Reflectance, Transmittance and Absorptance of HDPE, LDPE, Glass and Sand Layer Used in a SAH

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Abstract: The total Infra-red (IR) transmission of polymer films is a very important property in engineering, which determines their suitability for a specific application at a given temperature level. Aiming to investigate the percentage IR transmission of two polymer material films and glass of a particular thickness, an analysis is developed for the comparative evaluation of this very important physical property. Sand is a solid and a poor conductor of heat. That means that when sunlight hits sand, all the energy of the sunlight is absorbed in the first millimeter or so of the sand, the heat stays there or spreads only a few millimeters down. So those few millimeters get quite hot. High transmittance and absorptance of top cover and absorber plate are among the factors that contribute to the high efficiency of a SAH. Transmission and reflection spectra were obtained from the Spectro 320 Optical Spectrum Analyzer. IR Radiation (IR) was obtained from a lamp and measurements made at room temperature and relative humidity of 21°C and 25%RH respectively. The study shows that the transmittance of clear HDPE, LDPE and glass are 0.84, 0.72 and 0.72 respectively at wavelengths 791.90, 735 .02 and 820.89nm. The absorptance of sand layers was found to be 56% and 59% for grey and brown sand respectively.

Key words: HDPE, LDPE, reflectance, transmittance, absorptance.

1. Introduction

Light or in general electromagnetic radiation can behave in various ways when it encounters an object along its path. It may either be transmitted, reflected, absorbed, refracted, polarized, diffracted, or scattered depending on the composition of the object and the wavelength of the light. Reflection is the process by which electromagnetic radiation bounce back either at the boundary between two media (surface reflection) or at the interior of a medium (volume reflection), whereas transmission is the passage of electromagnetic radiation through a medium. Absorption on the other hand is the transformation of radiant power to another type of energy, usually heat, by interaction with matter.

At temperatures above absolute zero, all the atoms in molecules are in continuous vibration with respect to each other. When a beam of electromagnetic radiation of intensity I0 is passed through a substance, it can either be absorbed or transmitted, depending upon its frequency, u, and the structure of the molecule it encounters. Electromagnetic radiation is energy; thus when a molecule absorbs radiation it gains energy as it undergoes a quantum transition from one energy state ($E_{initial}$) to another (E_{final}). The frequency of the absorbed radiation is related to the energy of the transition by Planck's law:

$$E_{final} - E_{initial} = hc/\lambda \quad (1)$$

The portion of the sunlight-spectrum that reaches the earth's surface is limited as shown in Fig. 1.

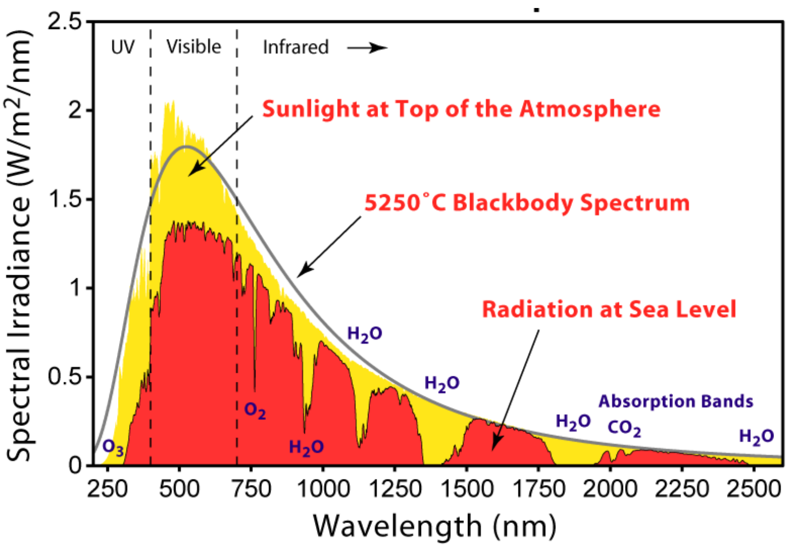

Fig. 1. Solar radiation spectrum [1].

Investigation of irradiative properties of thin solid films has been the subject of substantial theoretical and applied research over the past few decades owing to their considerable practical importance in optical and photovoltaic components [2], [3]. However, remarkably less attention has been devoted to the investigation of optical and irradiative properties of polymer films, which are crucial for a broad range of modern engineering applications [4]

Most of the higher energy X-rays, gamma rays, and cosmic rays never make it through the atmosphere due to their absorption by ozone, leaving only UV, Visible, and IR rays. Ozone absorption even takes care of the highest energy UV radiation, blocking radiation below 290nm. The solar energy that reaches the surface is limited to the wavelength range 290 to 2450nm. The total radiant solar energy consists of (in order of increasing energy): 37.8% IR (700-2450nm), 55.4% visible light (400-800nm), and 6.8% UV light (290-400nm) [5].

Solar air heater (SAH) is a type of solar collector extensively used in many applications such as in residential, industrial and agricultural fields [6], [7]. The main applications of SAHs are space heating, drying and paint spraying operations. Numerous SAH devices have been developed and used experimentally [8]. A glass or plastic cover is fixed above the absorber plate and the system is insulated thermally from the back and sides. SAHs are simple in design and maintenance. Glass is quite interesting as a cover for solar thermal devices because it absorbs almost all the IR (IR) radiation re-emitted by the absorber plate, resulting in an enhancement of the thermal efficiency of the solar collector by creating a greenhouse effect [7]. Nevertheless, the use of glass as a solar collector cover in rural zones of developing countries has two major disadvantages, its high cost, as underlined by Njomo (1995)[9], and its fragility both during transportation and in service. It is the reason why, for several years, transparent plastic covers have been used widely in these zones (particularly polyethylene because of its widespread availability) to construct moderate cost solar air heaters [10]. These solar collectors are used mainly for foodstuff drying [11], [12] and water heating, building heating, and in various agricultural applications [13].

The main drawback of a SAH is that the heat-transfer coefficient between the absorber plate and the air stream is low, which results in a lower thermal efficiency of the heater [14]. However, different modifications are suggested and applied to improve the heat-transfer coefficient between the absorber plate and air [15]. There are different factors affecting the SAH efficiency such as collector length, collector depth, type of absorber plate, glass cover plate, wind speed [13] surface geometry of the collectors [16] and porosity of the absorber [15], [17]. Increasing the absorber plate area will increase the heat transfer to the flowing air, but on the other hand, will increase the pressure drop in the collector; this increases the required power consumption to pump the air flow crossing the collector [18]. Several configurations of SAHs have been developed and used [19]. Various designs, with different shapes and dimensions of the air flow passage in plate type solar air collectors were tested [20]-[22]. In this research, a single pass SAH with semicircular top cover is adopted, constructed and its efficiency of absorptance investigated. The Optical Spectrum Analyzer (Spectro 320) used for this study, is a useful tool that gives spectral analysis transmission and reflection spectra. These spectra carry information that can directly infer absorbance of any radiation between 200nm- 880nm by samples of different materials. The Optical Spectrum Analyzer (Spectro 320) was used to measure the transmission and reflection of UV radiation by PE. From the equation

$$A=1 - (T+R) \tag{2}$$

where A is absorption, T is transmission and R the reflection all expressed as percentages gives an approximation of percentage absorption.

2. Materials and Methods

2.1. Materials

HDPE, LDPE films, brown and grey sand samples and normal glass of thicknesses 3 mm were used in this research where their optical properties were investigated. Steel wire, plywood and sawdust were also used in the construction of the SAH model. LDPE film was obtained from Horticulture Department of Egerton University while HDPE, steel wire and glass were obtained from dealers in Nakuru town. Brown and grey sand Samples were obtained from Kitale and Egerton University respectively.

2.2. Methods

HDPE, LDPE, and glass samples were cut into 4cm × 4cm pieces for IR transmission measurement while a sample holder made of glass was designed for transmission and reflection measurements of sand. A lamp (1.8A, 10V) was used as a source of IR. The lamp irradiates light of all wavelengths. The Optical Spectrum Analyzer-Spec 320 was used for all these measurements in the wavelength range of 700-880nm. During IR transmission and reflection measurements the temperature of the samples was kept at room temperature.

A schematic view of the single pass air collector is shown in Fig. 2. Plywood of 2mm thickness, painted with black color from inside and outside was used to make the frame of the collector. The bottom of the collector was insulated with 2 cm thick sawdust adequately since it is a good insulator and locally available material. The SAH frame has a dimension of 100 cm in length (L), by 50 cm width (W). Clear HDPE paper of 3 μm, thicknesses was used for glazing while brown sand layer of thickness 3 cm was used as an absorber. Steel wires were welded to make the frame of the collector which was semicircular in shape in order to ensure that at any given time, there is solar radiation received by the collector. Two holes of diameter 3 cm were left on either sides of the collector to act as inlet and outlet of air. Inlet hole was at a lower level than the outlet hole in order to ensure that cold air enters while the heated air exits through the other hole which is at a height as shown in Fig. 2. Thermocouples were placed at different positions in order to measure inlet and outlet temperatures of the moving air.

Transmission and reflection measurements were done using an Instruments Systems 320 Optical Spectrum Analyzer aided by Spec Win software while absorption measurements were calculated from the data obtained from transmission and reflection measurements. The instrument based on diffraction theory of light and employing solid state detectors, is able to give resolved spectra (Transmission and Reflection) of constituent wavelengths. It has an integrating sphere with the three measuring apertures. These are the 0°, 90 and 180 degrees apertures for the connection with the analyzer, reflection and transmission measurement respectively. This sphere provides the interaction of the instrument with the samples and radiations to be measured.

Fig. 2. The prototype of a SAH with HDPE as top cover and brown sand.

3. Results and Discussion

3.1. Reflection and Transmission Measurements of HDPE, LDPE and Clear Glass

Emission of the lamp is considered for comparison with solar IR that reaches the earth's surface. There is a maximum peak at 791.90nm with an irradiance of 0.745 W/m^2. The solar IR reaching earth's surface is between (700- 2450) nm with maximum peak of 1.1 W/m^2/nm as shown in Fig. 1. It is this radiation that is responsible for heating on the surface of the earth [1]. The percentage transmission of IR by HDPE between wavelengths (700 - 880) nm is shown in the Fig. 3.

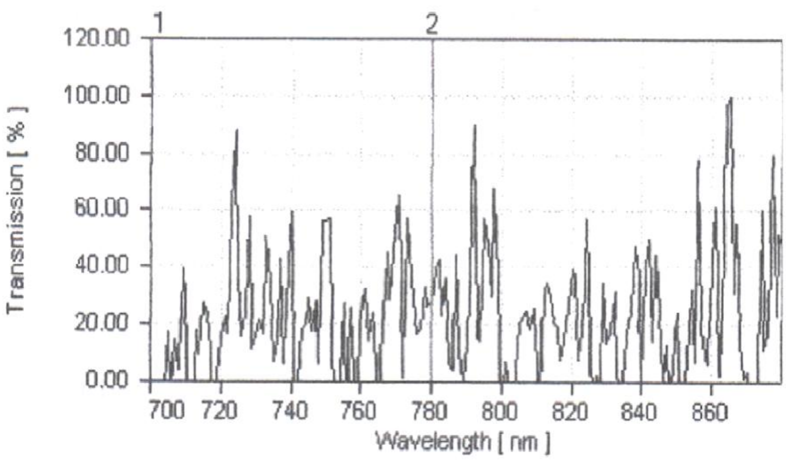

Fig. 3. Transmission (%) of HDPE in the wavelength range 700 - 880nm.

Transmittance of the IR radiation by the 3um HDPE film within the range (700-880) nm is below 80% except at 726nm, 790nm and 876nm with peaks of 87%, 90% and 80% respectively as shown in Fig. 3. Transmittance is measured and read with 0% being the reference line from the spectrum analyzer. These values of transmittance indicate that HDPE transmits IR well across the wavelength used.

The transmittance of clear glass of thickness 3mm was also investigated. Results indicate that the transmittance of clear glass is below 60% except at wavelength 821 nm with a peak at 76% (Fig. 4)

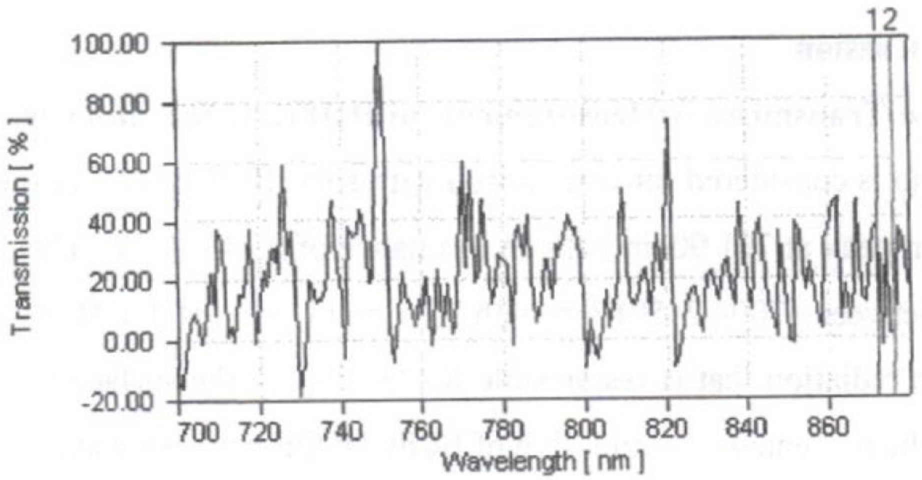

Fig. 4. Transmission (%) of 3mm clear glass in the wavelength range (700 – 880) nm.

The transmittance of LDPE was also investigated. Fig. 5 shows that transmittance of LDPE is highest at 790 nm with a peak at 82% which decreases as the wavelength increases.

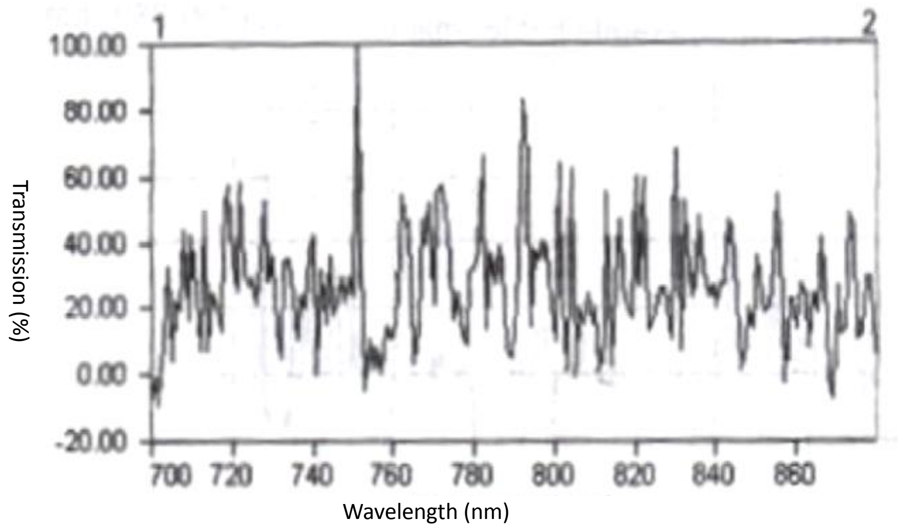

Fig. 5. Transmission (%) of LDPE in the wavelength range 700- 880nm.

3.2. Absorption Measurement of Sample Holder Made of Glass

Absorption of IR by sand layer was not measured directly by Spectro 320 Optical Spectrum Analyzer. Both reflectance and transmittance of the empty sample holder were measured in order to determine its absorptance after which reflectance and transmittance of sample holder with sand were measured. Fig. 6 and Fig. 7 were obtained.

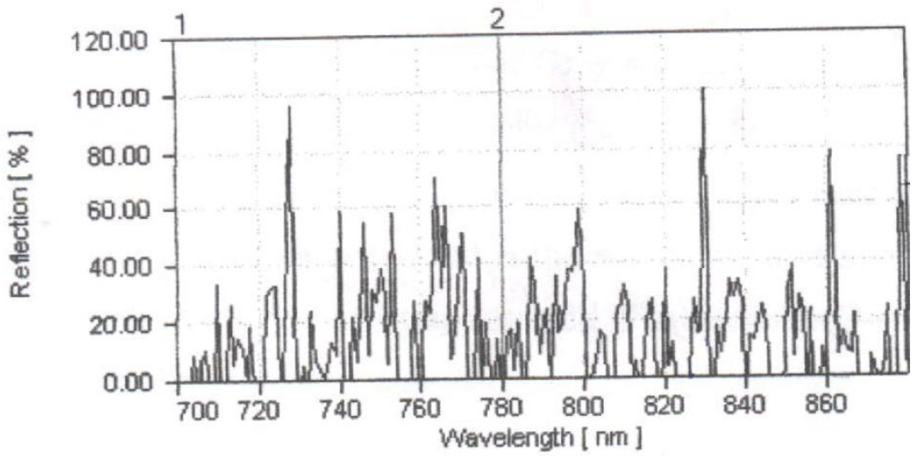

Fig. 6. Reflection (%) of IR by sample holder made of glass (700-880) nm range.

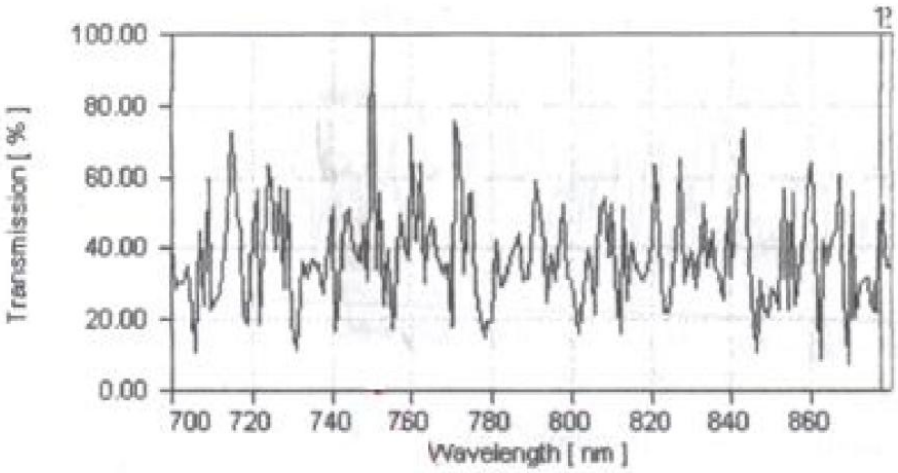

Fig. 7. Transmission (%) of glass made sample holder (700-880) nm range.

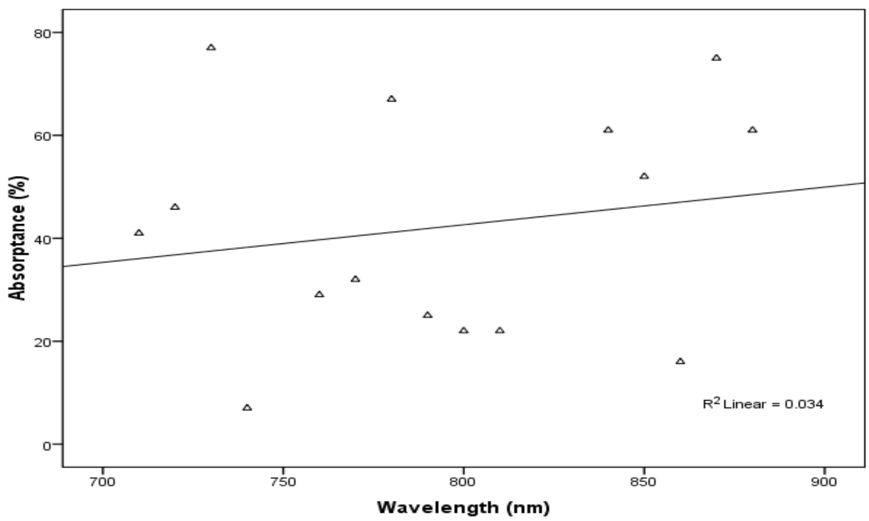

Fig. 8. Absorptance of IR by glass made sample holder at (700-880) nm range.

Generally, Transmission of IR by the sample holder is lower than Reflectance for various wavelengths with a peak of 78% at 770 nm. This implies that most of the wavelengths are absorbed. To determine the absorptance of IR by the sample holder, equation 2 was applied. A graph of Absorptance against wavelength was drawn using SPSS software version 16.0with data obtained in Table Al. The graph gives absorption in reference with the 0% line. Absorption of IR was generally high with a maximum of 77% at 730 nm with a minimum of 7% at 740 nm as shown in Fig. 8.

Table 1. Absorptance of IR by Sample Holder Made of Glass with Grey and Brown sand Layers at (700 – 880) nm Range

Wavelength (nm)	Absorptance % (glass made sample holder)	Absorptance % (sample holder plus grey sand)	Absorptance % (sample holder plus Brown sand)
710	4 1	87	07
720	46	33	05
730	77	68	58
740	07	28	65
750	-	37	10
760	29	77	12
770	32	53	32
780	67	62	50
790	25	61	49
800	22	36	43
810	22	45	60
820	-	60	81
830	-	38	12
840	61	14	71
850	52	68	20
860	16	28	59
870	75	16	58
880	61	71	80

3.3. Absorption Measurement of Grey and Brown Sand Samples

High absorptance value of the absorber plate is among the factors that contribute to high efficiency of a SAH. In this research, sand layer is used as an absorber. It was necessary to determine which colour of sand is the best to be used as an absorber. Brown and Grey colour sand layers were used in this research. To determine their absorptance, Spectro 320 Optical Spectrum Analyzer was used. Holding of sand was not possible and a sample holder made of glass was designed its properties investigated and then used. Transmittance and Reflectance of the sample holder with sand were measured in order to determine the Absorptance after which the Absorptance of empty sample holder was subtracted to determine the Absorptance of sand alone. Fig. 9 and Fig. 10 were obtained.

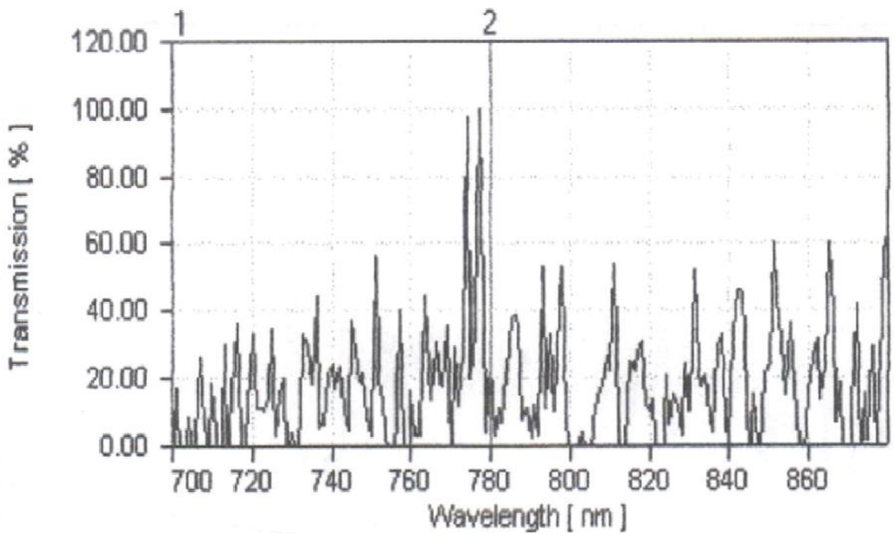

Fig. 9. Transmission (%) of IR by sample holder made of glass with grey sand layer at (700-880) nm range.

Reflectance of Grey sand is high with a maximum of 92% at 798 nm while Transmittance values are less than 60% except at 775 nm where the value is 98%. As compared to Transmittance, Reflectance of IR by sample holder made of glass with grey sand layer is higher than Transmittance for various wavelengths (Fig. 9 and Fig. 10). Using Fig. 9, Fig. 10 and equation 2, it was possible to determine the absorptance of sample holder with grey sand. Maximum Absorptance is 87% and occurs at 710 nm while minimum Absorptance is 25% at 880 nm (Fig. 11).

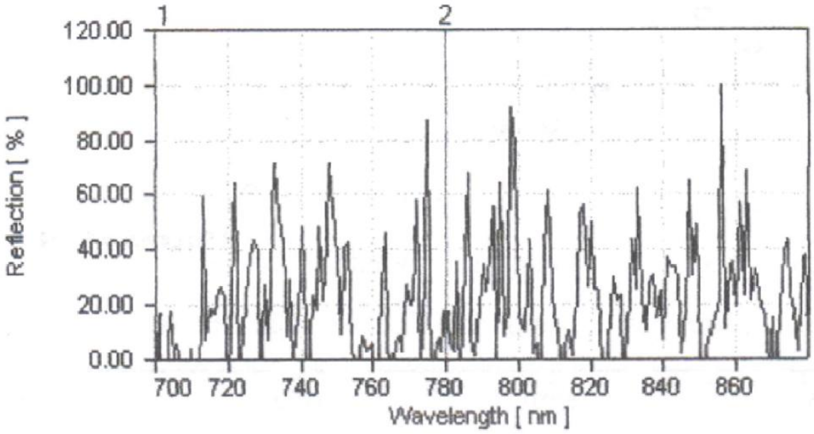

Fig. 10. Reflection (%) of IR by sample holder made of glass with grey sand layer at (700-880) nm range.

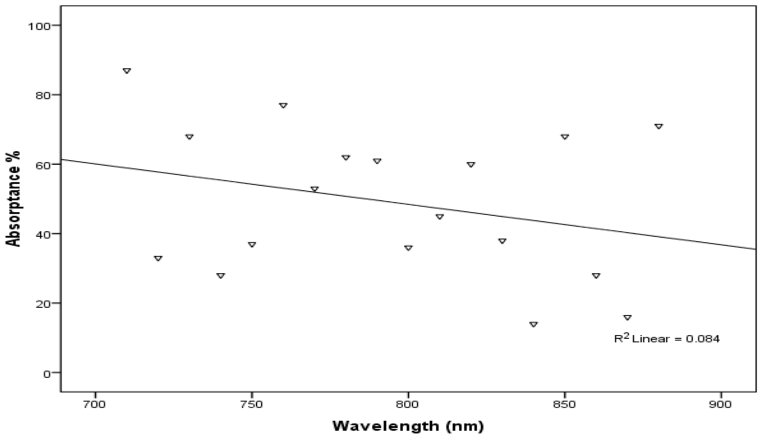

Fig. 11. Absorptance of IR by sample holder made of glass with grey sand layer at (700-880) nm range.

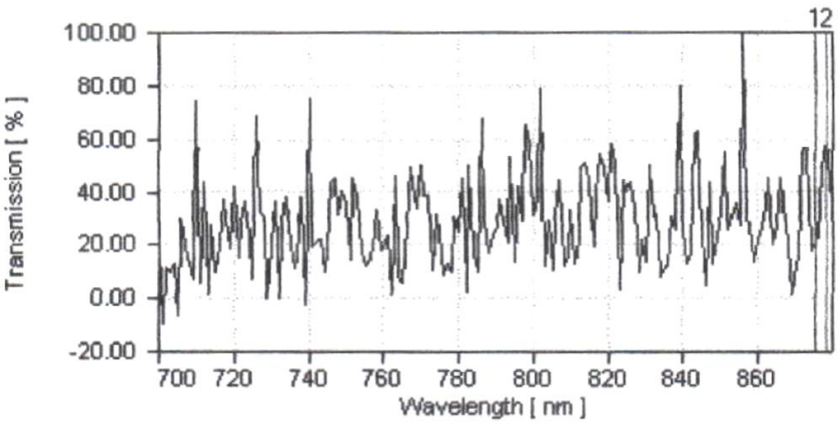

Fig. 12. Transmission (%) of IR by sample holder made of glass with Brown sand layer at (700-880) nm range.

Fig. 12 and Fig. 13 above show that Transmittance of the sample holder made of glass with Brown sand layer is lower than Reflectance as expected due to its color. The maximum value of Transmittance is 80% which occurs at 812 nm and 840 nm. In order to determine the Absorptance of Grey sand alone, Fig. 10 and Fig. 13 were used. The highest value of Absorptance was found to be 56% at 860 nm. In order to determine the Absorptance of Brown sand, the above procedure was repeated. Fig. 14 was obtained.

The maximum percentage Absorptance of Brown sand was found to be 59% at 810 nm from Fig. 14.

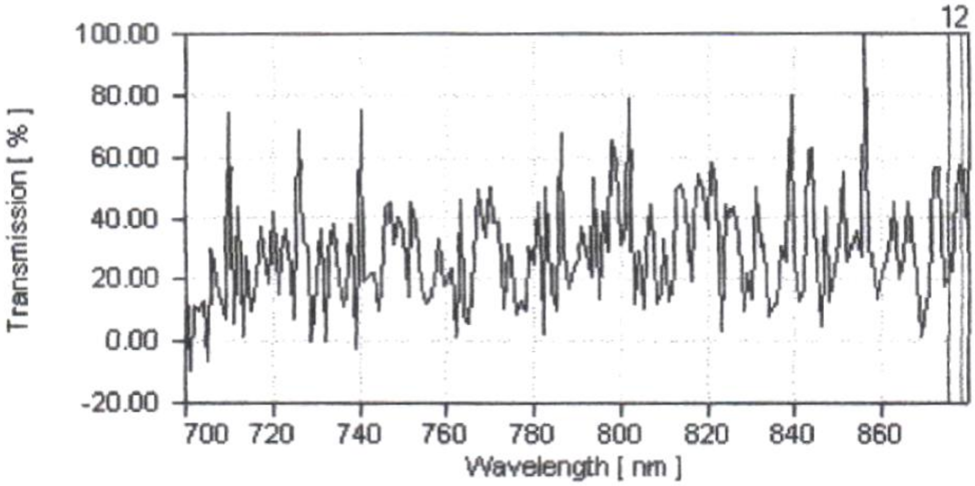

Fig. 13. Reflectance of IR by sample holder made of glass with Brown sand layer at (700 - 880) nm range.

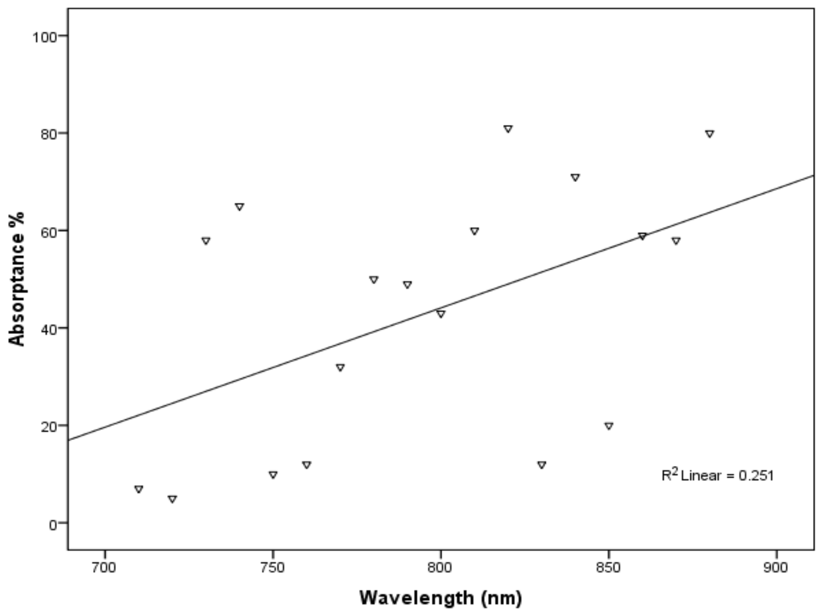

Fig. 14. Absorptance of IR by sample holder made of glass with Brown sand layer at (700-880) nm range.

4. Conclusion and Recommendation

Transmittance of top cover and Absorptance of the absorber plate are among the factors that determine the efficiency of any SAH. High values of these factors results to high efficiency. Clear HDPE paper was found to have a Transmittance of 0.84 at wavelength 791.90 nm while the Transmittance of LDPE and glass was found to be 0.72 each at wavelengths 735.02 and 820.89nm respectively. The Absorptance of brown and grey sand was also investigated. Brown sand was found to have a higher Absorptance value of 59% at 810 nm than grey sand which was found to have an Absorptance value of 56% at 860 nm. Brown sand and HDPE paper is therefore recommended for use as an absorber plate and top cover respectively. Brown sand and sawdust are locally available materials while steel wires and clear HDPE paper are available in various shops at an affordable cost.

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