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Experimental investigation for the influence of a basement inside collector on solar chimney effectiveness

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ABSTRACT

The aim for this work is to investigate, both experimentally and theoretically, the effect of abasement inside collector on performance for the Power Plant of Solar Chimney (PPSC). The small prototype of a chimney was built with a chimney height of 6 m, diameter 0.25 m, and collector diameter 7.5 m, covered with glass. The experimental data gathered under actual weather conditions in Baghdad city. Analytical solutions were then used to solve mathematical governing equations of continuity, momentum, and energy using Fortran 90, these results then compared with the experimental results. The experimental results explain that maximum differences between airflow temperature and ambient air reached 25.5 ℃, airflow air velocity 19.2 m/s, the available power 84.6 W at a collector angle of 12°, and a small pebble with tubes in the ground under the collector. In summary, airflow temperature, airflow velocity, and available power increases by tubes fill with water with small pebbles.

KEYWORDS

Solar radiation, Power Plant of Solar Chimney, small pebbles, thermal storage layer.

INTRODUCTION

Hundreds of years ago, humans used many resources including wood, coal, natural gas, and oil to generate the power and light needed for everyday activities. However, at present growth in the human population is increasing the need for new types of energy. Fuel extraction has become more costly and there are signs of depletion of available oil. Add to this the negative effects on ambience due to global warming and destroy to ozone strata the time has come to look for other sources for power generation renewable energy and to explore how to obtain maximum benefits from it. Renewable energies such as wind sun tidal movement and geothermal energy derived from the earth's natural resources have important advantages in that they do not result in harmful residues such as dual-gas carbon dioxide and other harmful emissions effects. These gases/emissions also affect the ozone layer and increase global warming. At present, more electricity is produced using renewable energies compared to the past and many countries are working to increase this type of energy production using renewable energies, the most important and popular being solar energy. Solar chimney power plant (SCPP) is the new process used to achieve electrical power their potential increasingly appreciated in recent decades. A solar chimney works in same way as hydroelectric power but where hot air is used instead of water. This kind of power plants uses sunlight to increase the internal energy of air a turbine changing kinetic energy to electrical energy. The first system was built with a diameter of solar collector for 240m and height chimney for 200m in Manzanares in 1970 by Schlaich [1] and Haaf et al. [2]. The principle aim of the SCPP is to convert solar, energy to thermal kinetic, energy.

Following this, many research and studies have been carried out to improve the effectiveness of PPSC. The study carried out [3] developed a numerical analysis for SCPP employed solar chimney in the Manzanares. He concluded quite simply which solar chimney is basically the large-scale power generator. Buğutekin [4] that the ground acted as a thermal storage layer making the system work by spreading heat under the collector from late at night when temperature is at a minimum, until morning. Publication by Al-Azawie [5] used six different bases black stone, ceramics, dark green painted wood, sawdust, sand, and sand and pebbles. The results indicated that the best materials are black stone and ceramics but because of availability, the black stone is recommended for use as the best absorbent material for a solar chimney. A theoretical research then by Ming [6] study thermal storage layer under collector by consisted of water and sandstone. Their results indicated that the water-energy storage layer and sandstone could reduce the difference between peak and valley values of the system's power output. Karimi [7] theoretical study discuss two different types and thickness of thermal energy storage systems; stone and water, the study found that The most efficient depth of combined water-stone is 0.15m deep water and 1m of stone. Oboetswe Motsamai et al. [8] found that airflow in the chimney varies with solar irradiation and that ground material acts as thermal storage. Jae Choi [9] Under the collector, a water storage system was built to preserve heat energy overnight, power output was compared with the water storage system across the water storage depth, the results showing that as the water storage system increased in depth, power increased at night and decreased during the day. Robera Daba [10] then found that soil, in general, provides the best thermal storage as it can change the profile power. The purpose of this study was to investigate the effect of the ground on the output of the solar chimney power plant as a thermal storage layer works and the variations of different types of it.

Description of the system (SCPP)

The system of solar chimney include of chimney, turbine and solar collector which represents the three fundamental components needed in each system to generate power as shown in Figure (1) . Air is heated under a collector by the radiation of solar and flows towards the chimney because of the buoyancy and different pressure between ambient air and hot air. The hot air then rotates the turbine which is installed in the chimney inlet or at the collector outlet. The main part of the system is the collector which converts solar radiation into thermal energy. Hot air flows at ground levels under the collector which works as a heat absorption layer or a greenhouse. The effectiveness for solar collectors depends on many operating conditions, such as the inclination of the collector, the thickness of the cover materials, the speed of the wind, the length of the collector, the depth of the collector and the type of absorber material used. Its direction and tilt angle define the orientation of the collector. Tilt angle difference affects the amount of solar radiation hitting the surface of the collector. Thus, to optimize the system's efficiency, solar collectors need to be tilted at a suitable angle. The collector is covered by glass or plastic materials and opens to allow a flow of air. Glass is widely used because it has high transmittance (0.85-0.9) of incoming short wave solar radiation, at the same time ignoring longwave radiation [11]. Solar energy is available only in daylight but a continuous output of power over 24 hours can be achieved by placing, a thermal collector on the ground. Thermal storage layers absorb heat during the day from solar radiation and discharge it into the collector at night.

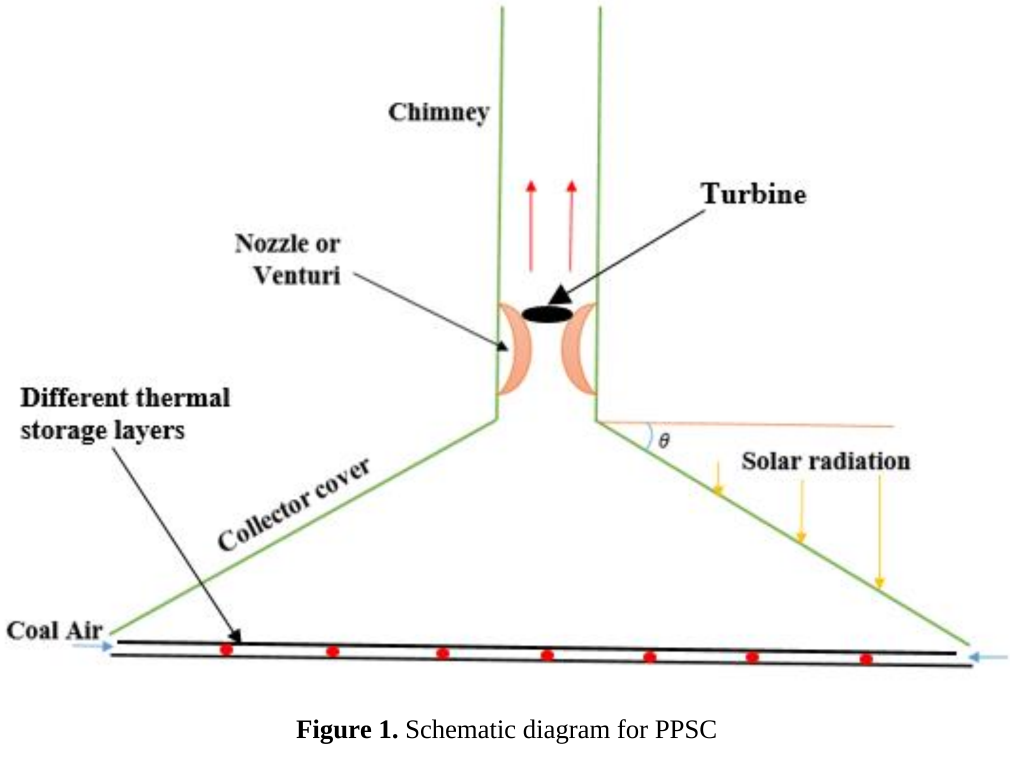


Figure 1. Schematic diagram for PPSC

The solar chimney is a vertical solid pipe situated at the central end of the collector. Turbines are installed at the inlet of the tower. The ground down collector can be used as a thermal storage layer to absorb heat in daylight hours and transfer it to air in collector at night.

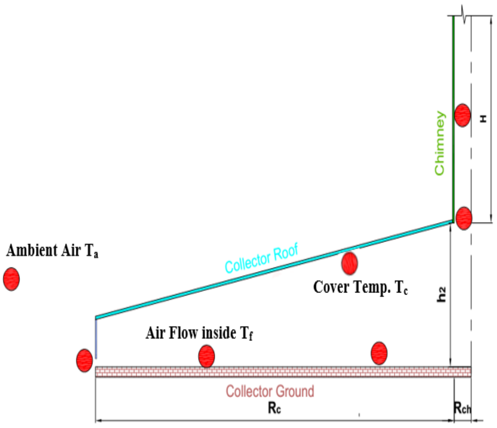
Experimental work

The solar chimney power plant contained the chimney diameter of 0.25 m and height of 6m. Collector has a height for 0.75 m at its center , diameter for 6 m, , and was covered with glass sheets, having a maximum inclination angle 12° . These eight parts are fixed with the base of the chimney by a flexible joint. The details of the collector frame consist of (6 m) diameter of air solar horizontal canopy of (4mm) At varying heights above ground from the entrance, window glass panels, but the height at the middle remains constant and equal to 75 cm. Collector structure was manufactured from a steel angle to carry glass panels. It is designed to contain eight parts (triangles) to give a full circle. It is made of 8 parts to be easy to assemble and dissemble and to control the solar collector inclination from the ground surface for two angles (8° and 12°). The chimney consists of PVC tube 6 m height and 25 cm diameter and 3 mm thickness. It is held by (4-iron) stand and fixed with 4-steel cables to prevent the movement due to the strong winds.

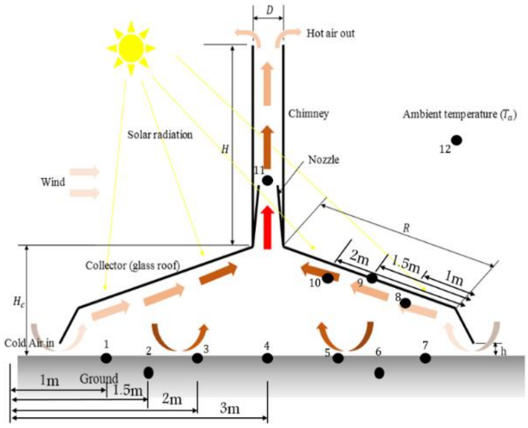
At daylight, the absorbing ground is heated up by solar radiation that comes from the sun and transmitted through the collector’s glass. At night, the air stream is heated up by energy storage in ground, the upper ground surface have a temperature lower than that in bottom. This is because of heat transfer between two ground surfaces by conduction and transferred the heat to air stream by convection. The natural roof without insulation does not have energy storage when it compared with the other ground types. To guarantee 24 hours continuous operation, multi types of ground was studied as a basement energy storage. The three kinds of grounds (natural ground, small pebble, and tubes filled with water with small pebble). The natural roof without insulation does not have energy storage when it compared with the other ground types. Small pebble spread under the collector with 5cm thick and then added tubes (5cm diameter) filled with water inside the collector; these grounds were insulated from the roof surface by 5cm thick pebble cork to reduce the losses to a minimum to be neglected [12].

Experimental procedure

After assembling the experimental model, it was left for one week without taking any readings to stabilize with the environment. Different parameters were studied in this work to find the optimum collector inclination angle and the basement for the collector. Two different inclination angles for a collector (8°, 12°) were tested on different grounds and with glazing cover. Initially, the natural ground was used under the collector, after coating the bricks with black paint to absorb more heat during the day. Then to guarantee 24 hours continuous operation, multi types of the ground were studied as a basement energy storage. Three basement types (adding grounds) were studied taking into consideration the roof surface, the first bed was natural ground. The second contained known as a heat storage basement black pebble (5 cm thickness) to absorb more additional heat at daytime, which heats up by solar intensity during daytime and releases its storage heat at the absence of the sun. The third basement was pebbles with tubes fills with water. For all parameter measurements, were taken every half hour over 24 hours using the thermometer data logger in August 2018. Measurements included the temperature of the absorbing ground, airflow temperature at flow path, (from collector inlet to chimney), and the relation between this and solar radiation. It is necessary to measure the temperature of the air internally the collector and the ground at more than one location, as shown with reference to the ground (without pebbles) in figure 2-A, and when using pebbles on the ground and same it with cone, as shown in figure 2-B.



Thermometer nodes with natural ground



Thermometer nodes with small pebbles and the same with tubes of water

Figure 2. Thermometer nodes

RESULTS AND DISCUSSION

The variation in temperature between the ambient air and airflow inside the chimney was the main factor that affected on the velocity and then power so the figures below show the results of differences in temperature between air internal chimney and ambient air, over time [13-17]. The amount of air temperature rise through the collector indicates the amount of the thermal energy gained by air stream, when it is flowing over the ground surface towards the chimney. The ground temperature increases along the ground path towards the center to record maximum value under the chimney. This behavior is due to that air enters to the system from the collector gap reduces ground temperature. Hence, the entered air has a temperature equal to ambient while absorbing ground temperature is more than air temperature due to solar radiation and the greenhouse effect. So, when air flows over the ground surface it will heat up [18-23]. Figure 3 shows the results for angle inclinations of 12° and 8° with natural ground and glazing cover. The maximum experimental difference temperature obtained here was 19.1 ℃ at 12°, while the difference was 15 ℃ at an angle of 8°. Fig. 3 shows that the temperature increased with raise at inclination angle for collector. The total enhancement gained 21.5 %.

Figure 4 shows the results for angle inclinations of 12° and 8° with a small pebble ground and glazing cover. The maximum experimental difference temperature obtained here was 23.2 ℃ at 12°, while the difference was 20.6 ℃ at an angle of 8°. Fig. (4) also show that the increase in temperature continues after sunset as seen in Fig. (3) when in the natural ground, meaning that the small pebbles work as a better thermal storage layer, giving energy to the system after absorbing heat during daylight hours. The maximum experimental ground temperature under the collector was 69 ℃. Figure 5 shows the results for angle inclinations of 12° and 8° with mixed small pebble ground with tubes filled water and glazing cover. The maximum experimental difference temperature obtained here was

25.3 ℃ at 12°, while the difference was 21.1 ℃ at an angle of 8°. Fig. (5) also show that the increase in temperature continues after sunset until 2:00 AM. The maximum experimental ground temperature under the collector was 76 ℃. Figure (6) show the results on natural ground, a glass cover and angles of 12º and 8º degrees. The experimental velocity inside the chimney over time reached 13.2 m/s at an angle of 12º, while it reached 11.5 m/s at another angle.

This figure also shows that velocity increased with increases the inclination angle of the collector. Figure 7 show the results for angle inclinations of 12° and 8° with small pebble ground and glazing cover. The maximum experimental velocity obtained here was 18.8 m/s at 12. Fig. 4 Air velocity also continues after sunset (until 01:00 Am) because of the pebbles under the collector, the same as for temperature. Figure 8 Final condition show experimental difference in velocity over time for mixed small pebbles and tubes water. The velocity reached at maximum 18.2m/s. The tubes water enhances the storage of energy and increase the time reach until 02:00 Am. The maximum enhancement gained by tubes is 17.6 % in comparison it with natural ground in figure 6. Figures 9,10,11 Power behaves in the same way as temperature and velocity in that when the collector inclination angle is increased, the power will increase. Fig. (9) for inclination and difference between 8 and 12 angles and the maximum power reached in 12 degree at 40.95 w. fig.10 maximum experimental difference in power over time for small pebble reached to 84.2 W at last fig.11 for mixed small pebbles and tubes water the power is 86 W. The maximum enhancement in this case comparing a small pebble only with the last case small pebbles and tubes filled with water is 8.4%.

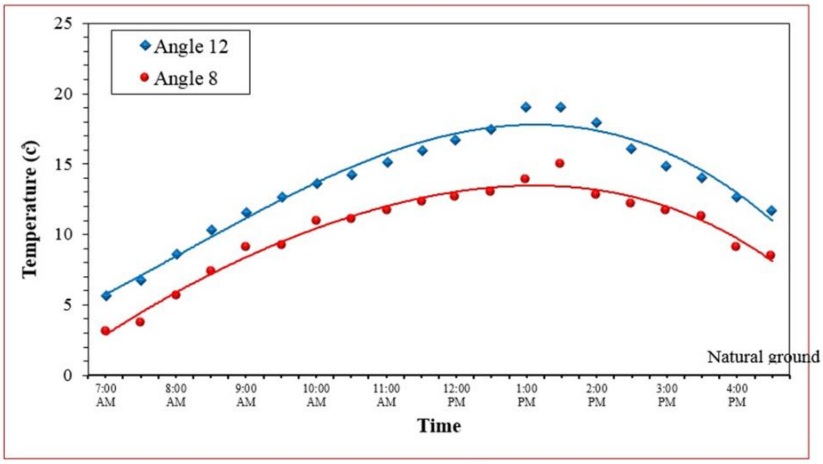


Figure 3. The experimental difference in temperature over time for natural ground

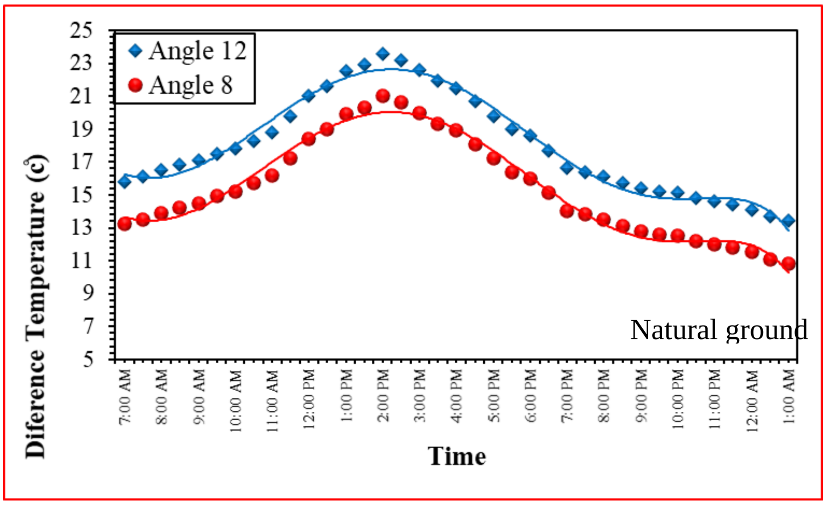


Figure 4. The experimental difference in temperature over time for a small pebble

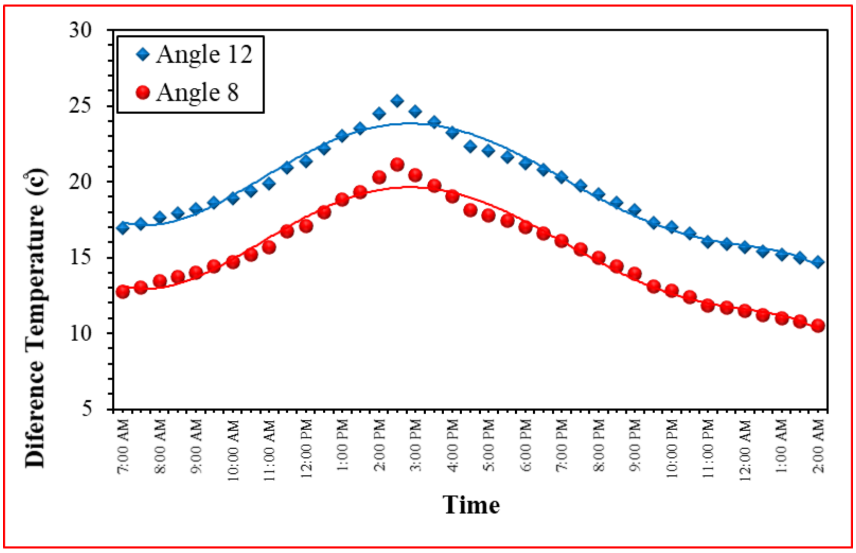


Figure 5. The experimental difference in temperature over time for mixed small pebbles and tubes water.

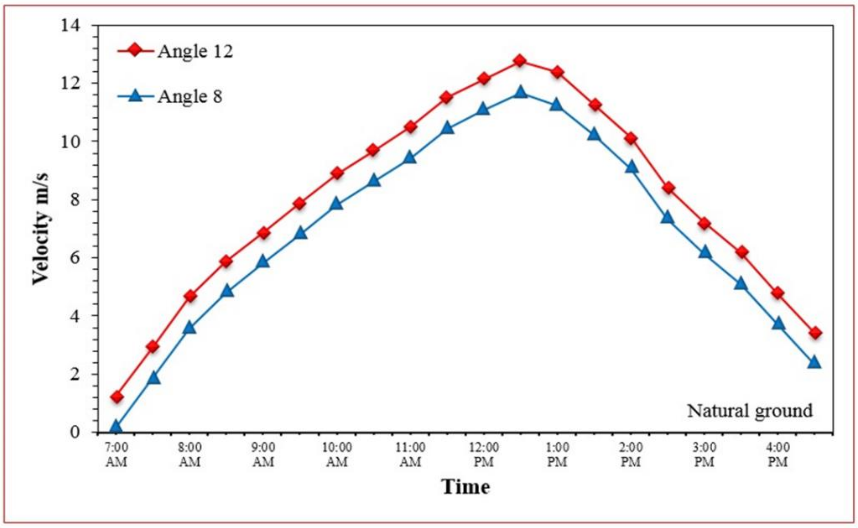


Figure 6. The experimental difference in velocity over time for natural ground

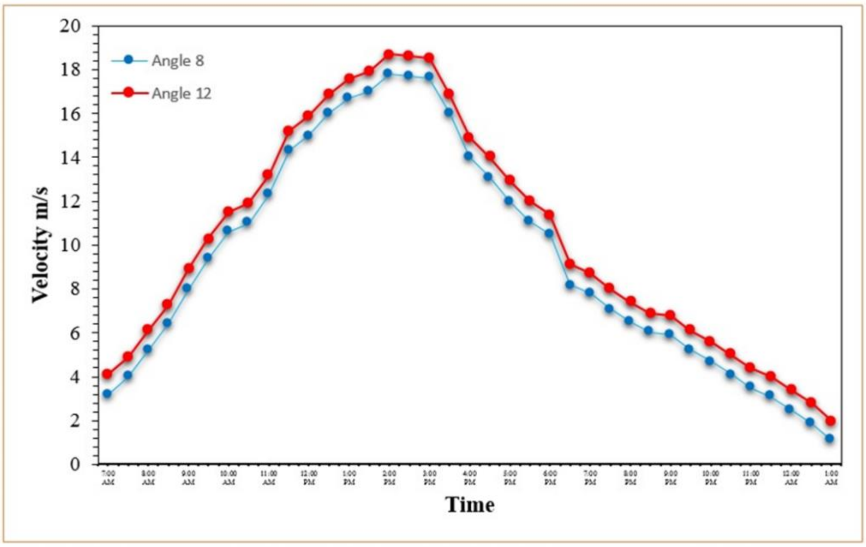


Figure 7. The experimental difference in velocity overtime for a small pebble

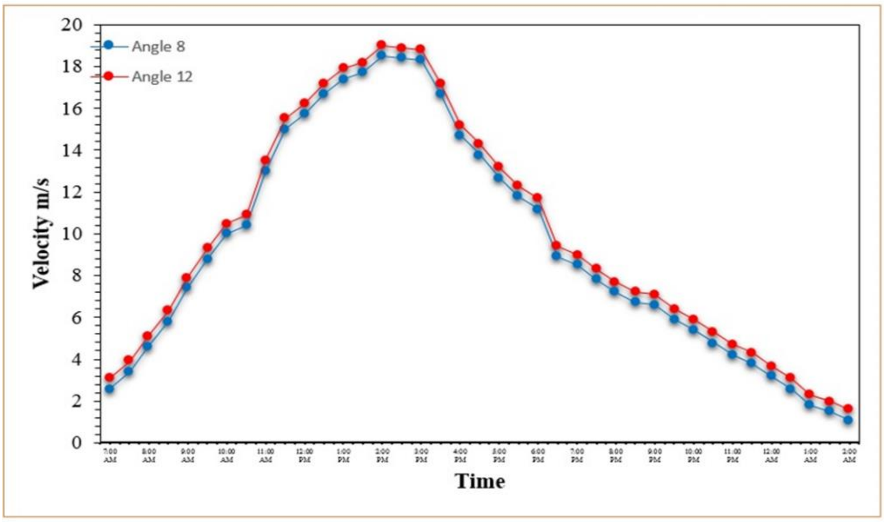


Figure 8. The experimental difference in velocity over time for mixed small pebbles and tubes water.

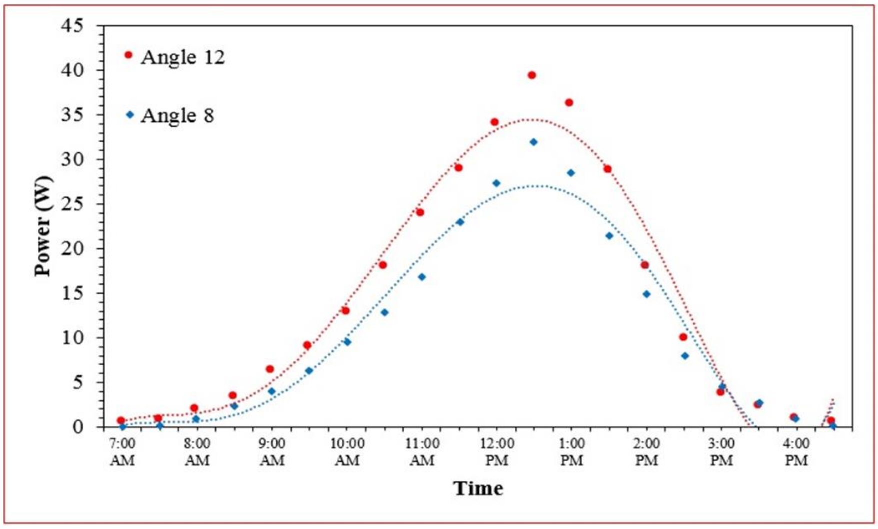


Figure 9. The experimental difference in power over time for natural ground

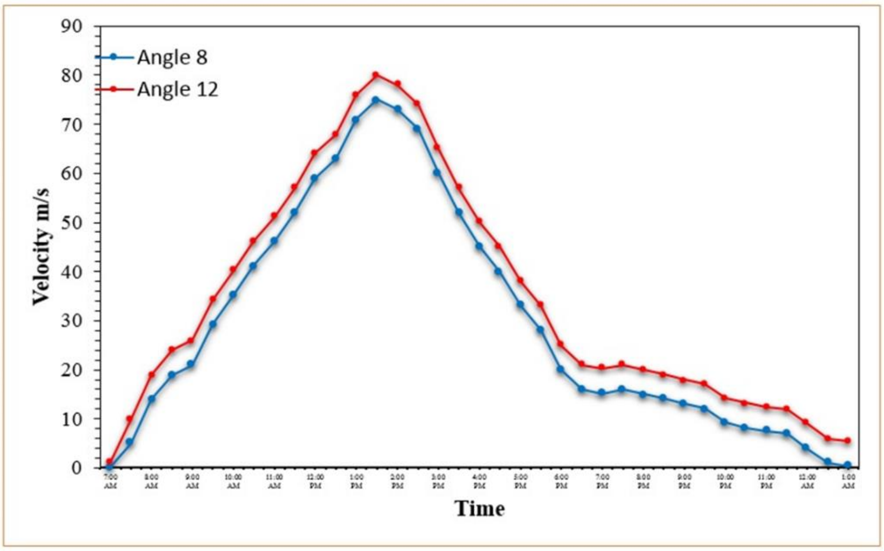


Figure 10. The experimental difference in power overtime for a small pebble

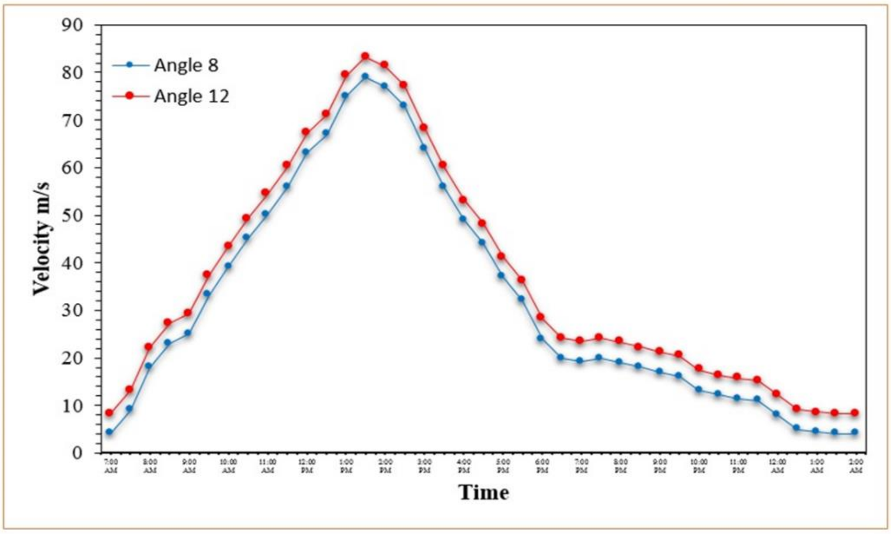


Figure 11. The experimental difference in power over time for mixed small pebbles and tubes water.

CONCLUSION

From the current study which examined the experimental collector design parameters impacting efficiency for (PPSC) the following conclusions can be drawn:

- Analytical solutions using Fortran 90 and experimental results for the prototype were found to have a good level of agreement. The percentage of error for all the results not exceeding 10 %.
- Experimentally, the maximum difference in temperature between airflow inside the chimney and ambient air was 25.5 ℃, airflow velocity was 19.2 m/s, and available power 84.5 W with a collector angle of 12°, a glass cover and a tubes full water with small pebbles on it.
- Increasing the storage of energy in the collector and the difference temperature, velocity, and power when used a tube with a small pebble.
- Using a tube with small pebbles increased the difference in temperature by 27.23 % and power output by 9.81 % compared to a natural ground
- For a large scale (SCPP) which recommended as effective for use under Iraqi solar radiation conditions.

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