INFLUENCE OF REFLECTED RADIATION COMPONENTS ON SOLAR COLLECTORS

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Summary

In this paper the authors investigated the process of reflection of a flat plate collector is to be studied. As the behavior of the performance of solar collectors is depending on a lot of factors, among them on the wavelength of the sun light, reflected solar radiation. Based on the measurements an analysis was carried out to determine the rate of scattered radiation. Incident irradiance on a non-horizontal surface from a variety of incident angles may cause the reflectivity to change. Assumptions about the reflectivity of vertical surface are frequently made for a variety of purposes but are rarely quantified. The paper introduces the result of the measurements and the analysis.

Introduction

At the Department of Physics and Process Control, Faculty of Mechanical Engineering, Szent István University, Gödöllő various solar applications were installed for educational, demonstrational and research purposes, such as PV and solar thermal units, transparent wall insulation and solar dryer unit.

A geometric model of active surface described both for flat plate and vacuum tube collectors which is demonstrated as (Kocsány et al, 2011). Due to the design of evacuated tube collector a shadow effect has taking into account. Based on theoretically calculations the geometrical model has carried out to determine the active surface of two type of collectors (vacuum tube and flat plate) at any time of day. In spite of a shadow effect must be taken into account the vacuum tube collector reached the total useful surface under lower incident angle than flat plate collector, which shows at the same angle a growing tendency.

Based on the measured data, the rate of reflected radiation is principally depends on the angle of incident radiation (Esfamichael et al, 2000). The angle between the incoming radiation and the normal of surface is close the reflection is less than otherwise. Solar radiation includes both beam and diffuse components. Three types of scattered radiation are known as specular (the angle of incoming radiation is equal to the reflected), diffuse (obliterates all directional characteristics of incident radiation) and general (Shah, 2004.). In general, the magnitude of the reflected intensity a particular direction for a given surface is a function of the wavelength and the spatial distribution of the incident radiation. Long-wave radiation is can be emitted by several things like a collector or by the atmosphere (Cooper, 1969). At this stage of the work the reflection of the total radiation is considered without wavelength dependence.

As the behavior of the solar collectors is depending on a lot of factors, among them on the spectral distribution of the solar radiation, spectral measurements were started. Based on the measurements an analysis was carried out to determine the rate of the red and infrared radiation (the most important part of the spectra for the collectors) in the incoming power.

Calculation of the solar power crossing the covering glass

The Kirchhoff's law says, that

$$\rho + \alpha + \tau = 1. \qquad (1)$$

where ρ, α and τ are the reflective, the absorptive and the transmission coefficient of the material. Each coefficient is the function of the wavelength and they are depending on the incident angle of the radiation. In our case the absorption is considered negligibly in the first model, so if the reflectivity is measured, than the transmission can be determined as $\tau = 1 - \rho$.

For determination of the incident angle dependence of the properties, an experiment was carried out with two types (polycrystalline and amorphous silicon) PV modules.

The measurements were made in a black room with a shaded light source and a shaded optoelectronic sensor with voltage output facing to each other. Shading of light source and sensor is important to focusing the light on a determined place and also to get information about reflection from directly reflected radiation. The tilt angle was calculated by the height of the light source, sensor and distance from the measured equipment both of them were set in the same position. Three type of measurements were done. At first time the experiment was carried out without shading the light source and the sensor, after that a cover was made by a black cardboard paper on the light source and the sensor too. The average of the experiment results is shown in Table 1. To comparing the issue experiment were also made on simple glass.

Tab. 1: Averages of measurements and reflectivity and the transmission coefficient

	Sensor voltage output [mV]			ρ			τ		
α [°]	PC	ASI	Glass	PC	ASI	Glass	PC	ASI	Glass
90	0,293	0,300	0,269	0,7244	0,7417	0,6650	0,2756	0,2583	0,3350
80	0,332	0,340	0,308	0,7991	0,8167	0,7405	0,2009	0,1833	0,2595
70	0,315	0,331	0,291	0,7500	0,7871	0,6921	0,2500	0,2129	0,3079
60	0,293	0,307	0,264	0,7018	0,7362	0,6332	0,2982	0,2638	0,3668
50	0,301	0,307	0,277	0,7314	0,7454	0,6715	0,2686	0,2546	0,3285
40	0,327	0,339	0,299	0,7694	0,7969	0,7043	0,2306	0,2031	0,2957
30	0,304	0,295	0,293	0,7029	0,6821	0,6775	0,2971	0,3179	0,3225
20	0,343	0,320	0,306	0,7849	0,7315	0,7002	0,2151	0,2685	0,2998
10	0,345	0,363	0,360	0,7859	0,8276	0,8208	0,2141	0,1724	0,1792

From the measured data absorptive and transmission coefficient were calculated and normalized as it can be seen on Fig. 1.

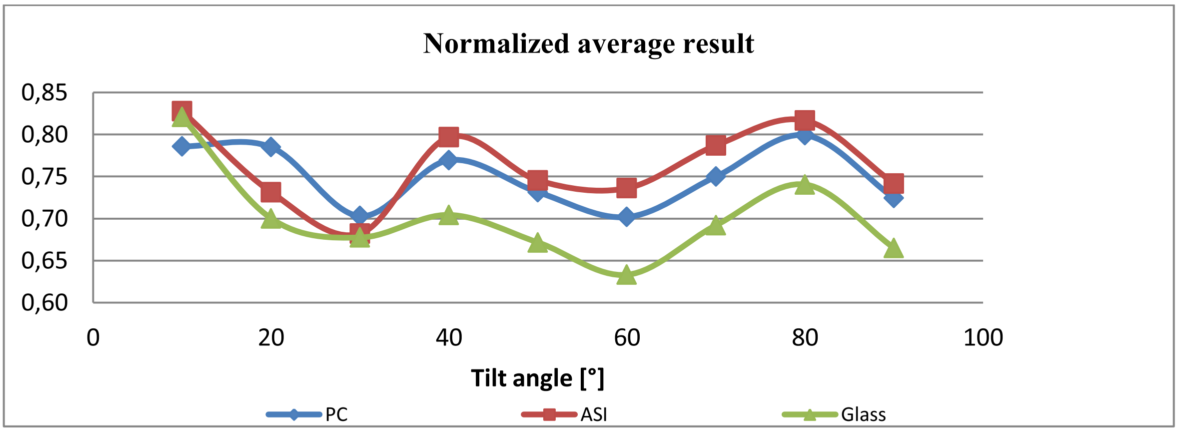

Fig. 1: Average of experiment results

A periodicity was thought to recognize on diagram above that is the reason more experiment was done with four different color filters (Table 2). Measured data shows nearly the same results on Fig. 2 there is no difference between the separate filters. Only the Infrared color varies from the others. As Fig. 3. diagram shows that the reflected rate of the infrared radiation is lower than other, than the other ranges, so the glass has good transmission coefficient in this - for the solar devices important - range.

Tab.2: Measurements with color filters

	PC [mV]					ASI [mV]				
α [°]	**Green**	**Red**	**Yellow**	**Blue**	**InfraR**	**Green**	**Red**	**Yellow**	**Blue**	**InfraR**
10	271,3	274,1	275,3	270,6	258	295,1	297,7	299,6	294,6	281,8
20	305,9	308,8	310,5	304,5	288,2	258,5	261,1	261,6	257,9	246,6
30	277,6	281,4	281,9	278,5	264,9	297,2	298,6	300,6	295,3	280,2
40	231,4	233,1	234,1	229,6	215,8	265,3	266,7	267,3	265,6	250,4
50	231,3	233,2	234,5	230,8	217,4	243	244,6	245,4	242,8	229,5
60	220,6	228,4	233,2	228,5	218,9	234,4	233,7	235,7	230,6	217,2
70	188,6	190,5	191,8	187,6	192,6	201,5	204,1	204,3	201,2	212,8
80	274,6	276,4	278,8	273,8	215,7	270,7	272,3	272,9	270,1	239,7
90	233,7	237,4	238,7	234,8	248,9	248,2	248,3	248,7	246,1	273,1

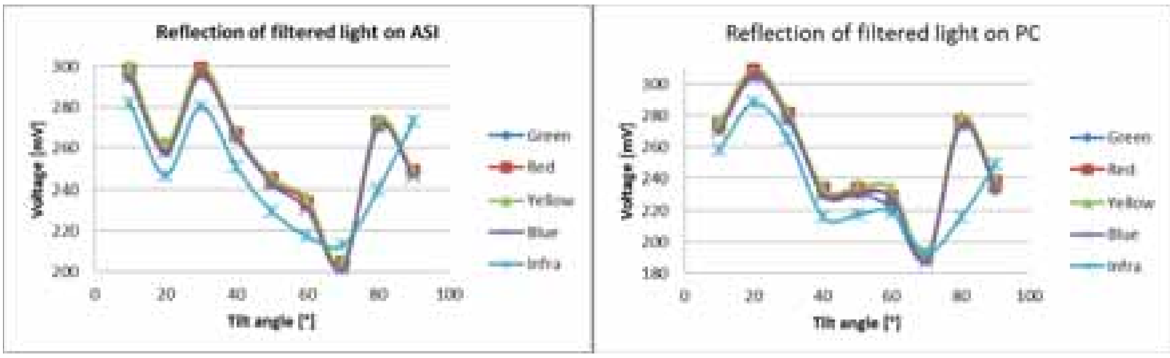

Fig. 2: Results of filtered light reflection

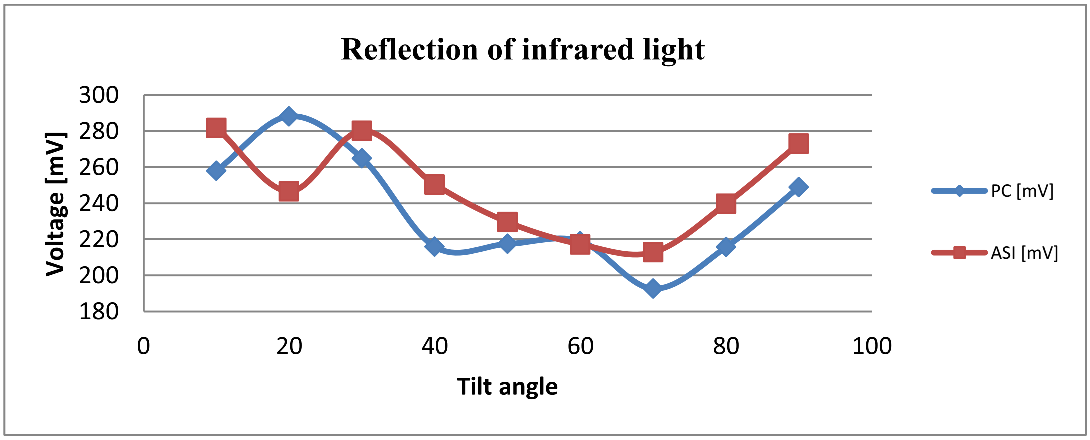

Fig. 3: Reflection of infrared light

From the experiment the transmission coefficient, as the function of the incident angle can be get for each type of modules as the next function:

$$\tau(\varphi) = 1E\text{-}10x^6 - 3E\text{-}08x^5 + 2E\text{-}06x^4 - 1E\text{-}04x^3 + 0{,}0012x^2 + 0{,}0141x - 0{,}0148. \quad (2)$$

The developed model

At the beginning of the article the active surface model was introduced, now its improvement with the angle dependent transmission is introduced.

Let's consider, that there is an elementary surface of a glass covered solar equipment of $\overrightarrow{dA}$ and the direction of the solar radiation ($\vec{I}$) is coming from the direction of φ, compared to the direction of the normal direction ($\vec{n}$) of the elementary surface (Fig. 4).

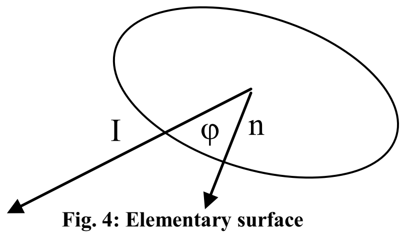

Fig. 4: Elementary surface

For this elementary surface the active (useful) area was calculated as $dA' = dA \cdot cos\varphi$. In our case the power density (irradiation) of the solar radiation reaching the cell surface has to be determined as well. It can be calculated as the product of the irradiation and the transmission coefficient. So the power hitting the covered elementary surface can be determined as:

$$dI' = I \cdot \tau(\varphi) \cdot \cos\varphi \cdot dA \cdot d\varphi \quad (3)$$

As the values are varying from place to place, the integration of the elementary power provides the total hitting power on the absorber surface:

$$I' = \int I \cdot \tau(\varphi) \cdot \cos\varphi \cdot dA \cdot d\varphi. \quad (4)$$

Of course the irradiation and the transmission coefficient are the function of the wavelength, too:

$$I' = \int I(\lambda) \cdot \tau(\varphi, \lambda) \cdot \cos\varphi \cdot dA \cdot d\varphi. \quad (5)$$

This integration is quite simple for a flat plate collector, as the φ degree is the same for the total collector surface, so it can be calculated as

$$I' = I \cdot \tau(\varphi) \cdot \cos\varphi \cdot A, \quad (6)$$

if the wavelength dependence is eliminated.

For the vacuum tube collector real integration has to be done, but due to the complicated functions numerical method was used. The integration for this case is shown in Fig. 5.

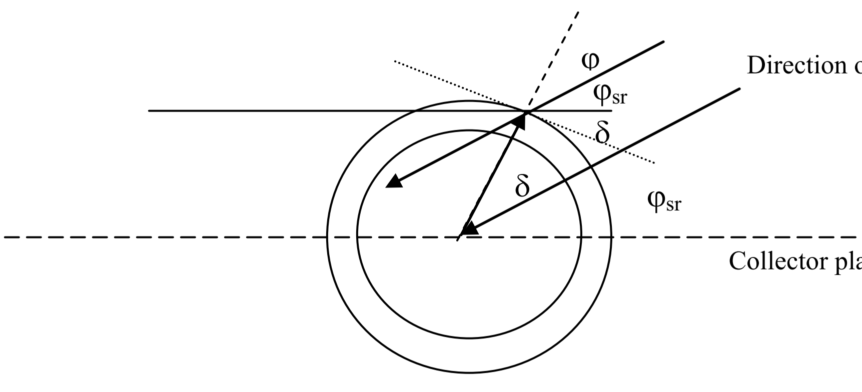

Fig. 5: Numerical method scheme of vacuum tube

φ_{sr} is considered to be the direction of the solar radiation compared to the plane of the collector (the plane of the axes of the vacuum tubes). A variable angle of δ is used to determine the place of the elementary surface on the tube. From the figure it can be seen, that

$$\varphi = 90° - (\varphi_{sr} + \delta). \quad (7)$$

Based on this notation the same calculation was carried out again, as it was described during the determination of the useful surface, but instead of the

$$I_{useful} = \sum dA \cdot \cos\varphi. \quad (8)$$

formula, the

$$I_{useful} = \sum I \cdot \tau(\varphi) \cdot \cos\varphi \cdot dA. \quad (9)$$

is used.

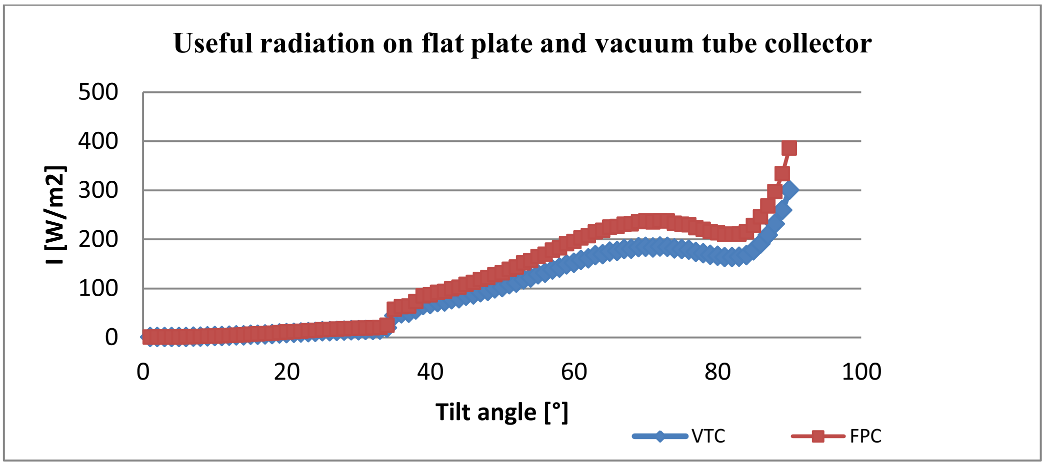

Fig. 6: Numerical method scheme of vacuum tube

The useful radiation on flat plate and vacuum tube collectors is shown Fig. 6. for the tilt angle range of 10-90°. The interval is simulated the time from sunrise until noon when the direction of incoming radiation perpendicular to the collector surface. On the graph a sudden increase can be seen which is caused the sun moving, because at that time the collectors are shaded by the building.

Conclusions

Developed model was carried out in order to determine what proportion of the incoming radiation can reached the absorber. Last diagram above shows that on flat plate collector utilize more incoming radiation than vacuum tube, but it is must be taken into account that the heat loss factor could change the results which is not included in current model calculation.

Reflected infrared light shows lower values than others the reason of this effect is infrared light part of the long-wavelength range, so it can be concluded that this part of spectra is absorbed and converted better into thermal energy.

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