KAJIAN TERHADAP SIFAT-SIFAT 'BALLASTIC BLACK' YANG MENYALUT PADA PERMUKAAN TIUB VAKUM SURIA – MENGIRA EFISIENNYA MELALUI PERUBAHAN FLUKS MATAHARI

(STUDY ON THE CHARACTERISTICS OF BALLASTIC BLACK COATED ON SOLAR EVACUATED TUBES – DETERMINATION OF EFFICIENCY FACTOR FOR VARYING SOLAR INSOLATIONS)

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List of Nomenclature

I_O	Initial intensity (W/m^2)
I_t	Attenuated intensity (W/m^2)
C	Concentration
l	Path length (cm)
ε	Absorptivity constant (cm^{-1})
t	Indicates transmittance
E	Absorbance (abbreviated as ABS)
R_a	Arithmetical mean deviation (μm)
R	Root mean square deviation (μm)
Y	Peak (μm)
N	Number of reading
α	Absorptance
τ_b	Beam radiation transmittance
$\tau\alpha$	Transimittance-absorptance product
η	Solar conversion efficiency
C_O, a_O, η_O	Concersion factor
C_1, a_1, η_1	Loss coefficient (W/m^2K)
C_2, a_2, η_2	Loss coefficient (W/m^2K^2)
T_m	Average manifold temperature (^OC)
T_a	Ambient air temperature (^OC)
T_i	Inlet collector water temperature (^OC)
A, A_C	Collector area or absorber area (m^2)
G	Insolation lever (W/m^2)
C_P	Specific heat at constant pressure (J/kgK)
ρ	Density (kg/m^3)
V	Volume flow rate (m^3/s)
m	Mass flow rate (kg/s)
R	Radius of evacuated collector (m)

L	Length of evacuated collector (m)
$F^{'}$	Collector efficiency factor
F_R	Heat removal factor
U_L	Heat loss coefficient (W/m^2K)
Q_U, q_U	Useful energy collector (W)

Abstract

The important characteristics of Ballastic Black when mixing with Thinner was identify from this research. Volume percentage method is one criterion to mix the Ballastic Black and Thinner. The relevant properties are useful to estimate the efficiency of the solar evacuated tube. The thin film thickness is relevant to the percentage of the Ballastic Black. Besides, the surface roughness of each sample was measure by machine Surftest Mitutoya SV400 and the surface distribution is test by Scanning Electron Microscope (SEM). The absorptance and transmittance of different percentages of Ballastic Black and Thinner was test by hit with different wavelength. Efficiencies of solar useful heat gain can calculate by TRNSYS, SPF Report and Theoretical method. Transmittance-absorptance product ($\tau\alpha$) was calculated by multiply the transmittance ratio of the uncoated sample into the absorptance ratio of the coated sample. This transmittance-absorptance product is important to calculate the collector thermal efficiency and the useful heat gain.

Abstrak

Pelbagai sifat yang penting tenteng larutan 'Ballastic Black' telah dikemukakan dalam laporan ini. Larutan ini telah dicampurkan dengen sejenis pelarut iaitu 'Thinner'. Campuran dijalankan dengan kaedah campuran isipadu dengan komposit yang berbeza. Sifat-sifat larutan adalah berkaitan bagi mengira kecekapan penyerapan tenaga suria. Ketebalan lapisan yang dikotkan itu adalah bergantung kepada komposisi yang terkandung dalam larutan itu. Tambahan pula, kekasaran permukaan akan disemak dengan menggunakan 'Machine Surftest Mitutoya SV400' dan kajian tentang permukaan yang dikotkan itu dijalankan melalui Scanning Electron Microscope (SEM). Kadar penyerapan dan kadar penebusan bagi sampel yang berlapis hitam itu telah dikaji dengan menghentam panjang gelombang yang berbeza. Kecekapan bagi penyerapan tenaga suria dapat ditentukan melalui kaedah 'TRNSYS', 'SPF Report' dan 'Theoretical method'. Nilai 'Transmittance-absorptance product' ($\tau\alpha$) dapat ditentukan melalui hasil darab kadar penyerapan bagi permukaan berkot dengan kadar penebusan bagi permukaan tidak berkot. Nilai ini penting untuk menentukan kecekapan dan jumlah tenaga yang akan diserap dari tenaga suria.

Chapter 1: Introduction

Solar energy describes a new method of harnessing energy from the light of the Sun. This has been present in many traditional building methods for centuries, but has become of increasing interest in developed countries as the environmental costs and limited supply of other power sources such as fossil fuels are realized. This is already in widespread use where other supplies of power are absent such as in remote locations and in space.

As the Earth orbits the Sun, it receives approximately 1,400 W/m² of energy, as measured upon a surface kept normal (at a right angle) to the Sun. Of the energy received, roughly 19% is absorbed by the atmosphere, while clouds on average reflect a further 35% of the total energy. The generally accepted standard is 1020 W/m² at sea level.

After passing through the Earth's atmosphere, most of the solar energy is in the form of visible and ultraviolet light. Plants use solar energy to create chemical energy through photosynthesis. Human use this energy when burn wood or fossil fuels or when consume the plants as a source of food.

Basically there are three types of collectors, which are flat-plate, evacuated-tube and concentrating.

1. The <u>Flat-Plate system</u> comprises an insulated, weatherproofed box containing a dark colour solar absorber plate under one or more transparent covers. Normally, Water passes through pipes located below the absorber plate. As the fluid flows through the pipes it is heated. This collector, although inferior in many ways to evacuated tube collectors and concentrating collectors, is still the most common type of collector in many countries.
2. <u>Evacuated-tube collectors</u> are made up of rows of parallel, transparent glass tubes. (twin-glass tube) tubes consist of a glass outer tube and glass inner tube. The inner tube is covered with a selective coating that absorbs solar energy well but inhibits radiative heat loss. The evacuated from mean that, the space between the two glass tubes to form a vacuum, which is to eliminates heat loss by conduction and convection. These tubes perform very well in overcast conditions as well as low temperatures. This is because the tube is 100% glass, there problem with loss of vacuum due to a broken seal is greatly minimized. Twin-glass tube may be used in a number of different ways, including ***open water flow***, heat pipe, or U pipe configuration.

3. Concentrating collectors for residential applications are usually parabolic troughs that use mirrored surfaces to concentrate the sun's energy on an absorber tube (called a receiver) containing a heat-transfer fluid. This type of solar collector is virtually antiquated as it compares poorly with evacuated tube solar collectors in terms of reliability and efficiency.

1.1 Background

Solar energy is one of the future energy development faces great challenges due to an increasing world population, demands for higher standards of living, demand to reduced pollution and a much discussed end to fossil fuels.

Besides, an energy crisis is any great shortfall or price rise in the supply of energy to an economy. It usually refers to the shortage of oil, electricity or other natural resources. The crisis often has effects on the rest of the economy. There has many recessions are precipitated by an energy crisis of some form. In particular, the production costs of electricity rise, which raises manufacturing costs.

Evacuated tubes are the absorber of the solar water heater. They absorb solar energy converting it into heat for use in water heating. There are several types of evacuated tubes in use in the solar industry. ***Open water flow*** collectors use the most common "twin-glass tube". This type of tube is chosen for its reliability, performance and low manufacturing cost.

The evacuated tube consists of two glass tubes made from Pyrex glass. The outer tube is transparent and it allowing light rays to pass through. The inner tube is coated with a selective chemical coated material which is excellent solar radiation absorption and minimal reflection characteristics. This evacuated tube is forms a vacuum, which is an important factor in the performance of the evacuated tubes to reduce the heat to ambient.

Evacuated tubes are the absorber of the solar water heater. They absorb solar energy converting it into heat for use in water heating. Vacuum tube is a perfect type to absorb heat from loses by conduction and convection. The insulation properties are perfectly that while the inside of the tube may be rise to 150°C / 304°F but the outer tube is still cold to touch. This means that evacuated tube water heaters can perform well even in cold weather when flat plate collectors perform poorly due to heat loss.

1.2 Problem Statement

The increasing of global warming, increasing of crude oil price and many environment problems, the environment friendly method such as solar energy is the potential alternative energy to develop. Therefore, this is important to develop a new technology to overcome these environment problems.

This research is to identify the characteristics on coated material which is Ballastic Black. The examples of the characteristic are absorptance, transmittance, surface roughness, thickness and the surface distribution.

After that, the results will apply in the theoretical method to calculate the efficiency of evacuated tubes solar collector. The results from theoretical method will compare to the results from transient simulation program (TRNSYS) and the sun protection factor (SPF) report.

1.3 Objective

- Identify the physical characteristic of the coated material on the inner evacuated tubes. Such as the thickness, surface roughness, and surface distribution.
- Furthermore is to identify the absorptance and transmittance ratio of the Ballastic Black when hit by different wavelength (190nm-500nm).
- Calculated the efficiency of the evacuated tubes coated with Ballastic Black when water pass thought the tubes.
- Therefore, compare the result from theoretical to the results from TRNSYS and SPF reports.

1.4 Scope

Study Ballastic Black properties to learn further about the absorptance, transmittance, surface roughness, thickness and surface distribution. The useful properties will help to get high efficiency of evacuated tubes solar collector.

Theoretical and experimental efficiencies of evacuated tube solar collectors using chemically coated absorber materials in contact with the working fluid will be investigated. There is a good degree of similarity between the experimental and software simulation results.

These solar evacuated tubes can apply in shower system and as water power plant pre-heater. These two applications are to collect solar energy to heat up the water temperature. So, the cost of electricity will reduce for shower system and the source to burn the water will reduce because the water was heated before pass thought the boiler.

Chapter 2: Literature Review

2.1 Volume Percentage Concentrations

Percentage concentrations are use as a common step to expressing a solution. Firstly, the composition of compound is remaining same and the concentrations of solution are variable. Secondly, the percentage calculated by volumes as well as weight, or even both together. Volume percentages are the familiar expressing step to calculate the percentage concentrations.

When the solution is made by mixing two or more liquids, the volume percent is usually used. Volume percent is usually used when the solution is made by mixing two liquids. One potentially confusing thing about volume percent stems from the fact that the volumes of liquids are not always additive. Sometimes the volumes change when two liquids are mixed together.

$$Volume\_percent = \frac{Volume\_of\_solute}{Volume\_of\_solution} x100$$

2.2 Wet Coating Technologies for Glass

Large area or high volume coatings on glass have been developed for a variety of products like plate glass for architectural and automotive glazing, hot and cold end coatings for container glass or for other articles from glass, like solar evacuated tubes

Wet coating materials can be employed as transparent and non transparent materials. Non transparent materials mainly may be used for decoration purposes for example using printing techniques. Transparent materials in form of organic paints never gained significance in practical applications. This however does not represent the potential of wet coating materials in any way. The application potential results from the opportunity of synthesizing unique material properties and to combine it with cost-effective coating techniques

In the flow coating process the liquid coating system is more or less poured over the substrate to be coated as shown schematically in figure 2.1. The coating thickness depends on the angle of inclination of the substrate, the coating liquid viscosity and the solvent evaporation rate. Flow coating processes at present are used for outfitting of automotive glazing from polycarbonate with hard coating but also can be used for float glass to employ functional coatings. The advantage of the flow-coating process is that non-planar large substrates can be coated rather easily. As a variation of this process, the spinning of the substrate after coating may be helpful in order to obtain more homogenous coatings. If no spinning process is employed, the coating thickness increases from the top to the bottom of the substrate.

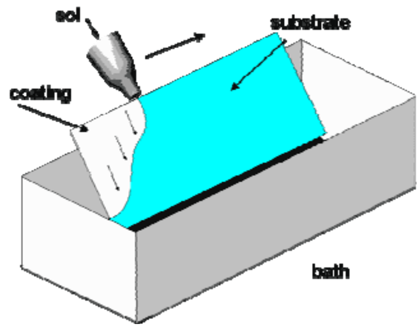

Figure 2.1: Scheme of the flow-coating process

2.3 Spectrophotometer

Figure 2.2: Hitachi Spectrophotometer U-2000

The model U-2000 spectrophotometer is designed for absorption analyses of liquid, solid and gaseous samples in ultraviolet and visible spectral regions.

In this scheme, a monochromatic beam with intensity 'I_O' travels through a liquid phase having concentration 'C' and path length 'l', which results in the intensity of monochromatic radiation decreasing to 'I_t'.

With respect to the initial intensity 'I_O' and attenuated intensity 'I_t' of monochromatic radiation, the following equation (1) can be set up.

$$It/Io = 10^{-\varepsilon.c.l} = t \qquad \text{---------------------------------------}(1)$$

Where, 'ε' is a constant known as absorptivity, which varies depending on the sample.

Equation (1) represents the statement of Lambert-Beer law, and ‘ t ’ indicates transmittance which is often expressed as a percentage, ie ‘ t x 100 = T’ (percent transmittance or %T) .Also, the common logarithm of inverse transmittance can be expressed as follow:

$$\log(1/t) = \varepsilon.c.l = E \qquad \text{-----------------------------------(2)}$$

Where, ‘ E ’ is called absorbance (abbreviated as ABS)

Absorbance ‘ E ’ is proportional to concentration ‘ C ’ and is a unit of measurement indispensable for quantitation determination.

For special samples, note that the laws expressed by equation (1) and (2) are not applicable to the following special samples.

- Fluorescing sample
- Appreciably turbid sample

2.4 Surface nature assessment

Figure 2.3: Machine Surftest Mitutoyo SV-400

The surface roughness test is carrying out by the machine surftest Mitutoyo SV-400. Then from the machine can get the reading of Ra and Rq. Where the Ra is Arithmetical mean deviation of the profile from the mean line, formula as show below:

$$R_a = \frac{1}{N}\sum_{i=1}^{N}\left|Y_i\right| \qquad \text{-------------------------------------(1)}$$

Meanwhile, Rq is Root mean square deviation of the profile from the mean line, formula as show below:

$$R_q = \left[\frac{1}{N}\sum_{i=1}^{N} Y_i^2\right]^{\frac{1}{2}} \qquad \text{-------------------------------------(2)}$$

2.5 Development of TRNSYS Models for Predicting the Performance of Water-in-Glass Evacuated Tube Solar water Heaters in Australia

(I.Budihardjo, G.L.Morrison and M.Behnia)

The performance of a solar water heater incorporating water-in-glass evacuated tubes was evaluated using a transient simulation program, TRNSYS. The collector efficiency is the outlines from the experimental and numerical techniques used in modeling each component of the solar water heater.

The collector efficiency is usually tested under constant radiation by mounting the collector on a sun-tracking frame. The flow rate is controlled and the useful energy from the collector can be determined by measuring the inlet and outlet temperature under steady-state conditions.

The solar radiation was integrated over this period (1) and the increase of internal energy of the system; dE can be calculated by monitoring the increase of tank temperature. The increase of internal energy is the net result of the useful energy transferred from the collector minus the heat loss from the storage tank (2). The latter could be calculated knowing the heat loss coefficient of the tank. Therefore, useful energy gain of the collector over this short period of the peak radiation can be determined. Collector efficiency is the fraction of solar irradiation which is converted into useful energy to the tank (3) and is a function of the operating temperature of the collector. At higher temperature, heat loss from the collector is higher. Therefore, the useful energy gain is smaller for the same amount of radiation.

$$G = \int_{t_1}^{t_2} I dt \qquad \text{--------(1)}$$

$$Q_{U-collector} = dE_{system} + Q_{loss-\tan k} = mc_p(T_2 - T_1) + \int_{t_1}^{t_2} U_{loss-\tan k}(Tm - Ta) \qquad \text{--------(2)}$$

$$\eta = \frac{Q_{U-collector}}{GA} \qquad \text{--------(3)}$$

The heat loss coefficient of the evacuated tubes is known to vary with temperature. Hence, the efficiency can be modeled as:

$$\eta = \eta_0 - \eta_1 \frac{(Tm - Ta)}{G} - \eta_2 \frac{(Tm - Ta)^2}{G} \qquad \text{--------(4)}$$

The optical efficiency of the collector (η_0) was obtained to be *0.58* using a linear regression of the measured point. The coefficients $\eta_1 = 0.9271 Wm^{-2}K^{-1}$ and

$\eta_2 = 0.067Wm^{-2}K^{-2}$ were determined from the tube heat loss measurement described in Budihardjo et al.

2.6 Apricus Solar Collector efficiency

Solar water heater performance is often presented as a graph, or set of three performance variable. Value may be provided based on gross area, aperture area or absorber area. In Europe, aperture or absorber is often used, in the US, gross area is often. It doesn't really matter which values is used, as long as use the correct value.

The three performance variables for the Apricus solar collector as provided by the Sun Protection Factor, SPF in Switzerland (SPF report C632LPEN) is as follows (for metric calculation – absorber area):

- Conversion Factor: $a_1 = 0.717$
- Loss Coefficient: $a_2 = 1.52W/(m^2K)$
- Loss Coefficient: $a_3 = 0.0085W/(m^2K^2)$

As well as the three performance variables shown above, insolation level (G) in Loss $Watts/m^2$, ambient temperature (Ta) and average manifold temperature (Tm) must be known. These values give the value x, also sometimes presented as $T*m$, used in the formula below

$$\eta(x) = a_1 - a_2(x) - a_3G(x)^2 \qquad \text{-----------------------------------(1)}$$

$$x = (Tm - Ta)/G \qquad \text{---(2)}$$

In really ambient temperature will fluctuate, and manifold temperature will gradually increase as the water is heated. Furthermore insolation levels may fluctuate with intermittent cloud cover. In order to more accurately calculate energy output per day/month/year a more complete set of environment data must be considered and many (hourly) performance calculations throughout the day taken.

One factor which is not consider in the straight performance calculations outlined above, is the affect of transversal IAM values (Incidence Angle Modifier) on solar output throughout the day.

2.7 Prediction of Flat-Plate Collector Performance Parameters using Artificial Neural Networks

(Soteris A.Kalogirou)

At steady state conditions, the useful heat delivered by a solar collector is equal to the energy absorbed by the heat transfer fluid minus the direct or indirect heat losses from the surface to the surroundings.

The useful energy collected from a collector can be obtained from the following equation,

$$q_U = A_c F^{'}[G_t(\tau\alpha) - U_L(T_m - T_a)] \quad \text{---(1)}$$

Where $F^{'}$ = Correction factor

The correction factor represents the ratio of the actual useful energy gain to the useful energy gain that would result if the absorber surface had been at the local fluid temperature. In equation (1) the temperature T_m of the fluid depends on the T_o and T_i. The outlet temperature T_o ,depends on the effectiveness of the collector, whereas T_i depends on the characteristics of the complete solar heating system and the hot water demand if the fluid temperature is expressed in terms of the inlet temperature then equation (1) can be written as:

$$q_U = A_c F_R[G_t(\tau\alpha) - U_L(T_i - T_a)] \quad \text{---(2)}$$

Where F_R = Heat removal factor

Heat removal factor can be considered as the ratio of the heat actually delivered to that delivered if the collector plate were at uniform temperature equal to that the entering fluid. F_R is affected only by the solar collector characteristics, the fluid type, and the fluid flow rate through the collector.

$$F_R = \frac{mC_P}{A_C U_L}(1 - Exp[\frac{U_L F^{'} A_C}{mC_P}]) \quad \text{---(3)}$$

Finally, the collector efficiency can be obtained by dividing q_U by $(G_t A_C)$. Therefore:

$$\eta = F_R[\tau\alpha - \frac{U_L(T_i - T_a)}{G_t}] \quad \text{---(4)}$$

In reality however the heat loss coefficient U_L in previous equations is not constant but is a function of collector inlet and ambient temperature. Therefore:

$$F_R U_L = c_1 + c_2(T_i - T_a) \quad \text{---(5)}$$

Substituted equation (5) into equation (2),

$$q_U = A_c[\tau\alpha F_R G_t - C_1(T_i - T_a) - C_2(T_i - T_a)^2] \qquad \text{------(6)}$$

and, the efficiency can be written as:

$$\eta = F_R\tau\alpha - C_1\frac{(T_i - T_a)}{G_t} - C_2\frac{(T_i - T_a)^2}{G_t} \qquad \text{------(7)}$$

and it can denote $C_O = F_R\tau\alpha$ and $X = (T_i - T_a)/G_t$. Therefore:

$$\eta = C_O - C_1 X - C_2 G_t X^2 \qquad \text{------(8)}$$

Usually the second-order terms are neglected in which case $C_2 = 0$. In this case equation (8) plot as a straight line on graph of efficiency versus the heat loss parameter $(T_i - T_a)/G_t$.

2.8 Transmittance-absorptance product of solar glazing with transparent insulation materials.

(N.D.Kaushika, M.Arulanantham)

The transmittance-absorptance product of solar glazing containing the transparent insulation material (TIM) of square celled honeycomb is investigated. A method is developed for the determination of transmittance-absorptance product of beam, sky and ground diffuse solar radiations using the individual transmittances of cellular array and encapsulating covers; the internal reflections are taken into account.

The incidental solar radiation on the covers is partly reflected, absorbed and transmitted. The radiation falling on the cellular array undergoes reflection, refraction and absorption due to vertical walls while propagating through the cells. The propagation of radiation through the walls is due to internal reflections.

The transmittance-absorptance product of the cover system involves the determination of beam and diffuses radiation transmittances of covers and honeycomb cellular matrix.

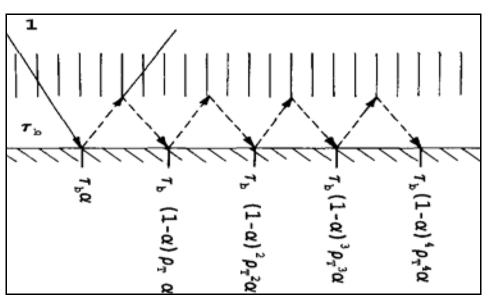

Figure 2.4: Internal reflections between TIM, covers and absorber plane