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EXPERIMENTAL STUDY FOR GROUND TYPE EFFECT ON SOLAR CHIMNEY POWER PLANT

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ABSTRACT

Solar chimney power plant is a technology capable to generate electric energy through a wind turbine using the solar radiation as energy source; nevertheless, one of the objectives pursued since its invention is to achieve energy generation during day and night. The ground under the power plant plays an important role on the energy balance and heat transfer, due to its natural behavior as a heat storage system. An experimental model was designed in Holley Kerbala city (Iraq), which consisted of a 3m collector radius with 8^{o} collector inclination angle and a 6m height of chimney been constructed and collector periphery opening height 3cm. Three kinds of grounds was studied in this work: sand, mixed from sand and pebble and the third is black pebble. The results show that the highest airflow temperature inside the chimney reached was 66.8C^{o} when using the black pebbles basement. The maximum basement temperature measured was 81.6C^{o} for the mixed basement. Also, the highest temperature difference reached was 23.2C^{o} for the same ground that have good performance during day light compared with pebble basement that have more energy saving in night.

KEYWORDS: Renewable Energy, Solar Chimney, Storage Energy, Ground Types, Efficiency

1. INTRODUCTION

The energy demand is increasing continuously due to the increase in population and industrialization. The depletion of conventional energy sources such as hydrocarbon fuels, atomic energy sources and associated pollution factors demands the research in the field of renewable/non-conventional sources of energy to achieve techniques the current energy crisis by solar energy. There are many to capture power from this non-conventional source of energy. The important method is solar power plants for producing electricity by using solar panels. There is an alternative for producing power from solar energy and it is known as solar updraft tower. It is a green energy producing system worked based on natural flow of air. The solar updraft tower consists of four essential elements: glass roof (collector), chimney (tower), energy storage (ground) and wind turbine. Sunlight transmits through the transparent cover of the solar collector and heats the ground below. Ambient cold air enters the collectors from the periphery of the collectors and heated as it flows along the collector toward the center. Due to the pressure formed by the density difference between the warm airflow and ambient cold air, the airflow enters the chimney and with the turbine the kinetic energy of the airflow is converted into the electric power. The solar chimney working principles are shown in Fig.1.

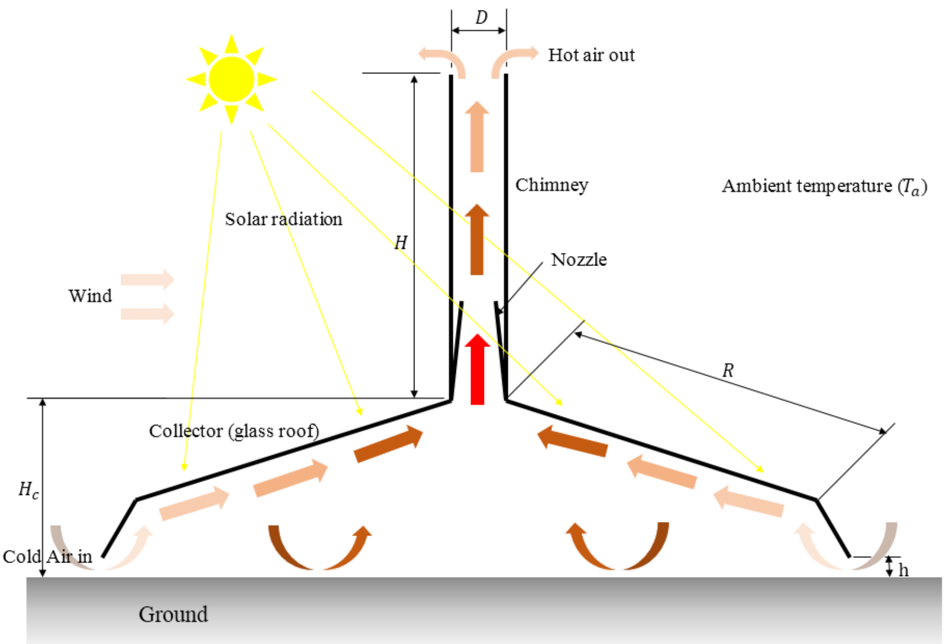

Fig. 1. Schematic diagram of solar chimney.

2. LITERATURE REVIEW

As the solar chimney power plant systems could make significant contributions to the energy supplies of many countries where there is plenty of desert land, which is not being utilized, beside sunlight available in Africa, Asia and Oceania, researchers have made many reports on this technology in the recent few decades (Tingzhen et al., 2008a). Since then, more and more researchers have been strongly interested in this solar power technology.

Shyia, (2002) studied experimentally and theoretically a real sample of solar chimney with five kinds of absorbing ground: aggregates, soil, sand underneath, asphalt soil and asphalt aggregate. Time of measuring were (12 am, 2 pm, 4 pm) in July year (2002). The important conclusions are: The high air velocity and temperature are at 2 pm, (3.12 m/s and 52.5 o C), respectively. The best absorption floor is asphalt aggregate. A good agreement was found between the experimental and theoretical results. In South Africa, Pretorius Cao et al., (2013) compared the power outputs of six different ground types: sandstone, granite, limestone, sand, wet soil and water. They found that the SCPP employing the wet soil and the sand have the lowest and highest power outputs respectively, and different materials lead to varying power outputs during the daytime and at night. They also concluded that increased ground absorptivity holds positive effects on annual solar chimney power output. Hammadi, (2008) have developed a mathematical model for a solar updraft tower with water storage system. He studied the effect of thermal storage system on the power production of the plant. the obtained results showed that the thickness of the water storage layer shifted the peak value of the output power far away from mid-day and more smoothing the output curve. Tingzhen et al., (2008b) analyzed the characteristics of heat transfer and airflow in the solar chimney power plant system with energy storage layer. Different mathematical models for the energy storage layer have been developed, and the effect of solar radiation on the heat storage characteristic of the energy storage layer has been analyzed. Simulation results show that the heat storage ratio of the energy storage layer decreases firstly and then increases with the solar radiation increasing from 200W/m2 to 800W/m2 and the average temperature of the chimney outlet and the energy storage layer increase significantly with the increase of the solar radiation. Chaichan and Hussein, (2011) studied the chimney's basements kind effect on collected air temperatures. Three basements were used: concrete, black concrete and black pebbles basements. The results show that the best chimney efficiency was found for pebbles base. Moreover, the highest temperature difference reached was 22ºC with the pebble ground.

This paper investigated in Iraq, Kerbela the effect of the variable ground types on airflow rate and air temperature distribution in the solar chimney. For this purpose airflow rate and temperature in the chimney, ambient temperature and surface temperature of ground are measured, and it take into account the effect of ground storage beside the absence of solar radiation in the night time.

3. EXPERIMENTAL PART

The solar tower's prototype was built as shown in Fig. 2. Air is heated by solar radiation under a circular transparent roof (6 meters dia) open at the periphery (3 cm) high from ground and angled from ground by 8^{O}. In the middle of the roof, that is a vertical tower (6 meters tall and 25 cm diameter) with large air inlets at its base (75 cm height from the ground) as shown in Table 1. As hot air is less density than cold air, then rises up into the tower. The cold air enters the collector by the gap between the collector and the ground, the air heated and lift gradually through the collector and enters the vertical tower. Continuous 24 hours- operation can be achieved by placing a thermal collector ground. For this purpose three kinds of grounds (adding grounds) were studied with taking into consideration the natural ground (roof surface), The first type was an ordinary sand ground, which heats up during day-time and releases its heat at night. The second type was mixed from sand and black pebble ground to absorb more heat at daylight. The third basement was black colored pebbles known as a heat storage substance to efficient air mixing by increasing its turbulence. The three kinds of grounds was published under the collector with 5cm thick, this grounds was insulated from the roof surface by 5cm thick pebble cork to reduce the losses to minimized value (can be neglected). The temperatures of air under the cover of collector, through chimney, ambient and ground was measured by (12) calibrated copper-constantan thermocouples type -K- distributed as shown in Fig. 3. The experiments were conducted in Iraqi summer days, started on the 25 July and finished on 7 August 2016. The tests were conducted in the roof of the mechanical engineering department (Kerbala University).

Fig. 2. Experimental rig of solar chimney.

Table 1. Main parameters for solar chimney power plant.

Property	Dimension (m)	Symbol
Collector radius	3	R
Chimney height	6	H
Chimney diameter	0.25	D
Height from collector outlet to ground level	0.75	Hc
Periphery (Surrounding air inlet)	0.03	h

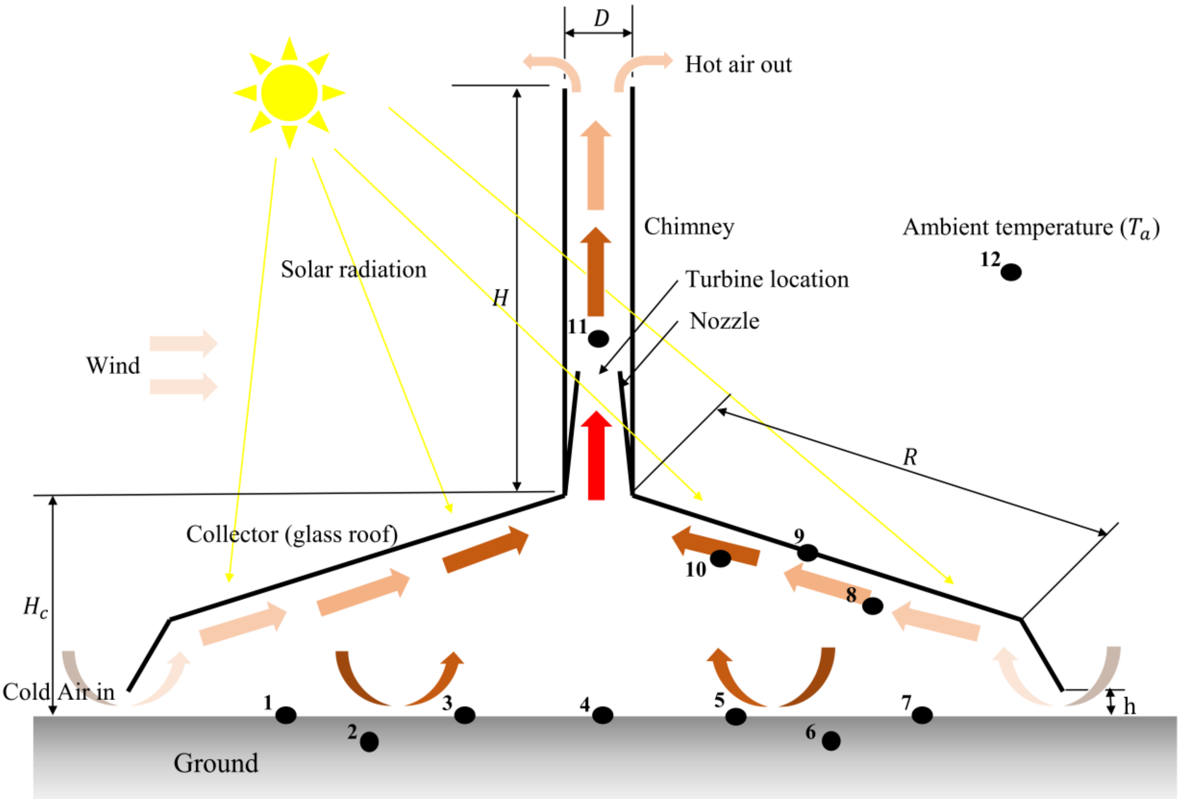

Fig. 3. Thermometer node positions

4. ASSUMPTIONS

The mathematical model of the solar chimney has been developed based on energy balance under the following assumptions (Bernardes et al., 2003; Direcksataporn, 2008; Zhou et al., 2007; Al-Abadi et al., 2010):

1. The performance of the power plant is analyzed at steady state flow, because solar radiation is transient in nature.
2. The collector cover temperature and the ground temperature don’t change along the collector radius (R), i.e. d/dr for Tc and Tg is zero.

3. Air is an ideal gas and the flow is incompressible across the chimney since Mach number is below 0.3.
4. The heat radiated to the chimney is ignored since the surface area of the collector is much larger than the surface area of the chimney. Therefore, heat transfer equation is considered for the collector.
5. The airflow in the system is due to buoyancy force in solar chimney.
6. The flow under the collector is considered as a flow between two parallel plates.
7. Thermal physical properties of the air are constant.
8. Neglect viscous dissipation.
9. The flow through the collector has complete symmetry with θ direction.

5. HEAT BALANCE

To find the heat gain to the air inside the collector, a heat balance to the collector, ground and air stream has been considered. The heat balance equations govern the collector's components are, see Fig. 4:

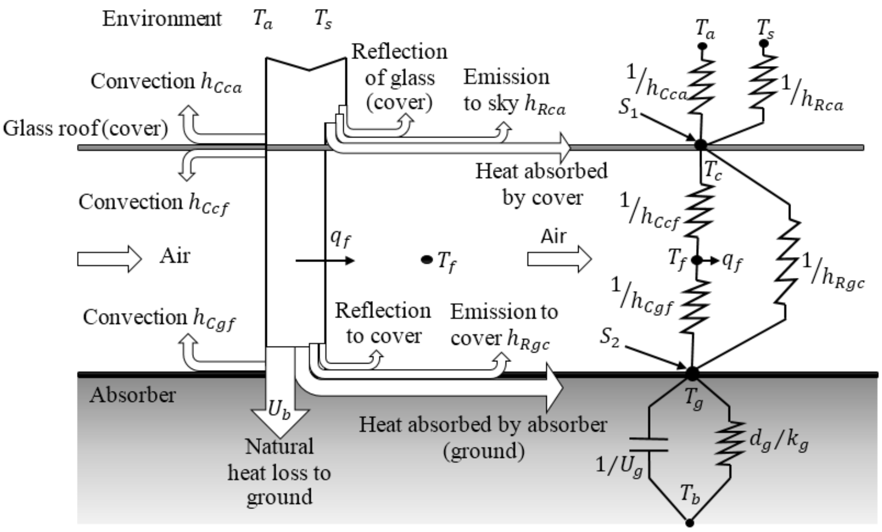

Fig. 4. Thermal network for the collector of solar tower.

The heat balance equation for collector roof cover is:

$$S_1 + q_{R-gc} = q_{C-ca} + q_{R-cs} + q_{C-cf} \quad (1)$$

The heat balance for the collector ground per area of the ground is:

$$S_2 = q_{C-gf} + q_{R-gc} + q_{abs-g} \quad (2)$$

Where: $S_1 = \alpha_c I$, $S_2 = \tau_c \alpha_g I$

The heat balance equation for air inside the collector is:

$$\left(q_{C-cf} + q_{C-gf}\right) * A_c = \left(\dot{m}C_p T_f\right)_{out} - \left(\dot{m}C_p T_f\right)_{in} \qquad 3$$

The total pressure developed due to buoyancy (equivalent to the power contained in the flow) is given by (Bilgen and Rheault, 2005, Zhou et al., 2007, Al-Abadi et al., 2010) as:

$$\Delta p, = g\left(\rho_a -, \rho_f\right)H \qquad 4$$

The airflow velocity in the chimney V_{ch} can therefore be expressed as:

$$V_{ch} = \sqrt{2g\ H\frac{(T_f - T_a)}{T_a}} \qquad 5$$

6. RESULTS AND DISCUSSION

Experimental data was measured for various grounds and days in order to analyses the performance of the solar chimney. The results show daily variations of ground surface temperature, ambient temperature and airflow temperature inside chimney. Figs. 5, 6, 7 and 8 show temperatures against time in an hour intervals. Fig. 5 represents the solar chimney behavior when sand ground was used in 27 July 2016. The results show the air temperature increases with time starting with sunrise, this increase was associated with an increase in the collected air and the basement temperatures. The maximum temperatures were achieved at 1 p.m. collected air was heated in this region (sunrise till 1 p.m.) by greenhouse effect while the direct radiation heated the ground. In these hours, the collected air was independent of the warm ground.

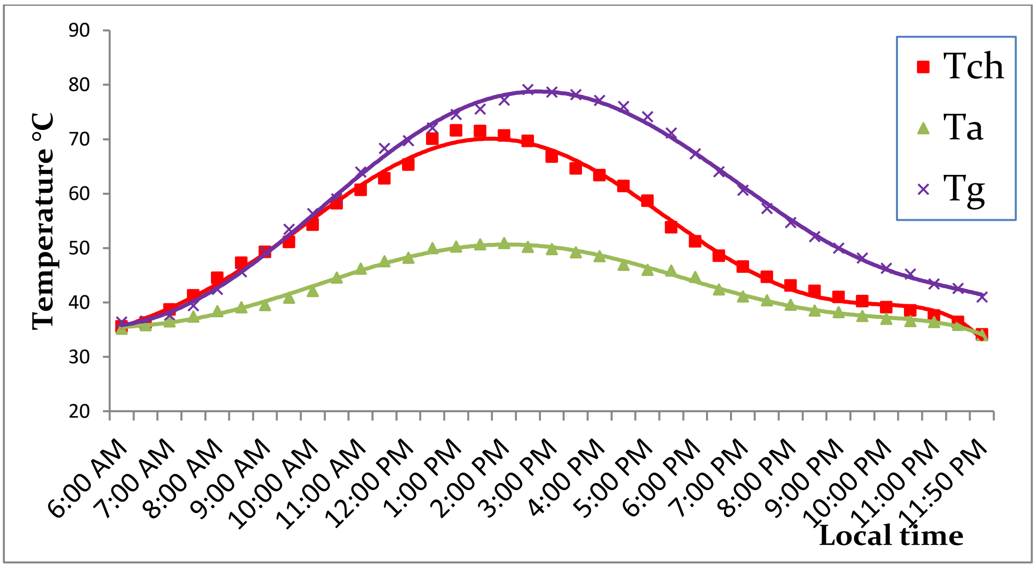

Fig. 5. Ground, chimney and ambient temperatures verse time for sand basement.

In this region, the collected air depends on the basement to warm up. The thermal storage for the sand ground was limited and achieved temperature differences for 11:50 p.m. after sunset. This limited time is due to the prototype chimney dimensions and ground material type. Economically, there are limitations to the chimney height and collector area to have good increase in the output power and any increment in these sizes get small percentage increase in the profit power output (Al-Abadi et al., 2010). The maximum difference between (Tch) and (Ta) was (21.6ºC). The maximum variation between air temperature (Ta) and ground temperature (Tg) for ordinary sand case was about (29ºC) at 2:30 to 4 p.m. where the highest temperatures were achieved, a maximum (Tch) reached was (71.6 ºC).

Fig. 6 represents the solar chimney behavior when the ground is mixed from sand and black pebble that used in 29 July 2016. This ground absorbed more solar radiation and heated more than sand basement where (Tch) reached a maximum temperature of about (73.4 ºC) in 1:30 p.m. The thermal storage of this basement is greater that in sand basement.

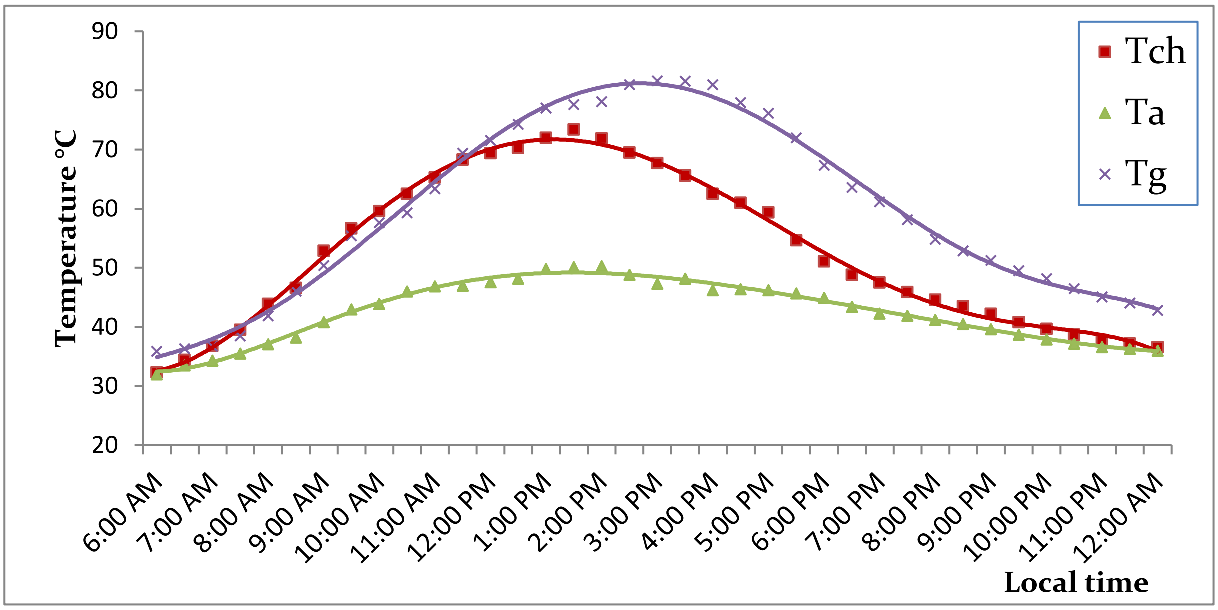

Fig. 6. Ground, chimney and ambient temperatures verse time for mixed basement (sand and black pebble).

Fig. 7 demonstrate the solar chimney behavior when black pebbles basement were used in 7 August 2016. The figure show that there are some improvements in temperature differences; the maximum temperature difference between (Tch) and (Ta) reached (23.2°C). The black pebbles ground absorbed solar radiation and heated more than ordinary sand and mixed sand and pebble basement due to its higher specific heat. The maximum pebble temperature obtained was (75.8°C). This thermal storage managed to continue operating for many hours after sunset, despite of the limited collector size. These results give black pebbles priority over sand and mixed basements. As well as it proves that a suitable basement combined with suitable solar chimney design manage to operate for 24 hours.

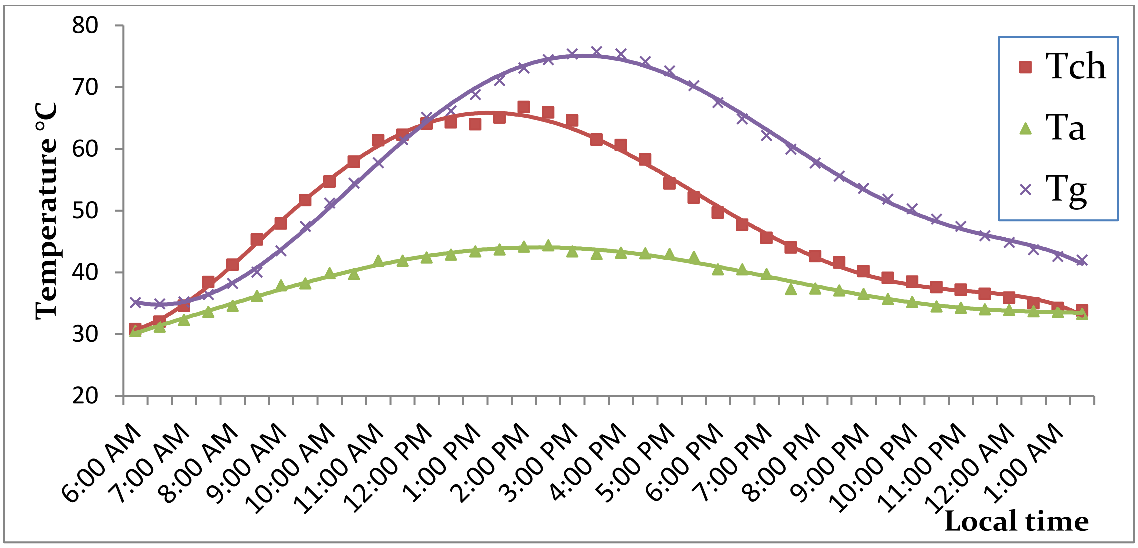

Fig. 7. Ground, chimney and ambient temperatures verse time for black pebble basement.

In Fig. 8, the ground temperature profile of a plant employing sand exhibits a low heat storage during night-time, with a much higher surface temperature than the other ground types during daytime. Once again the observed behavior may be attributed to the heat capacity of the employed ground type. The low thermal conductivity value of sand causes very little energy to be conducted and eventually stored in the ground. Consequently, most of the solar radiation received during the day only heats the ground surface, giving high ground surface temperatures. In effect, higher ground surface temperatures mean more energy is available to heat the collector air, which ultimately means a greater power output can produce. However, because very little energy is stored in the ground during the day, very little power is produced at night, contrarily with black pebble show significantly greater heat released during night-time and has lower surface temperature during daytime, compared to the other ground types. This is due to its large heat capacity, which provides black pebble with a good capacity for storing energy.

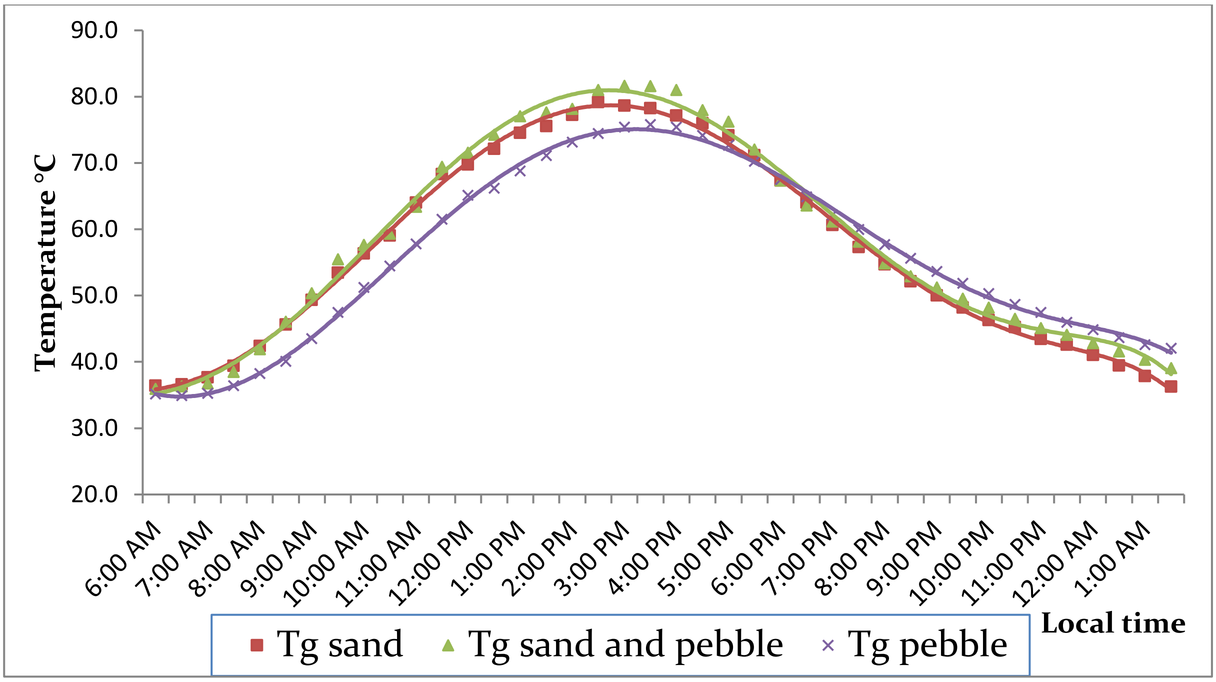

Fig. 8. The influence of various ground types on the surface ground temperature.

7. CONCLUSION

According to the results obtained from the proposed model, the following conclusions are drawn:

- ❖ The collector's outlet temperature and ground surface temperature are a function of solar intensity; they increase as the solar intensity increases.
- ❖ The solar chimney power plant have a suitable basement (black pebble ground) can achieve air heating for many hours operation after sunset.
- ❖ The results show that black pebbles basement had better thermal storage quality than sand or mixed ground.

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