reflectivity* (%) (as shown in figure 1) and *Average Emissivity (E)*(as shown in figure 2):

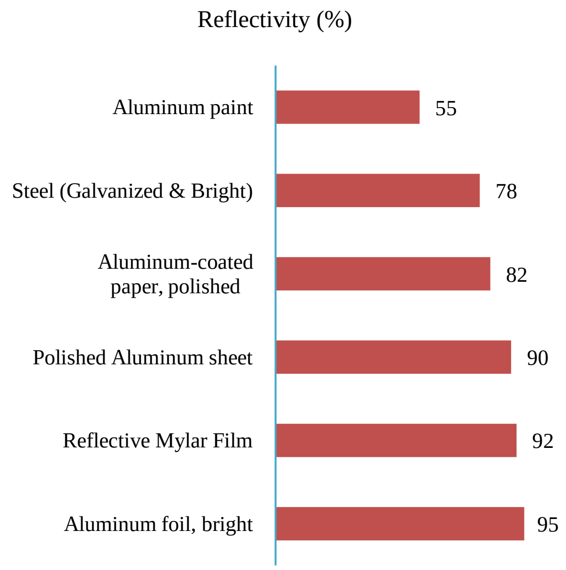

Figure 1

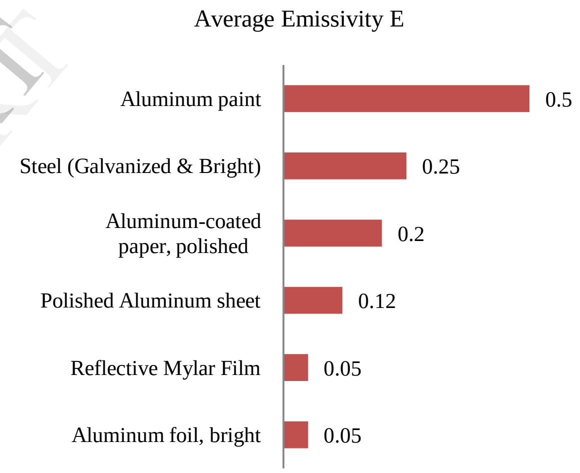

Figure 2

IV. Selective Surface Properties of Absorber

The selection of appropriate material for the absorber tube also plays an important role for efficient conversion of solar energy into thermal energy. As the working fluid passes through the absorber tube, the maximum energy radiated by the collector surface should have maximum impact on the absorber tube. On major scale of use, Copper (Cu) and Aluminum (Al) tubes are utilized as absorber material. The optimize use guarantees the maximum conversion of solar energy into process heat. The comparative analysis between Cu and Al is made on the basis of their absorptivity, thermal and electrical properties, as shown in figure 3 (a) and 3 (b):

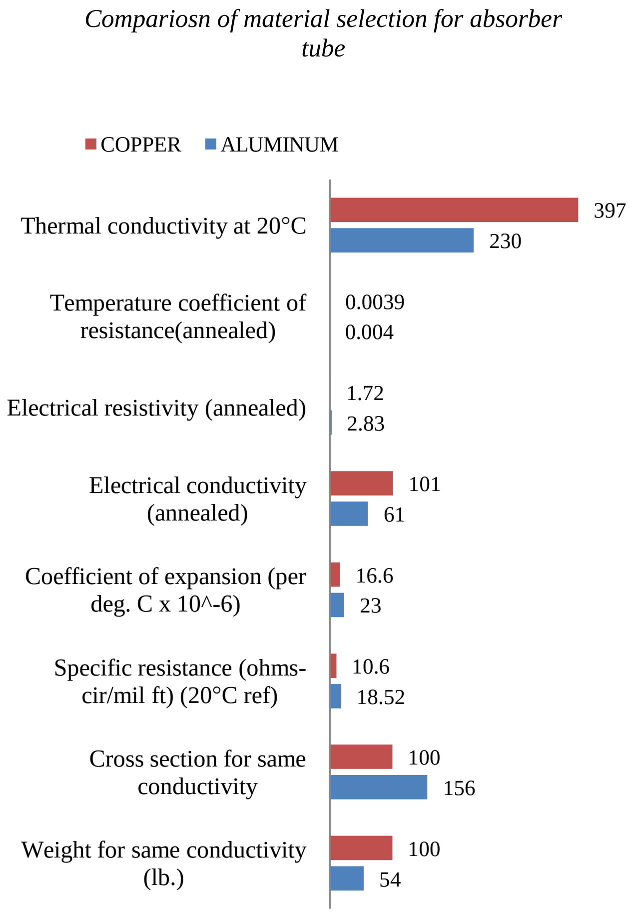

Figure 3 (a)

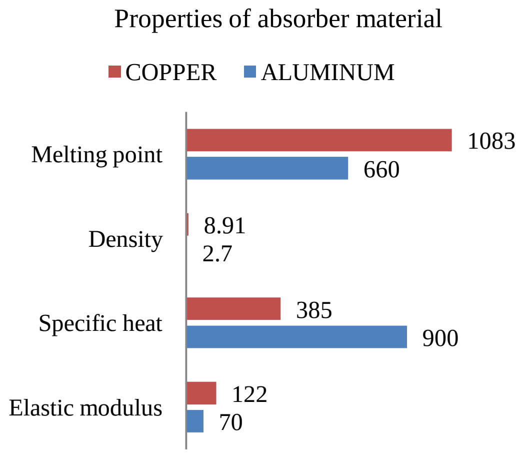

Figure 3 (b)

An efficient way to reduce thermal losses from the absorber of a solar heating panel is by using selective absorber coatings. An ideal selective coating is one that is a perfect absorber of solar radiations while being a perfect reflector of thermal radiations. Due to this property of coating, it will make a surface, a poor emitter of thermal radiation. Thus a selective coating must increase the temperature of an absorbing surface. If back losses of an absorbing surface are ignored, then at steady state conditions:

Solar flux absorbed = Thermal flux emitted

A selective surface is a surface that has a high absorptance for short-wave radiations and low emittance of long-wave radiation. A large number of experimental selective surface treatments and coatings have been tested; some of them are compared, as shown in figure 4:

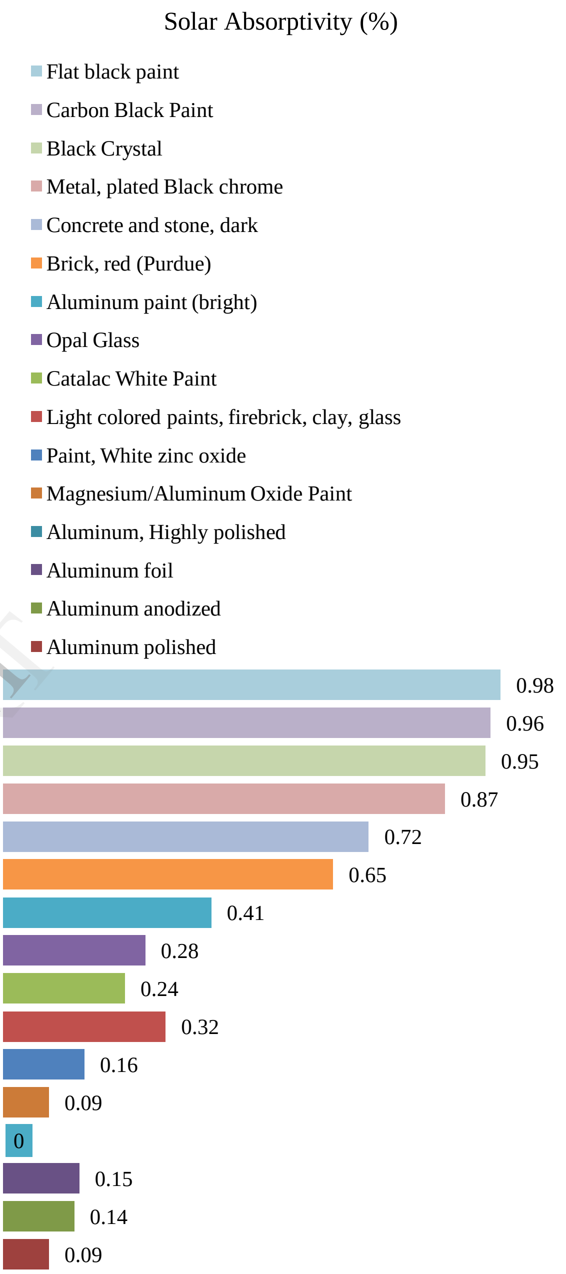

Figure 4

The figure 4 above shows the Solar Absorption (%) property of different materials being used for absorber tube coating. It has been observe from figure that flat black paint coating possess the maximum solar radiation absorption property with 98% and heat loss through conduction remains up to2% only. The figure 5 shows the Surface emissivity (%) of different materials:

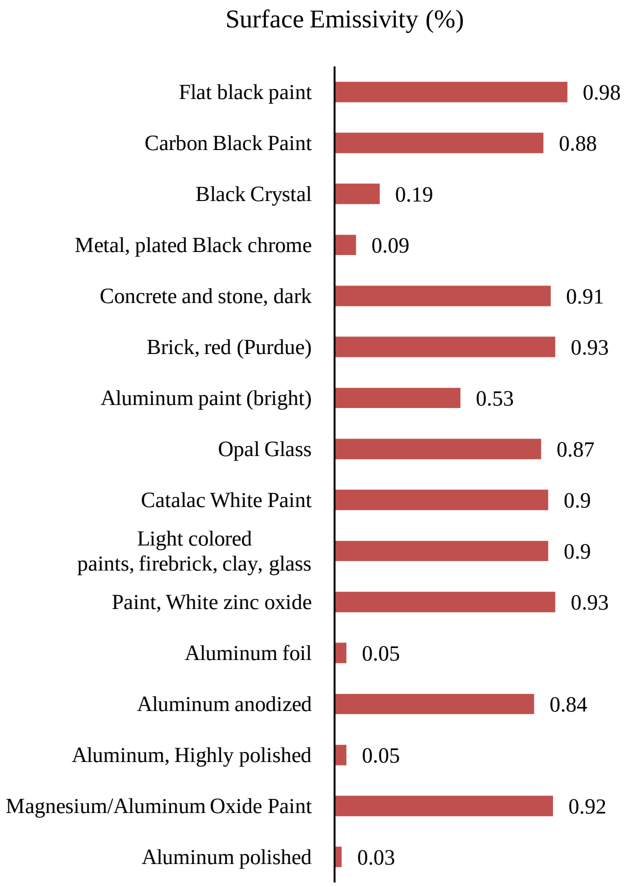

Figure 5

A selective material should possess the following characteristics:

1. Its properties should not be change with the use.
2. It should be able to withstand the temperature level associated with the absorber surface of a collector over extended periods of time.
3. It should be able to withstand any short-term temperature rise that may occur when no useful heat is removed.
4. It should be withstand atmospheric corrosion and oxidation processes.
5. It should be economical.

V. 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. Surfaces with desiredproperties can be obtained byadopting different effects of thematerials and may be preparedby using different techniques. On the basis of the comparison made, for material selectivity, it is desired to make an optimize choice. For a good reflector, the reflectivity percentage or transmissivity should be as high as possible and emissivity (the relative ability of materials surface to emit energy by radiation) should be as low as possible. From above comparison made for acting as reflector, aluminum foil, bright possesses the same property. And, for a good absorber, the material selectivity is based on the percent absorptivity, which should be as high as possible and surface emissivity should be low. On basis of comparison made flat black paint possess the property of being a good absorber. Because a good radiator is a good absorber. The black oxide (or flat black) coating is thick enough to act as a good solar absorber, with an absorptivity of 98% (approximately).

But the main problem associated with the coating surface is that it should essentially and completely be transparent to long-wave thermal radiation emitted by an object at a temperature of several hundred degrees. Since the bright metals, like aluminum foil, have low emissivity for thermal radiation and since the thin oxide coating is transparent to such radiation, the combination is a poor radiator of heat. As most of the selective surfaces are composed of a very thin black metallic oxide on a bright metal base, due to this at large temperature conditions, the coating may get irregular at some points and the overall heat loss coefficient, i.e. U_L, is reduced. At this stage, thermal analysis for the system may get non-uniform and the cost of maintenance of the system will be affected. Due to this the life cycle cost analysis may not provide proper analysis.

VI. REFERENCES

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