A high absorbance material for solar collectors’ applications

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Abstract. In this work, we proposed a low cost material to be used as an excellent absorber for solar collectors, to increase its thermal efficiency by the high capacity to absorb solar radiation. The material, known as “smoke black” (soot) can be obtained by the incomplete combustion of organic materials, such as the oxygen-acetylene, paraffin, or candles. A comparative analysis between the optical properties (reflectance, absorbance, and emissivity) measured on three covered copper surfaces (without paint, with a commercial matte black paint, and with smoke black) shows amazing optical results for the smoke black. Reflectance values of the smoke black applied over copper surfaces improves 56 times the values obtained from commercial black paints. High values of emissivity (E=0.9988) were measured on the surface covered with smoke black by spectrophotometry in the UV-VIS range, which represents about 7% of increment as compared with the value obtained for commercial black paints (E=0.938). The proposed high absorbance material can be easily applied on any kind of surfaces at low cost.

1. Introduction
Solar collectors for heating fluids require increasing the reception area of the solar radiation, and/or to increase the absorbance of the surface coating in order to improve the thermal efficiency. In a preliminary work [1], a proposal for increasing the reception area of solar radiation without changes in the diameter and number of copper tubes, consists in changing the typical circular cross section for an elliptical geometry with the same diameter of the tubes. Thus, an increment of about 42% in area for solar reception is possible if an eccentricity of e=0.95 on the elliptical tube is used. Metal makes a good thermal conductor, especially copper and aluminium. In high performance collectors, a "selective surface" is used in which the collector surface is coated with a material having properties of high-absorption and low-emissivity. The selective surface reduces heat-loss caused by infrared radiant emission from the collector to ambient. There exist in the literature several works reporting the good qualities of the selective absorber surface. For example, Peter et. al. [2] reported a surface of 99% of absorbance. The studied structure is composed of a reflective metal layer, a roughly quarter-wave layer of lossy dielectric, and a top metal layer that is patterned with an array of subwavelength apertures.
Some companies [3, 4] produce commercial selective solar absorptive layers both for flat plate and tubular collector solar systems but with a major cost. The layer configuration is formed by three parts: an IR-reflective part to guarantee low emissivity, an oxide solar absorptive part and an antireflective part for maximum solar absorption, as well as to resist degradation. Recently, a new type of ultra-thin meta-materials [5] was proposed to obtain broadband absorbers through surface plasmons.

2. Theory
When the radiative energy arrives on a surface, the total energy can be divided in three fractions: absorbed (A), reflective (R) and transmitted (T). Thus, by energy conservation, \( A + R + T = 1 \). On the other hand, according to Kirchoff's law, an isothermal body in thermodynamic equilibrium possess emissivity equivalent to its absorbance. An ideal black body assume that the absorbed energy is totally emitted, such that its emissivity is \( E = 1 \). If the body is opaque to the visible wavelength range (\( T = 0 \)), as our case, then, energy conservation reduces to \( A + R = 1 \). With these considerations, the reflectance \( R \) can be determined by measuring the absorbance \( A \), and consequently, the emissivity \( E \) of the black body.

3. Experimental Setup

Samples preparation
Groups of three samples of laminated cooper of 25 mm x 25 mm as obtained from commercial tubes of 1.27 cm-diameter used for plane solar collectors were prepared. Before preparation, samples were ultrasonically cleaned with acetone, and isopropyl alcohol. The first group of samples were analyzed without coating on the copper sample. The second group of samples was totally covered with commercial mate black paint with an aerosol-type application. Third group of samples was completely covered with “smoke black” as obtained from the incomplete combustion provided by an oxygen-acetylene welder equipment. For the third group, we suppose that the covered surface is mainly formed by diminutive particles of carbon as a result of the incomplete combustion and maybe some disordered nanotubes can be included.

Spectrophotometry measurements
Optical measurements (absorbance and emissivity) on samples were done with a Jobin Yvon/Spex UV-Vis spectrophotometer in the 300-800 nm wavelength range. The light source used was an incandescent lamp (white light) with a solid state germanium detector. For reflectance measurements a home made sample holder was used which is capable to measure the incident and reflected light at 45º. The experimental setup used is similar to the proposed by the National Centre of Metrology in México [6].

4. Results

Figure 1 shows the results of the reflectance of the three samples as a function of the wavelength. The vertical scale is logarithmic for better appreciation. Arrows shows the values of the reflectance for 400 nm and 800 nm, respectively. From Figure 1, it is observed the reflectance reduction when the copper surface is covered with a black paint. Minor reflectance is observed for the surface with a smoke black cover. The reduced value of the surface (\( R = 0.05% \)) covered with smoke black seems as a black body.

Figure 2 shows the emissivity (absorbance) as measured for the two samples of copper as a function of the wavelength. In figure 2 is shown the copper samples covered with black paint and without covering. Arrows indicate the values of the emissivity (absorbance) at 400 and 800 nm. Note the important advantage when the black paint in included on copper as compared with the surface copper only.

The copper sample covered with smoke black is shown in Figure 3 alone given the larger differences in the absorbance scale. From Figure 3 it is observed that the smoke black cover presents almost ideal black body behaviour. The high absorbance measured on the smoke black (\( A = 99.95% \))
makes it a good candidate to be used for recovering the metallic surface of plane solar collectors for increasing its absorbance. A higher value of emissivity (absorbance) was also reported on surfaces prepared with vertical carbon nanotubes [7].

![Figure 1](image1.png)

**Figure 1.** Optical reflectance as measured from three different copper surfaces.

![Figure 2](image2.png)

**Figure 2.** Emissivity (absorbance) of a copper surface without and with commercial mate black paint.

5. **Conclusions**

Three surfaces of copper for solar collector applications were optically analyzed in order to determine the emissivity (absorbance) value. Copper surfaces requires to be covered with some kind of black paint in order to increase its absorbance; otherwise, the reflective fraction increases, and diminishing the thermal efficiency. However, smoke black as obtained by the incomplete combustion of a oxy-acetylene welder equipment and applied on copper surface, demonstrate to have higher absorbance
than other commercial black paints. A near black body behaviour was measured on the copper surface when ultra-low reflectance of 99.95% was measured for smoke black paint. The smoke black cover was applied on a plane solar collector for heating water, obtaining an increase of 15 °C over a similar plane solar collector but with commercial black paint. Combining the smoke black and the elliptic geometry of tubes on a plane solar collector, its thermal efficiency increased in about 13 % as compared with a similar solar collector but without these innovations.

![Graph of emissivity vs wavelength](image)

**Figure 3.** Emissivity (absorbance) of copper surface covered with smoke black. High emissivity (absorbance) values between 99.88% and 99.95% were measured.

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