Basement Kind Effects on Air Temperature of a Solar Chimney in Baghdad - Iraq Weather

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Abstract

A solar updraft tower power plant (solar tower) is a solar thermal power plant that utilizes a combination of solar air collector and central updraft tube to generate an induced convective flow which drives pressure staged turbines to generate electricity.

This paper presents practical results of a prototype of a solar chimney with thermal mass, where the glass surface is replaced by transparence plastic cover. The study focused on chimney's basements kind effect on collected air temperatures. Three basements were used: concrete, black concrete and black pebbles basements. The study was conducted in Baghdad from August to November 2009.

The results show that the best chimney efficiency attained was 49.7% for pebbles base. The highest collected air temperature reached was 49ºC when using the black pebbles basement also.also, the maximum basement temperature measured was 59ºC for black pebbles. High increaments in collected air temperatures were achieved in comparison with the ambient air temperatures for the three basement kinds. The highest temperature difference reached was 22ºC with the pebble ground.

Keywords: Solar chimney, basement effect, concrete, pebbles, storage efficiency.

1. Introduction

Sun is the principal source of almost all kinds of energy, both conventional and non-conventional. The sun is approximately 1.4 million km in diameter and 150 million km from the earth. Its temperature is close to 5500°C at its surface and emits radiation at a rate of 3.8×10^{23} kW. This power is supplied by nuclear fusion reactions near its core which are estimated to continue for several billion years. (Lovegrove and Dennis**,** 2006).

The input of solar radiation to the biosphere is the source of energy which drives our weather systems and so in turn, winds, hydroelectric and biomass energy systems. Solar radiation can be used directly for photovoltaic energy conversion and for solar thermal conversion (Xinping, Yang and Hou, 2007).

Electricity can be generated from solar radiation through the following methods:

- Photovoltaic cells
- Solar thermal power
- Solar tower / chimney (Bilgen and Rheault, 2005).

A recent development in solar energy is a solar tower/chimney. It is a method used for large-scale generation of electricity from solar radiation. The principle is very simple (Onyango and Ochieng, 2006). A solar chimney is an air-heating solar collector that runs automatically on sun power alone. It is based on the well known principle of greenhouse effect, chimney updraft effect, and wind turbine. Air is heated by solar radiation under a low circular transparent or translucent roof opened at the periphery; the roof and the natural ground below it form a solar air collector (Pretorius and Kroger, 2005). In the middle of the roof a vertical tower is installed with large inlet at its base. The joint between the roof and the tower base is airtight. As hot air is lighter than cold air, it rises up the tower. Suction from the tower then draws in more hot air from the collector, and cold

air comes in from the outer perimeter (Xinping, Yang and Hou, 2006). Due to greenhouse effect, the air is warmed in the solar collector. The warm air is moves from the periphery of the solar collector towards its center in order to ''escape' to upper layers of atmosphere through the solar chimney (fig.1). This moving stream of warm air leaves part of its thermodynamic energy to the air turbines that are geared with appropriate electric generators.

An indicative diagram for a Solar Chimney Power Plant is shown in fig.1.

In 1903, Spanish Colonel Isidoro Cabanyes first proposed a solar tower power plant in the magazine La energia electrica. One of the earliest descriptions of a solar tower power plant was written in 1931 by a German author, Hanns Gunther. Beginning in 1975, Robert E Lucier applied for patents on a solar tower electric power generator. These patents were granted in Australia, Canada, and the USA between 1978 and 1981.

The first studies on solar chimneys were reported in 1993 by Bansal et al. They present a stationary state model to describe a solar chimney, consistent by a conventional chimney linked to an air solar heater. Hirunlabh et al. report in 1999 the results of an experimental solar chimney, composed of a glass surface, air channel and a metallic black wall as collector surface. Khedari et al. in 1999 made a comparative study among different configurations of solar chimneys classified as, roof solar collector, modified Trombe wall, Trombe wall and metallic solar wall. In 2003 Ong and Chow reported the experimental and theoretical results of a solar chimney similar to the Hirunlabh one.
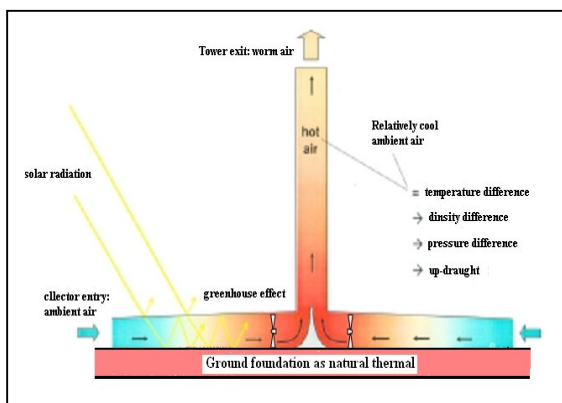

Fig.1. Solar Tower Working Principles.

Solar towers have a number of special features:

1. The collector can use all solar radiation, both direct and diffuse. This is crucial for tropical countries where the sky is frequently overcast (Koonsrisuk and Chitsomboon, 2006).
2. Due to the soil under the collector working as a natural heat storage system, updraft solar towers can operate 24 hours on pure solar energy, at a reduced output at night. If desired, additional water tubes or bags placed under the collector roof absorb part of the radiated energy during the day and releases it into the collector at night. (Ong and Chow, 2003).
3. Solar towers are particularly reliable and not liable to break down, in comparison with other power plants. Turbines and generators - subject to a steady flow of air - are the plant's only moving parts. This simple and robust structure guarantees operation that needs little maintenance and of course no combustible fuel (Onyango and Ochieng, 2006).
4. Unlike conventional power stations (and also some other solar-thermal power station types), solar towers do not need cooling water. This is a key advantage in the many sunny countries that already have major problems with water supply (Haase and Amato, 2005).
5. The building materials mainly concrete and glass needed for solar towers, are available everywhere in sufficient quantities. In fact, with the energy taken from the solar tower itself and the stone and sand available in the desert; they can be reproduced on site. Energy payback time is two to three years (Shyia, 2002).
6. Solar towers can be built now, even in less industrially developed countries. The industry already available in most countries is entirely adequate for solar tower requirements. No investment in high-tech manufacturing plants is needed (Schlaivh et. al., 2005).
7. Even in poor countries, it is possible to build a large plant without high foreign currency expenditure by using local resources and work-force; this creates alarge number of jobs while significantly reducing the required capital investment and thus the cost of generating electricity (Xinping, Yang and Hou, 2007).

Nevertheless, solar towers also have features that make them less suitable for some sites:

A. They require large areas of flat land. This land should be available at low cost, which means that there should be no competing usage for

the land e.g, intensive agriculture (Koonsrisuk and Chitsomboon, 2006).

B. Solar towers are not adequate for earthquake prone areas in this case tower costs would increase drastically (Direcksataporn, 2008).

C. Zones with frequent sand storms should also be avoided, as either collector performance losses or collector operation and maintenance costs would be substantial there (Xinping, Yang and Hou, 2006).

In the objective of this study was to examine the effect of basement types on the air temperatures of aprtotype solar chimney designed and constructed for this purpose, in Baghdad autumn days.

2. Experimental Set Up

The solar tower's prototype was built as shown in Fig. 2 air is heated by solar radiation under a low circular transparent roof (6 meters dia) open at the periphery (2 cm high from ground); the roof and the ground below it form a solar air collector. In the middle of the roof that is a vertical tower (4 meters tall and 20cm dia) with large air inlets at its base (10 cm height from the ground). The joint between the roof and the tower base is airtight. As hot air is lighter than cold air, it rises up the tower. Suction from the tower then draws in more hot air from the collector, and cold air comes in from the outer perimeter. Continuous 24 hours- operation can be achieved by placing a thermal collector ground. For this purpose three kinds of grounds were studied, The first was an ordinary concrete ground, which heats up during day-time and releases its heat at night. The second was selective black colored concrete ground to absorb more heat at daylight. The third basement was selective black colored pebbles known as aheat storage substance and for giving efficient air mixing by increasing its turbulance. The idea was to investigate the best basement material that makes solar radiation cause a daily constant updraft in the tower.

The temperature of air under the transperace cover was measured by (6) six calibrated copper-constantan thermocouples distributed uniformly around the vertical chimney. Also, the rising air temperature through the chimney was measured by means of caliprated thermocouples. These thermocouples were fixed in variable manner, to give acurate analysis of the moving air through the chimney. The first thermocouple in the group represents collected air temperature (T_c). The

temperature of the air entering the chimney (T_a) was measured by thermometer fixed away from the chimney. The basements floor temperature (T_f) was measured by means of three thrmocouples distributed in the west, south and east directions, with a distance of 1.5 metre from the centre of the collector; the avarage of these thermocouples readings was taken as (T_f). Temperatures were read by caloibrated digetal electronic thermometer, through a selector switch. Fig. 2 represents prototype diminsions and thermocouple distribution, while Fig. 3 shows a photographic picture for the tested prototype solar chimney.
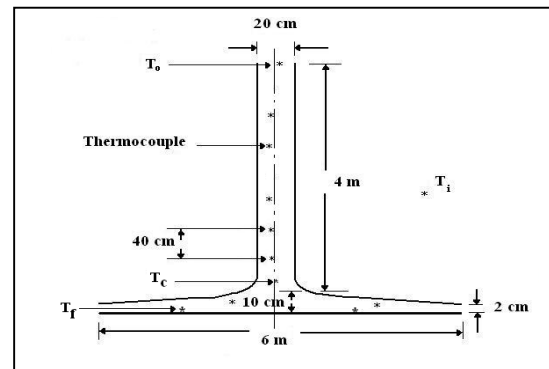

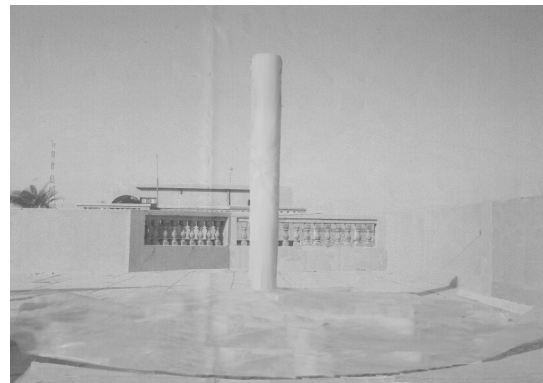**Fig.2. Schematic Diagram of the Solar Chimney and Thermocouples Distribution.**

Fig.3. The Solar Tower's Prototype.

The experiments were conducted in Iraqi autumn days, started on the first of August and finished on the end of November 2009. The tests were conducted in Saydia city, west of Baghdad. Three grounds were prepared; the first one was ordinary concrete ground, the second one was ordinary concrete ground painted with selective black color, and the third was selective black colored pebble ground. Table 1 represents the thermal properties for the used material. The

prototype chimney was fixed in each ground, for 10 days. Temperature readings were taken, so for each ground there are readings for three months; the resultant average were undertaken to compare the three cases. Temperature readings operation began at sun shine and continued after sunset until the basement reached its starting temperature. These temperatures demonstrated the thermal storage in the basement.

Table 1,
Typical Thermal Properties for Tested Materials (Mc Quiston et al).

material	Density (ρ) kg/m3	Conductivity (k) W/m °C	Conductance W/m² °C	Specific heat kJ/kg °C
Concrete	2020-2180	-	3.0-3.5	0.92
Pebble	2080	0.92-1.12	-	5.28

2.1. System Efficiency Calculations

Solar tower system consists of three main parts: collector, tower and turbine. In this study no turbine was used, and the concentration was on thermal energy gathered by solar chimney collector by its various basements.

In calculating system efficiency the procedure mintioned in (Schlaich et al, 2005) was used .

The basic function for solar chimney is to convert heat flow produced by the collector into kinetic energy. The n efficiency can be calculated by:

Total system efficiency = $\eta_{coll} \cdot \eta_{tower} \cdot \eta_{turbine}$

$$... (1)$$

where:

η_{coll}- Collector efficiency.
η_{tower}- Tower efficiency.
$\eta_{turbine}$- Turbine efficiency.

In this study there was no turbine to complete this conversion, and the focus was on the collector efficiency which is calculated by:

$$\eta_{coll} = \frac{P_{tot}}{\dot{Q}} \qquad ... (2)$$

P_{tot} - the pressure difference produced between collector outlet and ambeint air depends on the density difference of air caused by the temperature rise in the collector area and is calculated as follow:

$$P_{tot} = A_c \cdot g \cdot \int_0^{H_c} (\rho_a - \rho_c) \cdot dH \qquad ...(3)$$

with:
A_c- collector area.
H_c- tower hight.
ρ_a- air density in ambient temperature.
ρ_c- air density in the tower.

Thus P_{tot} increases with the tower hieght.

$$\dot{Q} = G_h \cdot A_c \qquad ...(4)$$

$\dot{Q}$- The solar energy input.
G_h- Average solar intensity taken from Iraqi Meteorology organization for 24 hours of the tested period. This efficiency was used to compare the three basements in this study.

The former equations illustrate a very important characteristic in the solar chimney; which is the chimney efficiency depends mainly on the chimney's tower height.

3. Results and Discussion

Figures (4 to 6) represent the solar chimney behavior when concrete ground was used in the three months of study. The results show the air temperature increases with time, starting from sun rise, this increase was associated with an increase in the collected air (T_c) and the basement (T_f) temperatures. The maximum temperatures were achieved at 2 p.m. Collected air was heated in this region (sun rise till 2 p.m.) by greenhouse effect; while the direct radiation heated the ground. In these hours the collected air was independent of the warm ground.
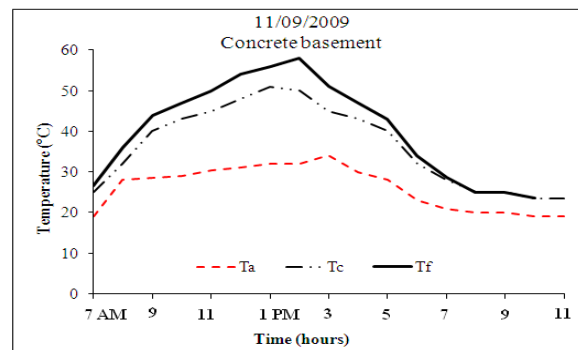
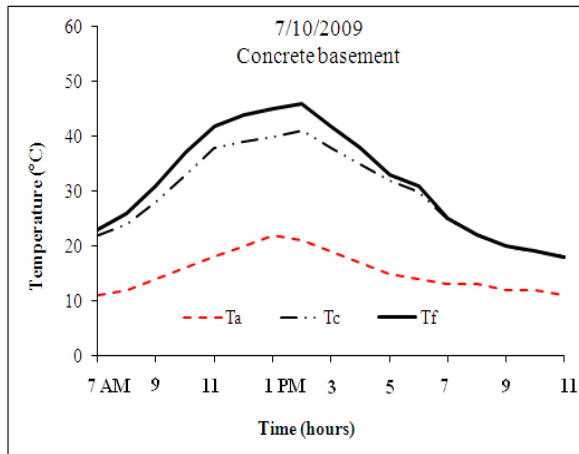**Fig.4. Concrete Basement and Air Temperatures at 11/9/2009).**

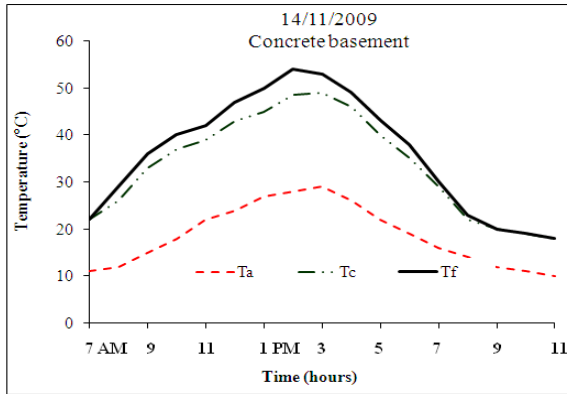**Fig.5. Concrete Basement and Air Temperatures at 7/10/2009.**

Fig.6. Concrete Basement and Air Temperatures at 14/11/2009.

All temperatures reduced after 2 o'clock at noon, until they reached the starting temperature after sun set. In this region the collected air depends on the basement to warm up. The thermal storage for the concrete ground was very limited and achieved temperature differences for about two hours after sun set. This limited time is due to the prototype chimney dimensions. It is believed that big collector area will give more thermal storage heat, and will introduce more working hours to the chimney. The maximum differnce between (T_c) and (T_a) was (19ºC). The maximum variation between air temperature (T_a) and ground temperature (T_f) for ordinary concrete case was about (25ºC) at 1 to 2 p.m. where the highest temperatures were acheived. The maximum (T_f) reached was (56ºC) in August days.

Figures (7 to 9) represent the solar chimney behavior when selective black colored concrete

ground was used. The average temperatures for three months operation period show that there were some improvements in temperature differences between ambient air and collected air, where the temperature got to (20ºC) at peak time.

The black colored concrete ground absorbed more solar radiation, and heated more than ordinary concrete basement where (T_f) reached amaximum temperature of about (57.6ºC) in August days. Also at 7 a.m. they were (temperatures measurment starting point), there were differences between (T_c) and (T_f) more than in the other months. The effect of solar radiation is more effiecient in hotter days, which means more system efficiencies will be obtained in summer months.

The thermal storage of black cloured concreate basement managed to continue warming collected air for three hours after sun set, despite the limited collector size.
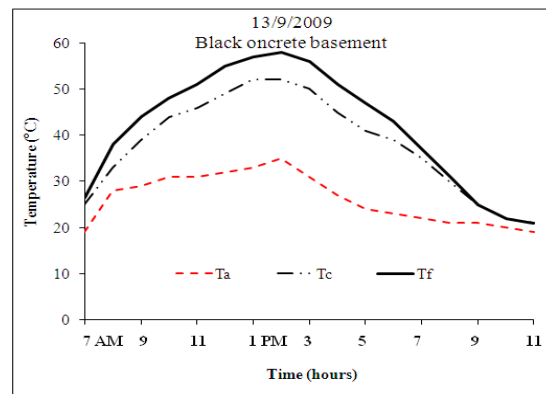

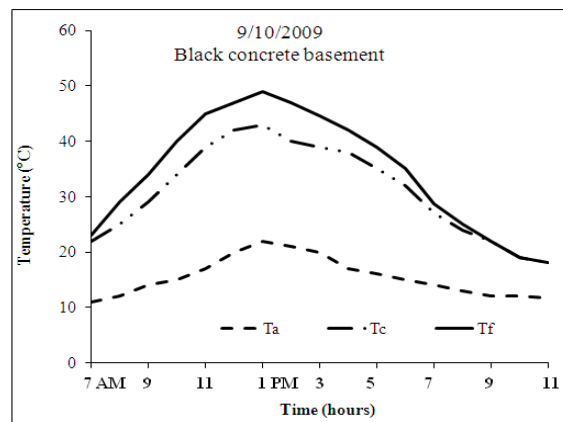**Fig.7. Black Concrete Basement and Air Temperatures at 13/9/2009.**

Fig.8. Black Concrete Basement and Air Temperatures at 9/10/2009.
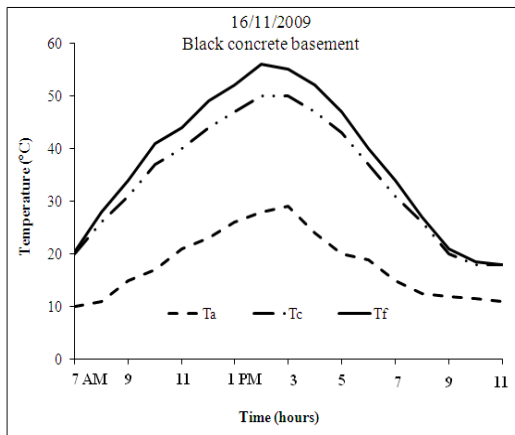
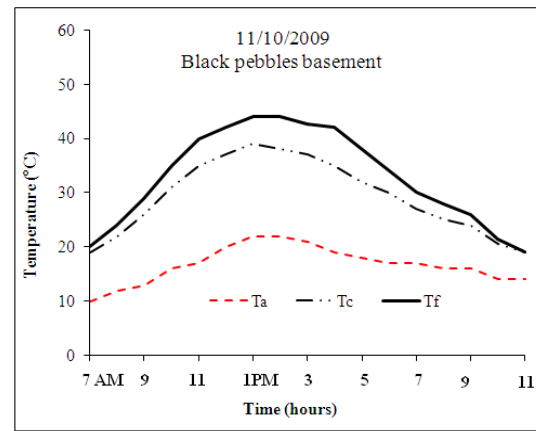**Fig.9. Black Concrete Basement and Air Temperatures at 16/11/2009.**

Fig.11. Black Pebbles Basement and Air Temperatures at 11/10/2009.

Figures (10 to 12) demonestrate the solar chimney behavior when black colored pebbles basement was used. The figures show that there are some improvements in temperature differences; the maximum temperaure difference between (T_a) and (T_c) reached (22ºC) at the peak time. The black pebbles ground absorbed solar radiation, and heated more than ordinary concrete basement due to its higher specific heat. The maximum temperature obtained was (59ºC). This thermal storage managed to continue operating for five hours after sun set, despite the limited collector size.

These results give black pebbles priority over ordinary and black concrete basements. As well as it proves that a suitable basement compined with suitable solar chimney design manage to operate for 24 hours.
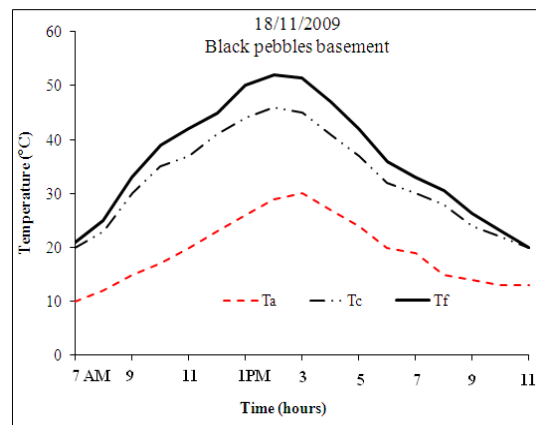

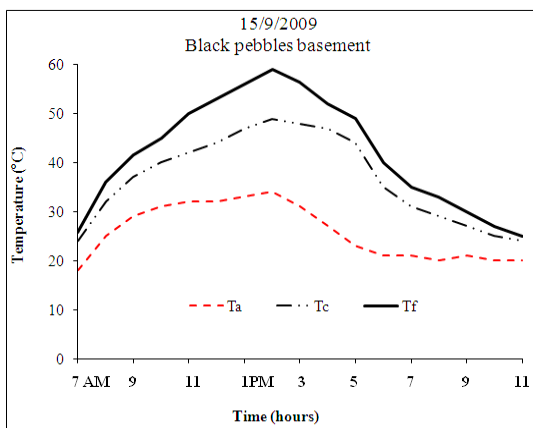**Fig.12. Black Pebbles Basement and Air Temperatures at 18/11/2009.**

The results demonstrate that the storage capacity of black concrete improved about 50% compared with ordinary concrete, while black pebbles improved this capacity with about 250% due to its thermal properties.

Fig.13 shows the chimney's collector hourly efficiency variation for the three systems with operation time. Because the studied system depends on solar energy, then it's collecting time starts from sunrise and ends at sunset. The pebbles basement collecting efficiency surpasses the other cases. The thermal storage improved with this ground, and enable the chimney to work for more time. On the other hand, coloring the concrete ground with black upgraded the thermal storage and improved its efficiency. The rsults concluded that the efficiency of solar chimney depends

Fig.10. Black Pebbles Basement and Air Temperatures at 15/9/2009.

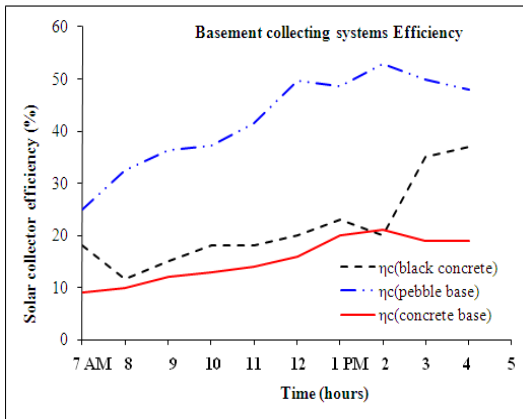highly on the thermal storage capacity of its basement material.

Fig.13. Average Efficiency Differences for Day Hour Fot Basment Systems.

4. Conclusions

The practical prototype model of the solar chimney power plant was designed and constructed to investigate the influence of basement kinds on chimney's air temperatures, in the region of Baghdad - Iraq. The effects of storage parameter, such as the solar radiation, the ambient temperature, and the heat storage capacity for ground materials on the power plant operation time are also investigated. According to the results obtained from the proposed model, the following conclusions are drawn:

1- The solar chimney power plant have a suitable basement (black colored pebble ground in this work) can achieve air heating for many hours operation after sun set. With suitable design the solar chimney power plant will manage to act 24 hours / day.
2- The results show that black pebbles basement had better thermal storage quality than ordinary concrete or black concrete ground.
3- Although the chimney prototype size was limited, it gave high temperature difference between T_c and T_a which reached 22°C. The maximum T_f reached was 59 ^{o}C when using black pebbles. This indicates the convenient of Iraqi weather for this type of plants.
4- Painting the basement with selective black colour increased absorped solar radiation, and thereby improved the system efficiency.

Notation

A_c	Collector area
H	Tower height
G_h	Average solar intensity
P_{tot}	Pressure difference produced between collector outlet and ambient air
$\dot{Q}$	Solar energy input

Greek letters

ρ_a	Air density in ambient temperature
ρ_c	Air density in the tower
η_{coll}	Collector efficiency
η_{tower}	Tower efficiency

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تأثير نوع القاعدة على درجات حرارة مدخنة هوائية في أجواء مدينة بغداد- العراق

مقدام طارق جيجان

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الخلاصة

تستخدم مدخنة الهواء أو البرج الشمسي تركيبة من مجمعات الهواء الشمسية وأنبوب سحب مركزي لتوليد تدفق هواء مسخن شمسيا" مستحث بالحمل، والذي يمكنة تحريك توربينات متعددة المراحل لتوليد الكهرباء.

الهدف من هذا البحث هو تقديم نتائج عملية لنموذج مدخنة شمسية ذو كتلة حرارية، إذ تم استبدال السطح الزجاجي بغطاء بلاستيكي شفاف، تركزت الدراسة على تأثير نوع قاعدة المدخنة على درجات حرارة الهواء، ولقد استخدمت ثلاثة أنواع من القواعد، قاعدة كونكريتية، قاعدة كونكريتية سوداءاللون وقاعدة من الحصى الاسود اللون، وتمت الدراسة في أجواء بغداد من شهر أيلول لغاية نوفمبر ٢٠٠٩.

تبين الدراسة أن أفضل كفاءة للمدخنة وأعلى درجة حرارة تم الوصول لها كانت 49.7% عند استخدام قاعدة من الحصى الأسود. وأعلى درجة حرارة للهواء المجمع أمكن الوصول لها كانت 49ºC باستخدام قاعدة الحصى الأسود أيضا، كما كانت أقصى درجة حرارة قيست لهذة القاعدة هي 59ºC، لقد تم الوصول لزيادة كبيرة في درجات حرارة الهواء المجمع مقارنة مع درجات حرارة الهواء الجوي للقواعد الثلاثة المدروسة، وأعلى فرق في درجات الحرارة أمكن الوصول له كان 22ºC بأرضية من الحصى الأسود.