ICMIEE18-223

Dust Effect on Glass Transmittance and Mirror Reflectance of Solar Collectors

Mehedi Hasan Tusar[*], *Amir Hamza Limon*, *Abdullah Al Noman*, *Goutam Das*
Department of Mechanical Engineering, Chittagong University of Engineering & Technology, Chittagong-4349, BANGLADESH

ABSTRACT
Almost every country in the world is leaning towards renewable energy and installation of solar power systems are increasing day by day. But, solar power systems are affected by dust deposition as it reduces optical efficiency of these systems. So, evaluation of dust deposition effect for a particular location needs to be carried out to predict the performance and installation of different solar power systems. In this experiment transmittance and reflectance loss of glass and mirrors are examined respectively at seven days interval for a period of three month in maximum solar irradiation season of Bangladesh to evaluate dust deposition effect on optical performance of them. It is found that glass and mirror suffered from 3% to 6% transmittance and 8% to 16% reflectance loss respectively over the experiment period.

Keywords: renewable energy, solar collectors, dust effect, optical efficiency

1. Introduction

The world is passing through energy crisis and demand of energy is increasing day by day. However, our fossil fuel stocks are decreasing and will diminish fully within this century. Nonrenewable energy reserves like oil, coal, gas will be depleted fully within 35, 107, 37 years respectively [1]. So, renewable energy sources are taking place in energy production and will be one of the major sources within few decades. Solar energy is one of the leading renewable energy resources. Photovoltaics (includes both concentrating and non-concentrating systems) and concentrating solar thermal systems (CST) are developed technologies to harvest solar energy. Both of these technologies suffer from dust deposition effect that reduces the energy performance of the system, causes degradation of the system, cuts down power generation and increases production and maintenance cost and lowers benefit. A lot of research is ongoing about what is the composition of dust, how dust effects the energy generation, how it degrades a system and its performance, what are the remedies, how to clean the systems for better performance with cutting water consumption at minimized cost. Dust mainly consists of quartz and silica components. Accomplishing elemental and mineralogical analysis, Eliminir et al. [2] found that dust accumulated on transparent covers of solar cells were composed mostly of quartz and calcite with smaller amount of dolomite and clay minerals. Dust deposited on solar panel or concentrator is fully site specific as dust concentration in greenery is less than dust concentration in the roadside or heavy industrial area in the same location. Dust particle available in air also differs in size with location, geography, wind, temperature etc. If dust deposition happens due to airborne dust particle then particle diameter is less than 70 micrometers [3]. Dust deposited on the solar panel scatters the light in random direction and provides shading in the panel prohibiting the transmission of incident solar energy in solar cells. Many researchers investigated the dust effect on output power for solar panels and collectors in different countries [4-6]. Nimmo, Saed [7] recorded 26% and 40% loss of efficiency respectively in solar collectors and PV modules at dry conditions in a period of 6 months in Saudi Arabia. Jiang et al. [8] experimented that when dust density increases from 0 to 22 g/m^2 the corresponding reduction of PV output efficiency grew from 0 to 26% and reduction has a linear relationship with dust deposition density. Vivar et al. [9] found soiling reduced 4% electrical output on average in flat PV module and concentrating photovoltaic (CPV) systems are more sensitive to soiling than flat plates. Solar energy converting systems use glass and mirror and dust reduces their transmittance and reflectance respectively. Due to this reason fraction of incident solar energy is lost that reduces system efficiency. Deposition of dust also depends on tilt angle and orientation of glass and mirror panels. A lot of investigator experimented effect of orientation and tilt angle for dust deposition in glass and mirror plates all over the world [10-12]. Garg reported 30% and 2% transmittance loss in one month for horizontal and vertical plates respectively for solar collectors (glass) in India [13]. Sayigh et al. [14] in Kuwait found 64%, 48%, 38%, 30%, 17% transmittance reduction after 38 days for 0^o, 15^o, 30^o, 45^o, 60^o tilt angles respectively for different types of glass. It has been seen that horizontal plates have more dust deposition than vertical plates. So, more energy is lost in horizontal plate than vertical plate and accumulation of dust on photovoltaic modules is of more concern in tropics than other region because of the lower tilt angles [15]. Since, Bangladesh is situated in tropical region thus lower tilt angle for PV panels, concentrators it is important to investigate the effect of dust on energy output for different solar modules. Solar modules use glass, glass mirror (one of the glass surfaces coated with reflecting material), polished mirror surface. Energy loss of these modules depends on the transmittance and reflectance loss of glass and mirror. In nearly similar experiment of this study a transmittance and reflectance loss of 22% and 19% for glass and mirror are recorded by Hasan et al. [16] for dust accumulation at different orientation and inclination at CUET, Chittagong from August to

* Corresponding author. Tel.: +88-01852610004
E-mail addresses: meheditusar95@gmail.com

September. However, evaluation of transmittance and reflectance using LASER lite is not a perfect technique for dust deposited plates because dust accumulates discretely and is not uniform throughout the plates. Since, LASER light does not diffuse so it measures localized effect of dust on glass and mirror plates. It will show greater loss for dust accumulated region while less for dust free region. So, better result comes if overall effect can be evaluated. In this experiment transmittance and reflectance loss of glass and mirror plates are studied at CUET, Chittagong region for 3 months (March-May) using diffuse light from LED source which is more realistic then LASER to study overall transmittance and reflectance loss.

2. Methodology

2.1 Test Facilities

For this experiment 22 pieces of 10×10 cm^2 glass and mirror samples in total were cut in equal dimensions from their respective large sections. Two pieces of the glass and mirror samples are stored carefully in the laboratory that are used as reference samples and the rest of the cut samples are used as the test samples. The loss of transmittance and the reflectance of the test samples are compared with that of the reference samples. A light is used as a source of LED. “Mastech” digital lux meter is used to measure the intensity of the incident lite on the samples. It gives output in three ranges 0-1999, 2000-19990, 20000-50000 lux with 5% tolerance using one silicon photo diode with filter operating at 9V. Two timber frames (in Fig. 3. (a)) were fabricated, which has four 45^o inclined sides in four earth direction (i.e. North, South, East, West) and one horizontal side. Each of the sides has two slots to hold and expose the test samples to outdoor condition at the investigation site. On the other hand, in order to ensure precautious handling of the test samples between the laboratory and the investigation site during data collection, two timber carriers (in Fig. 3. (b)) with ten slots each were fabricated. Two dark boxes (boxes with top covers and black walls) were used for glass and mirror samples to collect data in dark condition. The schematic of the boxes is shown in Fig. 1 and 2. There are slots to attach the LED lite, Lux meter and the test samples inside the boxes. Top cover of the box ensures no interference between the Lux meter and the external light.

2.2 Experimental procedure

In this experiment five orientation are selected i.e. east side, west side, north side, south side and horizontal to the floor. Two sample holders are placed in each of five orientation for dust deposition. Total ten glass and ten mirror sample holders are placed in these five orientations for depositing dust. The sample holders of each side are placed on timber frames 45º inclined corresponding to horizontal. Then whole setup is exposed to the environment and let the dust to deposit on them over time. Care is taken to ensure that the dust is accumulated on the sample holder freely and this dust and dirt are not removed by any agents other than wind and rain. Then the dust deposited glass and mirror samples are carried to the laboratory at every seven days interval using sample carrier for data collection.

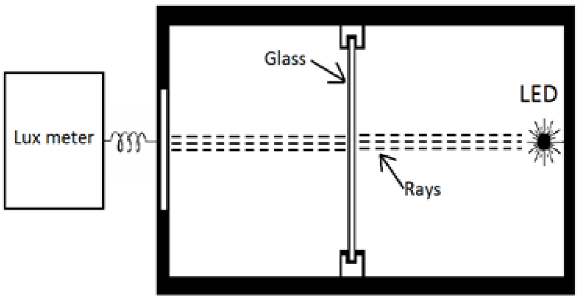

Fig. 1 Schematic diagram of experimental setup for glass transmittance measurement (top view).

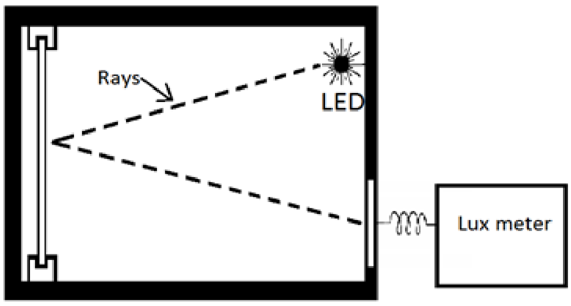

Fig. 2 Schematic diagram of experimental setup for mirror reflectance measurement (top view).

Every dust deposited glass samples are placed in experimental setup or dark box (in Fig. 1.) exposed to bright light to measure the illuminance of them using lux meter. Meanwhile illuminance of the clean reference glass sample prepared from same glass and stored in the lab is measured. Then normalized transmittance is found by dividing dust deposited glass illuminance by clean reference glass illuminance. Similar procedure is followed for measuring normalized reflectance of the mirror sample in another dark box prepared for mirror (in Fig. 2.).

Fig. 3: (a) Timber frame; (b) sample carrier [16].

3. Data analysis and discussion

The performance of solar collector drops gradually as dust is accumulated on its surface. The rate of decrease in the performance depends on the rate of dust deposition. The amount of accumulated dust increases with time which reduces transmittance and reflectance. As two glass sample holders are placed each side (east, north, west south and horizontal to the floor), the average of the two samples are considered for each side. Since illuminance of both dust deposited and reference glass sample are measured in same setup at same conditions the ratio of them gives normalized transmittance of glass samples. That expresses the resultant transmittance of dust deposited glass sample with respect to clean glass sample. Similar procedure goes for normalized reflectance measurement for mirror. Fig. 4 and 5 shows the normalized transmittance and reflectance of glass samples held at different orientation (East, West, North, South and horizontal orientation of earth) over time. From the Fig. 4 and Fig. 5 it is shown that the Normalized transmittance and normalized reflectance is first reduced as deposited dust is increasing on the samples, then transmittance and reflectance are increasing after some days and so on. It follows decreasing and increasing trend as time passes. The study conducted in summer season in Chittagong, Bangladesh and data was collected in seven days interval. There was uncertainty in weather at this period because sudden rain came anytime, and wind velocity was varied as well. For these reasons dust which is deposited on the glass plate was removed in some portion. When dust deposition was increasing transmittance and reflectance were decreasing for all samples, after some day's rainfall or heavy wind speed removed some portion of deposited dust and for this reason transmittance and reflectance was increasing and so on. From the Fig. 4 and Fig. 5 it also be shown that the decreasing rate of transmittance and reflectance is maximum for horizontal sample holders because of maximum dust deposition rate. Dust deposition rate is lower for other samples tilted 45º from horizontal as dust particles might be rolled downwards, washed by dew at night or these tilted plates captures more wind than horizontal samples. After horizontal sample average transmittance and reflectance decrease is maximum for south samples. it means dust deposition rate is maximum in south orientation after horizontal orientation. From Fig. 3 and Fig. 4 dust deposition rate in this location is found in following trend:

Horizontal > South > North > West > East

After studying three month's data it is found that dust deposition rate is minimum in East and West side samples. The main reason behind this attitude is wind direction in Chittagong during pre-summer season when dry air moves south from north and during post summer season warm air moves towards the land from the south (sea) [17]. Particulates which are mixed with this moving air is then deposited, when the air is introduced to any obstacle along its direction of motion.

Normalized transmittance, reflectance of glass and mirrors respectively varies with different orientations. Mirror has more reflectance loss than transmittance loss of glass plate. For better understanding of dust effect on glass and mirror samples these values are averaged and expressed in Fig. 5. As shown in Fig. 5 normalized transmittance and reflectance of glasses is first decreasing as amount of deposited dust is increasing then increasing as the amount of dust is removed by rain or strong wind effect and so on. Decrease of transmittance and reflectance is higher in March and lower in May. That indicates dust deposition rate is higher in March and lower in May in this location. The main reason is more rainfall in May then March.

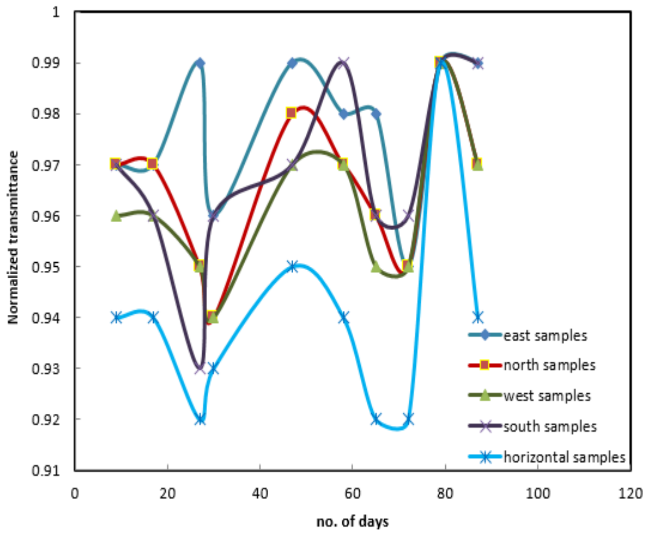

Fig. 4 Dust effect on the normalized transmittance of glass samples over time

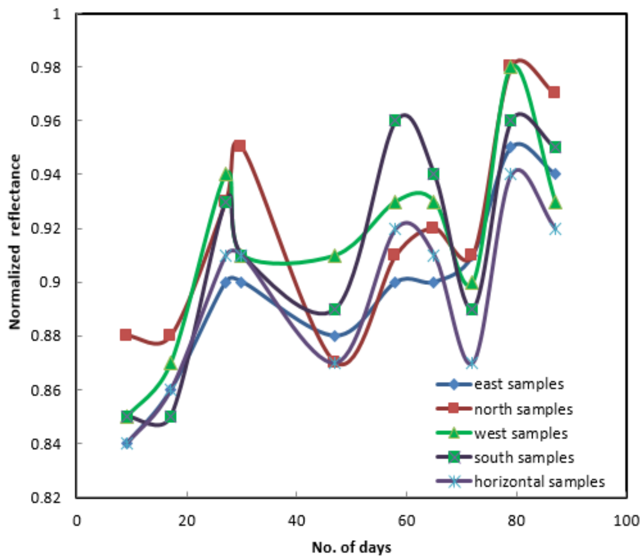

Fig. 4 Dust effect on the normalized reflectance of glass samples over time.

PV solar panels are protected with glass covers thus normalized transmittance gives the relative percentage of incident energy transmitted through dust deposited glass panel with respect to clean glass panel. Since mirrors are used in concentrating systems normalized reflectance is important in concentrating systems to understand energy loss and fraction of incident energy concentrated on receiver.

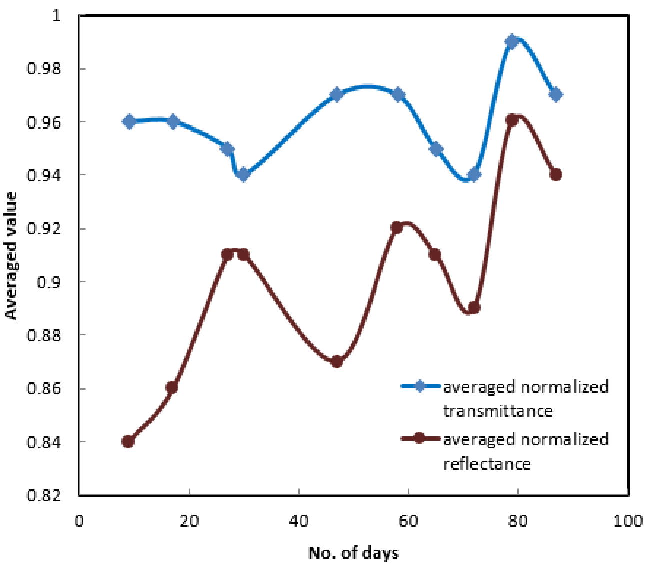

Fig. 5 Dust effect on the averaged normalized transmittance and reflectance of glass and mirror samples respectively over time

4. Results & Conclusion

4.1 Summary

An experimental investigation is done in CUET, Chittagong to find the loss of transmittance, reflectance of glass and mirrors respectively to predict the potential of different solar power systems. The findings of the study are listed below:

- Average values of normalized transmittance and reflectance varied in between 94% to 97% and 84% to 92% for exposed glasses and mirrors respectively. That is the transmittance of glass and reflectance of mirror dropped in between 3% and 6%, and 8% and 16% respectively.

- Mirror has more reflectance loss then transmittance loss of glass since the mirror used in this experiment was silvered on the opposite side of dust accumulated surface. So, incident light was affected twice for same dust deposition density.

- During the period of experiment in March, April and May raining occurred for many times in every month. In periodic checking it is observed that glass and mirror is cleaned up to 98% and 92% by raining, so requires less cleaning in these months.

- Decrease of transmittance and reflectance for glass and mirrors is higher in March and lower in May during summer season in this location.

4.2 Limitation & Further Research

Many of the state-of-the-art concentrating power plants use surface polished mirror where dust deposits whereas silvered glass mirror was used in this experiment. So, incident light will be affected only single time in state-of-the-art technology. For this, ongoing research focuses on reflectance loss of surface polished mirror.

REFERENCES

[1] S. Shafiee and E. Topal, “When will fossil fuel reserves be diminished?,” *Energy Policy*, vol. 37, no. 1, pp. 181–189, 2009.

[2] H. K. Elminir, A. E. Ghitas, R. H. Hamid, F. El-Hussainy, M. M. Beheary, and K. M. Abdel-Moneim, “Effect of dust on the transparent cover of solar collectors,” *Energy Convers. Manag.*, vol. 47, no. 18–19, pp. 3192–3203, 2006.

[3] Y. Shao, “Physics and Modelling of Wind Erosion,” *Phys. Model. Wind Eros.*, vol. 37, no. January 2008, pp. i–xv, 2009.

[4] F. Wakim, *Introduction of PV power generation to Kuwait.".* Kuwait City: Kuwait Institute for Scientific Researchers, 1981.

[5] M. Louy, Q. Tareq, S. Al-Jufout, Q. Alsafasfeh, and C. Wang, “Effect of dust on the 1-MW photovoltaic power plant at Tafila Technical University,” *2017 8th Int. Renew. Energy Congr. IREC 2017*, no. Irec, 2017.

[6] C. P. Ryan, F. Vignola, and D. K. McDaniels, “Solar cell arrays: Degradation due to dirt.,” *Proc. Solar 1989, Proceedings of the American Section of the International Solar Energy Society, Denver, CO.* 1989.

[7] B. Nimmo and S. A. . Said, “Effects of dust on the performance of thermal and photovoltaic flat plate collectors in Saudi Arabia-Preliminary results,” *Altern. Energy Resour. II*, vol. 1, no. 1, pp. 145–152, 1981.

[8] H. Jiang, L. Lu, and K. Sun, “Experimental investigation of the impact of airborne dust deposition on the performance of solar photovoltaic (PV) modules,” *Atmos. Environ.*, vol. 45, no. 25, pp. 4299–4304, 2011.

[9] M. Vivar *et al.*, “Effect of soiling in CPV systems,” *Sol. Energy*, vol. 84, no. 7, pp. 1327–1335, 2010.

[10] N. M. Nahar and J. P. Gupta, “Effect of dust on transmittance of glazing materials for solar collectors under arid zone conditions of India,” *Sol. Wind Technoloy*, vol. 7, no. 2–3, pp. 237–243, 1990.

[11] A. El-Nashar, “The effect of dust accumulation

on the performance of evacuated tube collectors," *Sol. Energy*, vol. 53, no. 1, pp. 105–115, 1994.

[12] L. Boyle, H. Flinchpaug, and M. Hannigan, "Impact of natural soiling on the transmission of PV cover plates," in *2013 IEEE 39th Photovoltaic Specialists Conference (PVSC)*, 2013.

[13] H. Garg, "Effect of dirt on transparent covers in flat-plate solar energy collectors," *Sol. Energy*, vol. 15, no. 4, pp. 299–302, 1974.

[14] A. A. . Sayigh, S. Al-Jandal, and H. Ahmed, "Dust effect on solar flat surfaces devices in Kuwait.," in *In Proceedings of the workshop on the physics of non-conventional energy sources and materials science for energy*, 1985, pp. 353–367.

[15] J. Kern and I. Harris, "On the optimum tilt of solar collector," *Sol. Energy*, vol. 17, no. 2, pp. 97–102, 1975.

[16] M. M. Hasan, A. A. Noman, M. H. Tusar, and M. Islam, "Effect of dust on the optical properties of the glazing materials of solar collectors: a case study." in Proceedings of International Conference of Mechanical Engineering & Renewable Energy, 2017, Chittagong.

[17] M. A. Khatun et al., "MET report on Climate of Bangladesh", *Norwegian meteorological institute*, no. 08/2016 ISSN 2387-4201