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Cleaning of Accumulated Dust Particle of a Flat Plate Solar Collector

Amir Hamza Limon, Muhammad Mostafa Kamal Bhuiya, Mostafizur Rahman and Majedul Islam*
Department of Mechanical Engineering, Chittagong University of Engineering & Technology (CUET), Chittagong 4349, BANGLADESH

ABSTRACT
An experimental investigation was carried out to find out the effective cleaning method of the glazing material of solar collector. The study emphasized on solar panel glazing material cleaning process using water force impinging by a nozzle. A nozzle is used to make a water jet having a velocity which is impacted on the glazing material of a solar plate collector. The project investigated the optimum position of nozzle with respect to glass at which the dust removing rate is maximum. The jet of different velocities were used to perform the experiment and the maximum tangential force was found between 30º-40º relative angle of impacted jet with respect to the glazing material at which the maximum cleaning can be possible. This project will help to ensure the maximum amount of solar beam reach to the receiver for power generation. It can be noted that this technique will help to clean the solar collector with a reasonable cost and effectively.

Keywords*: Accumulated dust, Cleaning, Water force, Nozzle, Glazing material*

1. Introduction

Globally, we are bound in different types of energy sources. But, in the past several decades energy requirements have been increased significantly and predicted that it rises to 50% by 2030(world energy outlook,2011). At this time, these requirements are met mostly from the conventional way (like coal, gas, oil etc.). Environment is being polluted by their exhaust and their reserves will be nearly finished after some era. For this reasons, implementation of renewable energy sources like solar power are rising. After implementation of solar panels some difficulties arise of their performance. Dust accumulation over glass plate of solar panels is one of the biggest problems because dust obscures the solar radiation and therefor reduces their efficiency, especially in those countries whose environmental condition is hard. Dust accumulation mostly depends on weather condition and geographical locations. To reduce this loss, many researchers have been developed different types of solar collector cleaning techniques and many of them are researching. The categories of cleaning solutions considered in this study include the following: manual cleaning, mechanized cleaning, hydraulic cleaning, installed robotic cleaning and deployable robotic cleaning [1]. Removal of dust particles from the surface of the solar cells and solar collectors is performed using surfactants [2]. A shield contains a clear panel with embedded parallel electrodes connected to a single-phase AC supply for producing an electromagnetic wave. The electromagnetic field produced by the electrodes on the surface of the panel repels dust particles that have already deposited on the panel surface, and prevents the deposition of further particles if they are charged with positive or negative polarities [3]. A deep study about the effectiveness of different cleaning methods, including natural cleaning, has been performed during two years in a semi-desert climate. Different cleaning methods were periodically applied to several reflector samples exposed in four separated test benches. Monochromatic specular reflectance measurements were taken before and after applying the cleaning methods [4]. The self-cleaning technology for solar cell array can promote efficiency of electricity produced and protect the solar cell. The methods of dust-removal, such as natural means, mechanical means, self-cleaning nano-film, and electrostatic means are presented [5]. The influence of cleaning on the PV panels using water as well as a surfactant was investigated experimentally using a non-pressurized water system [6]. Dust problem and recent developments made on automated cleaning system for solar photovoltaic modules which give brief overview on techniques like electrical, mechanical, chemical and electro static [7]. Fabricated superhydrophobic microshell PDMS showed a superior dust cleaning effect compared to that of flat PDMS, preventing the degradation by dust particles of solar cell efficiency. This transparent, flexible and superhydrophobic microshell PDMS surface provides feasibility for a practical application of superhydrophobic surfaces in solar cells [8]. A self-cleaning effect developed through the use of a super hydrophobic and water-repellent surface was demonstrated for solar cell applications [9]. A perfectly ordered microshell array was fabricated on a transparent and flexible polydimethylsiloxane (PDMS) elastomer surface. self-cleaning solar panels may be manufactured incorporating electrodynamic screens that will derive their power from the panel itself about 10 watts per square meter of a solar panel. This power is a small fraction of the power generated by a typical panel (800 watts) and is used only when cleaning is needed [10]. Many efforts have been made to address the severity of deposited particles like dust, water stains, carbon from smoke, pollen in agricultural regions, etc. on the efficiency reduction of solar devices, which results in additional costs either from oversizing the system or from cleaning it [11]. In the current study, the experimental data concerning the effect of three representative air pollutants (i.e., red soil, limestone and

* Corresponding author. Tel.: +88-01784353193
E-mail addresses: mkamalcuet@gmail.com

carbonaceous fly-ash particles) on the energy performance of PV installations are analyzed. According to the results obtained, a considerable reduction of PVs' energy performance is recorded, depending strongly on particles' composition and source[12]. Effect of dust, humidity and air velocity influences of the efficiency of photovoltaic cells[13]. Most popular solar collector concentrating technologies are Flat plate solar collector. In this paper, force of hydraulic jet impinging from nozzle is used for cleaning Flat solar panel collector and find out a better relative angle between plate & flow for better performance. All the tangential force acting on the plate can remove the dust, but highest force can remove maximum dust from the collector in minimum time.

It can be seen that the dust accumulation over solar collector is one of the biggest problems because dust obscures the solar radiation and therefore, reduces their efficiency. However, minimizing the cost of the cleanliness is a key issue for the solar-plant feasibility. Therefore, this work focused on optimizing the cleaning method of solar reflectors for CSP applications under real outdoor conditions in a semi-desert or hard climate.

2. Experimental Procedure

The study relates to cleaning glazing material of solar collector or other glass plates by using water jet impinging from nozzle, particularly for cleaning surfaces which may be horizontal, vertical or any other angular position. When a water jet strikes a plate with a force it flashes the surface. This force divided by normal force which acts normally to the plate and tangential force which act tangent of the surface. Normal force is responsible for wearing the surface and produces separation in water after striking. Water with tangential force move along the surface and washed away the dust particles along its path. If the tangential force increases water can washed away maximum possible of different type dust (oily dust, heavy particulates, Electrostatic precipitators etc.). As well as amount of water and time needed for proper cleaning reduces with increasing the tangential force of water jet. So, it is important to know better position of nozzle relative to the glazing plate from where jet is impinged.

Labor costs, maintenance cost and other technical cost could be lower by using this technique compare to other technique stated at previous article. This technique is convenient for those area where availability of water source is found lower as minimum amount of water needed for proper cleaning when the better position of nozzle is found.

2.1 Experimental setup

To conduct the experiment to find out better relative position of nozzle with respect to the glazing material several equipment were used. The experiment was conducted at Chittagong University of Engineering and Technology. Glass plate is a plate or may be a collector solar panel over which water jet is impacted at different height or angular position. It is placed on a force measuring device which calculates normal force of the impacted jet. It is connected to another force measuring device with wire which calculates tangential force. Wooden frame is a frame made of wood or ply which carries all other components. Two wooden frames were used, one was vertical, and one was horizontal. One weight measuring device measures normal force of impacted jet and another weight measuring device measures tangential force of impacted jet. Different sizes of pipes are used. One main pipe carried water with a nozzle connected to its middle from which water jet is released, constructed such a manner that it can rotate with a fixed height at different angle and can slide on a vertical scale at a fixed angle. A nozzle is structured at the middle of the main pipe such a manner that water jet released through it can splash maximum area of the glass plate. Pipe fittings are used to connect different pipe section where necessary. Rollers are used to minimize friction between the glazing material and the weight measuring scale.

In this experiment all the equipment is assembled to accomplish desired setup for finding out dependent variable or tangential force by manipulating the independent variable or relative angle of nozzle and glass plate.

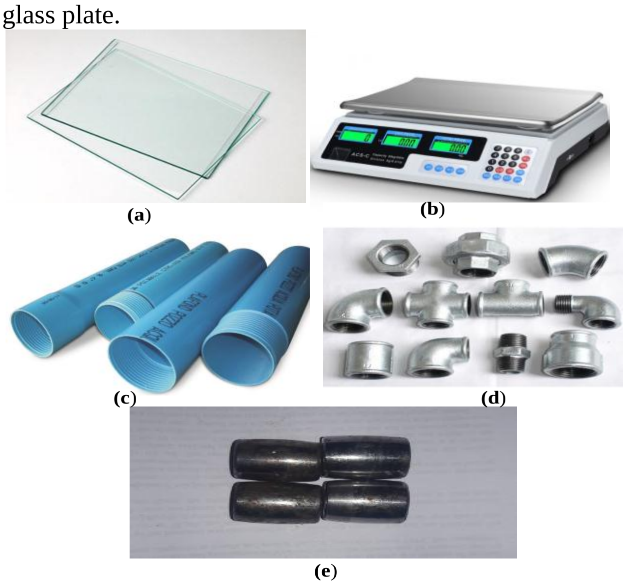


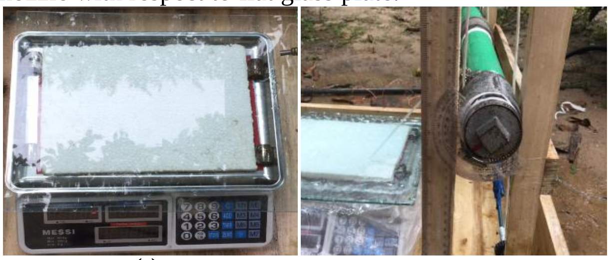
Fig. 1 (a) Glass plate; (b) Weight measuring scale; (c) PVC pipes; (d) Pipe fittings; e) Roller.

2.2 Experimental procedure

At first, horizontal wooden frame is made for the mechanical support which protects the other equipment. A vertical frame with a groove in the middle is made which can roll in horizontal direction along the horizontal wood frame. A 2-inch diameter PVC pipe is made in such a way that it's one end is closed with suitable fittings and other end is connected to a smaller 0.5inch diameter pipe with a bell reducer and nipple fittings. This smaller pipe is connected to the water source. A 3.5mm diameter nozzle relates to a tee fitting at the middle of that pipe.

Fig.2 A cleaning method of a glass plate as a glazing material

The whole pipe with the nozzle can made an up and down movement along the groove of the vertical frame. A vertical scale or ruler is placed vertically along vertical frame which indicate the vertical position (h) of the pipe or nozzle position with respect to glass plate. An angular scale is positioned at the closed end of the PVC pipe which indicates the angular position of the nozzle with respect to flat glass plate.



(a) (b)

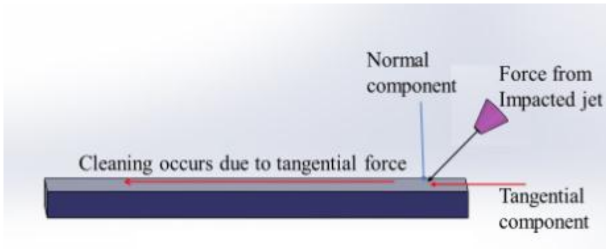
Fig. 3 (a) Weight measuring device with glass plate and roller; (b) Angular and vertical position measurement

The PVC pipe with nozzle can move up and down by lifting it by rope system. A weight measuring device is placed horizontally on the horizontal wooden frame just below the main pipe. This device can measure the normal force of the impacted jet striking on the glass plate. It can be calibrated. A glass plate is placed over the weight measuring device over which water jet is impacted. Between the glass plate and weight measuring device 4 roller are placed such a way that glass plate is situated over these rollers. The main tasks of these rollers are to minimize the friction between weight measuring device and glass plate. The water jet is impacted on the flat glass plate with a particular striking force and a particular relative angle between glass plate and impinging water jet. A normal force is measured by the weight measuring device. With the angle and this normal force, we can easily find out the striking force of the jet and tangential force. Our main aim is to find out the angle at which tangential force is maximum. This system includes cleaning using a fixed nozzle or a sliding nozzle from which water exits at high speed, located at the top of the panel. Water is pumped by a pump through pipe to the nozzle. A water jet is released from the nozzle which is impacted on the collector with a force controlled by operator. The point of impact of water jet on the collector can be changed by operator through controlling the angle between jet and plate. Tangential and normal component of impacted force can be measured from force or weight measuring device.

3. Results and discussion

In the experiment normal forces are collected at different heights and different angles simultaneously as shown in Fig.4. At first a relative height of the main pipe from where the nozzle is connected to the horizontal glass plate is fixed. Then different normal forces (kg) are collected with 10º interval from 90º to 10º or 20º. Then another relative height is fixed, and normal force is collected. The height changes with 2.54 cm interval from 12 cm to 24.7 cm.

When the jet velocity is 7.2236 m/s:
Different force acting on the glass plate which are changed by changing relative angular direction of water jet and by changing height. First fixed the height and angle of jet is manipulated to find out different value of the forces.



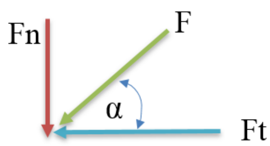


Fig. 4 Force analysis

Fn = Normal force;
Ft = Tangential force;
F = Jet striking force;
In this experiment we manipulated angle, α and found normal force Fn. Jet striking force F and tangential force Ft can be found by,

$$Fn = F \sin \alpha$$

$$F = \frac{Fn}{\sin \alpha}$$

$$Ft = F \cos \alpha$$

When height of the main pipe or nozzle from the glass plate is 12cm reducing as shown in Fig.5 (a) the relative angle brought the normal force and jet striking force into a decreasing line and at the same time tangential force is increasing. Maximum tangential force is found at 10º which is 2. 423N. When height of the main pipe or nozzle from the glass plate is 14.54cm as shown in Fig.5(b) reducing the relative angle brought the normal force and jet striking force into a decreasing line and at the same time tangential force is increasing. Maximum tangential force is found at 30º which is 2.1036N. When height of the main pipe or nozzle from the glass plate is17.08 cm as shown in Fig.5(c) maximum tangential force is found at 10º which is 2.224N. When height of the main pipe or nozzle from the glass plate is 19.62 cm as shown in Fig.5(d) maximum tangential force is found at 40º which is 2.2323N. When height of the main pipe or nozzle from the glass plate is 22.16cm as shown in Fig.5(e) maximum tangential force is found at 40º which is 2.4538N. When height of the main pipe or nozzle from the glass plate is 24.7cm as shown in Fig.5(f) maximum tangential force is found at 30º which is 2.5987N.

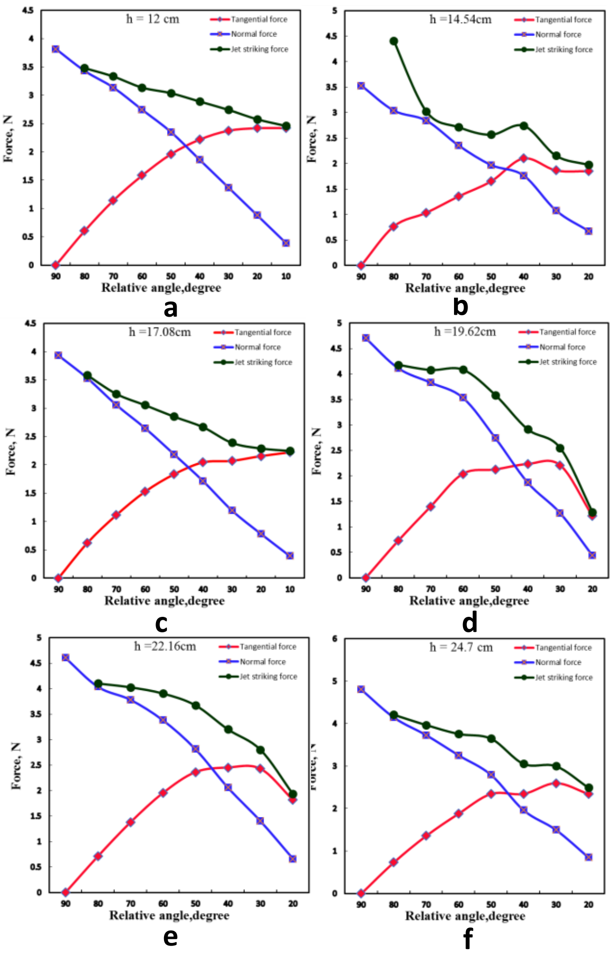


Fig. 5 Relative angle vs. different forces acting on the plate h=12 cm (a); h=14.54 cm (b); h=17.08 cm (c); h=19.62 cm (d); h =22.16 cm (e); h=24.7 cm (f); and velocity of jet is 7.2236 m/s.

When height of the main pipe or nozzle from the glass plate is 22.16 cm as shown in Fig.7(e) maximum tangential force is found at 30º which is 3.0578N. When height of the main pipe or nozzle from the glass plate is 24.7cm as shown in Fig.7(f) maximum tangential force is found at 30º which is 3.2273N.

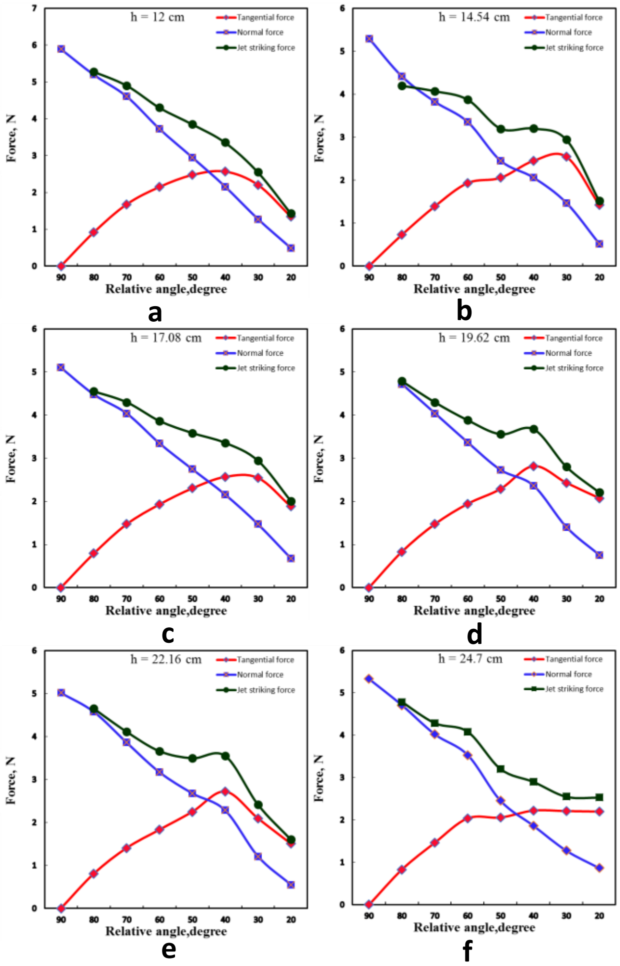


Fig. 6 Relative angle vs. different forces acting on the plate when; h=12 cm (a); h=14.54 cm (b); h=17.08 cm (c); h=19.62 cm (d); h=22.16 cm (e); h=24.7 cm (f) and velocity of jet is 10.01 m/s.

When the jet velocity is 10.01 m/s:

First fixed the height and angle of jet is manipulated to find out different value of the forces. When height of the main pipe or nozzle from the glass plate is 12cm as shown in Fig.6(a) maximum tangential force is found at 40º which is 2.5712N. When height of the main pipe or nozzle from the glass plate is 14.54cm as shown in Fig.6(b) maximum tangential force is found at 30º which is 2.5479N. When height of the main pipe or nozzle from the glass plate is 17.08cm as shown in Fig.6(c) maximum tangential force is found at 40º which is 2.5712N. When height of the main pipe or nozzle from the glass plate is 19.62cm as shown in Fig.6(d) maximum tangential force is found at 40º which is 2.8167N. When height of the main pipe or nozzle from the glass plate is 22.16cm as shown in Fig.6 (e) maximum tangential force is found at 40º which is 2.7208N. When height of the main pipe or nozzle from the glass plate is 24.7cm as shown in Fig.6(f) maximum tangential force is found at 40º which is 2.2205N.

When the jet velocity is 13.676 m/s:

First fixed the height and angle of jet is manipulated to find out different value of the forces. When height of the main pipe or nozzle from the glass plate is 12 cm as shown in Fig.7(a) maximum tangential force is found at 40º which is 3.3972N. When height of the main pipe or nozzle from the glass plate is 14.54 cm as shown in Fig.7(b) maximum tangential force is found at 30º which is 3.0355N. When height of the main pipe or nozzle from the glass plate is 17.08 cm as shown in Fig.7(c) maximum tangential force is found at 30º which is 3.0913N. When height of the main pipe or nozzle from the glass plate is 19.62 cm as shown in Fig.7(d) maximum tangential force is found at 30º which is 3.2273N.

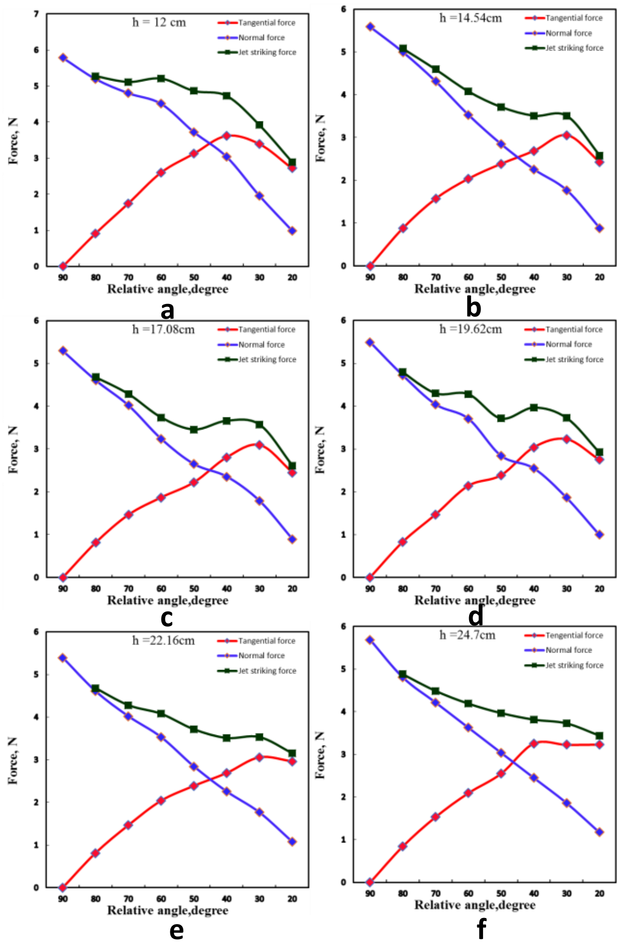


Fig. 7 Relative angle vs. different forces acting on the plate when h=12 cm (a); h=14.54cm (b); h=17.08 cm (c); h=19.62 cm (d); h=22.16 cm (e); h=24.7 cm (f) and velocity of jet is 13.676 m/s.

In the experiment when velocity of jet is used 7.2236m/s maximum tangential force 2.5987N is found at 30º relative angle and at a relative height of 24.7cm.

When the velocity of jet is used 10.01m/s the maximum tangential force 2.8167N is found at 40º relative angle and at a relative height of 19.62cm. When the velocity of jet is used 13.676m/s the maximum tangential force 3.623N is found at 40º relative angle and at a relative height of 17.08cm. Theoretically maximum tangential force could have been found at 45º relative angle as sine and cosec curve intersect at 45º each other at which tangential force and normal force would be same. Robinson et al. [14] showed that the higher shearing and slicing force was obtained when the angle of water jet is set from 0º-40º. In the experiment, the maximum tangential force was found between 30º-40º relative angle of jet. This is because of the splashing area which was large in these regions along tangential direction. But if further decreases the angle splash area increases but striking force would be decreases enough and liquid droplets increases which lowered the magnitude of tangential velocity. From the Fig.8, a relation of velocity, tangential force and height of the main pipe corresponding to the glass plate is obtained. From the Fig.8 it is seen that when velocity is increasing tangential force is also increasing but the relative height at which maximum tangential force was found is decreasing. Because as height is increasing the length of the impinging water jet from nozzle to the glass plate also increasing, as a result the contact area of water and ambient air is increasing. For these reason frictions between air and water jet is increasing with increasing the relative height of nozzle corresponding to glass plate. As a result, striking force as well as tangential force of impinging jet is decreasing with the increase of relative height.

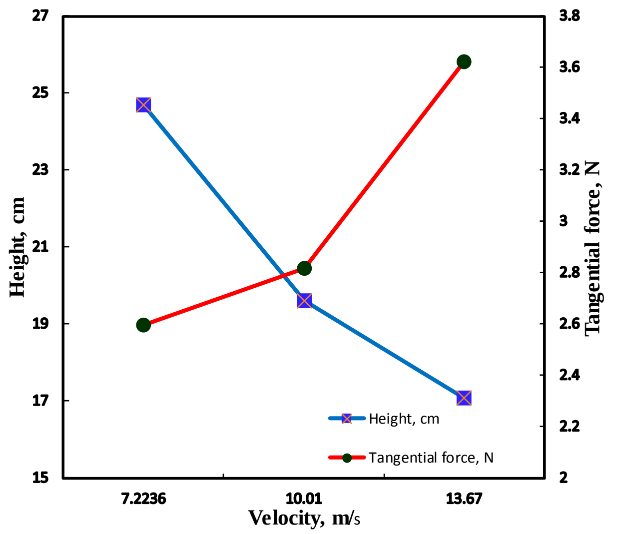


Fig. 8 Velocity vs. height and tangential force

If the velocity is increasing striking force as well as tangential force of water jet is increasing. But the angular position of impinging water jet at which maximum tangential force is occurred, is found between 30º-40º.

Generally, low carbon tempered glass sheets are used as the glazing material on the solar collector. The thickness of these glasses are varies from 3-5mm. the tensile strength of these sheets are varies from 40-50 N/mm^2 and the pressure resistance varies from700-900 N/mm^2 [15]. So, there is negligible damaging effect of using the velocity described above.

In this study, one nozzle is used for finding out the better position of that nozzle relative to the glazing material. After choosing the better position several nozzles should be used along the line of the glazing material of flat plate solar collector for cleaning using minimum amount of water.

5. Conclusion

This paper will focus mainly on the better cleaning process of solar PV collector to reduce the losses originated from dust. Dust is removed by the tangential force originated from water jet impact through a nozzle which is located at the optimum position corresponding to the collector without creating any damage of the collector. The paper investigated the optimum position of nozzle with respect to glass at which dust removing rate is maximum. After using jet of different velocity, it is seen that maximum tangential force was found between 30º to 40º relative angle of impacted jet with respect to the glazing material at which maximum cleaning can be possible. At this position maximum possible dust would be removed so that maximum possible solar beam can be reached to the receiver. when velocity is increasing tangential force is also increasing but the relative height at which maximum tangential force was found is decreasing.

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