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Dust and Pollution Deposition Impact on a Solar Chimney Performance

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Abstract— *The solar chimney is used to generate electricity from solar energy and consists of a solar collector connected to a chimney to generate a flow of hot air that moves the electricity-generating turbines. In this study, the effect of dust and pollutants deposition on the solar chimney prototype was studied, considering that Iraq, like many countries in the world, is exposed to dust storms several times a year and its atmosphere is loaded with pollutants from power stations, factories, and traffic.*

The results of this study showed that the cleanliness and transparency solar collector plays an important role in the performance of the solar chimney system. As dust suspended in the atmosphere or accumulated on the surface of the solar collector reduces the intensity of radiation transient through the transparent surface; the chimney is, therefore, greatly affected by dust deposition. The process of cleaning the solar collector brings back some losses of efficiency due to dust. It is found that the closer the cleaning periods are, the higher the output of the solar chimney.

Keywords— *solar chimney, dust, pollen, pollution, accumulation, deposition.*

I. INTRODUCTION

Today, the world suffers from a large population increase and excessive use of fossil fuels for energy production. The excessive use of fossil fuels has led to the emergence of environmental phenomena that did not exist previously, such as global warming and climate change [1, 2]. Both have negative impacts on entire societies and have forced these societies to think of modern ways to change the fuel used to produce energy and switch to the alternative, environmentally friendly types [3]. Oil and gas have caused the last decade the collapse of the global economy because of the volatility of their prices. Both importing and producing countries are concerned about the total dependence on oil as a unique energy source [4].

The shift to the use of renewable energies for the production of energy has become a realistic option, especially as many countries began to increase the proportion of renewable energies in the production of electric power, and this proportion is increasing. Renewable energies are diverse, including solar, wind, geothermal, biomass, and hydrodynamic energies [5]. The sun is the source of all energies, both traditional and non-traditional. The sun is the energy source that drives and generates weather systems, such as wind, hydropower and bioenergy systems. Solar radiation can also be used directly to obtain electricity using photovoltaic cells PV or by using solar thermal conversion [6, 7].

PV has proven their effectiveness and success and are becoming increasingly available at lower prices versus higher productivity [8]. The production plants of solar cells with capacities up to hundreds of megawatts have spread in many countries of the world [9]. Research is also ongoing to control the effects of environmental parameters on these cells such as the effects of solar radiation [10, 11], temperature [12, 13], and relative humidity [14, 15]. PV has high flexibility and can be operated in areas far from the grid and in rugged areas as well [16, 17]. They are also used in desert and irrigated crops on remote farms [18, 19].

The use of solar radiation in the heating of water for residential and industrial purposes in all parts of the world becomes common [20, 21]. Thermal transfer of sunlight is used in concentrated solar power plants. In these stations, mirrors reflect the sun's rays and focus it to a specific goal and raise the temperature to hundreds of Celsius degrees to use this temperature in the production of steam that operates turbines and generates electricity [22, 23].

The solar tower or solar chimney can be considered a new development in solar energy. In this system, electricity is generated by the use of solar radiation [24, 25]. The solar chimney collects the heat at the bottom of the collector and depends on heating it on the sun's energy only [26]. Heating causes air to expand and because the air outside the pool is cooler. If it is more intense, the less intense hot air is forced to move through the solar chimney, marching wind turbines [27, 28].

The solar collector that processes the air through solar radiation consists of a transparent circular surface and an open surrounding [29]. The solar collector consists of the transparent surface, which represents the roof and its base is the natural ground [30]. A vertical tower with a large entrance is installed at its base in the middle of the roof. The joint between the roof and the tower base is airtight [31]. As the hot air is lighter than the cold air it ascends the tower. Suction of the tower then draws in the hot air over the collector, and the cold air comes from the outer perimeter [32]. Because of the greenhouse effect, the air is heated in the solar collector. Warm air moves from the periphery of the solar collector towards its center, in order to "escape" to the upper layers of the atmosphere through the solar chimney (Figure 1). This moving current of warm air leaves part of its thermal energy to the wind turbines that are routed with the appropriate generators [33, 34].

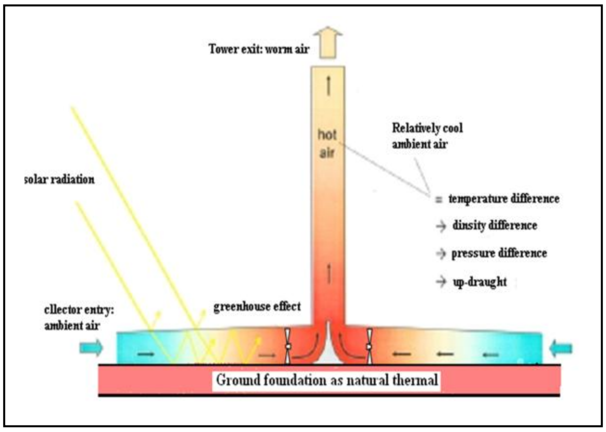

Fig. 1. Solar tower working principles

The solar chimney is characterized by its collector's ability to benefit from direct and indirect solar radiation, so it is useful in countries with overcast skies such as tropical countries [35, 36]. The solar chimney is characterized by a simple and solid structure and requires little maintenance and no moving parts or flammable fuel [37]. The solar towers do not need cooling water as in CSP stations [38]. The solar collector soil acts as a natural heat storage system, allowing the plant to operate for 24 hours with a partial reduction in production at night [39]. This reduction can be compensated by the supply of water pipes or capsules with variable phase material to increase thermal storage and use at night [40].

Dust is a real dilemma for some countries in the world, including Iraq [41]. This country has been subjected to several aggressive wars over the last four decades and an unjust economic siege for 14 years, which has destroyed the country's infrastructure [42]. In addition to this great destruction, drought and rain break have continued for twenty years, turning Mesopotamia into a sandy basin from which the dusty and sand storms reach the neighborhood [43].

Dust is characterized as one of the enemies of solar systems, it reduces the intensity of solar radiation reaching the solar system, and the accumulation on the surface prevents the light from entering into it [44, 45]. Dust acts like the shadow work on the solar system as it reduces the solar rays reaching the system [46, 47]. Dust varies from region to region according to its physical and chemical characteristics [48, 49]. The origin of the area from which the dust is rising has a major role in determining its specifications. Air pollution in large cities and overcrowded by power plants, refineries, and factories, in addition to the momentum of traffic can be added to the dust as an influential factor in solar systems [50, 51]. The accumulation of soot and hydrocarbons suspended in the atmosphere on the surface of solar systems can reduce the performance of these systems very much [52]. This study focuses on the study of the effect of the accumulation of dust and air pollutants on the surface of the solar collector of an air chimney on the performance of this chimney. Baghdad is the capital of Iraq is considered a part from the areas that are severely affected by the rise of dust and sand for many days during the year [53]. It is also a city crowded with locomotives, power stations, and factories, as well as millions of personal and public generators that are used to compensate for the severe shortage of electricity supply, which makes it as a city with high polluted air [54, 55].

II. EXPERMINTAL SETUP

In this study we build a solar chimney with the measurements shown in Fig. 2. The solar chimney consists of a circular solar collector with a diameter of 6 meter, which heats the air using the theory of the glass house and uses solar radiation passing through the transparent roof of the collector. The surrounding area is opened with 2 cm high from the floor. Thus the solar collector is composed of the ceiling and the floor. The 4 meters long and 20 cm in a diameter chimney was installed in the middle of the roof. The height of the chimney shall be about 10 cm high and the floor and its joint with the transparent roof was sealed.

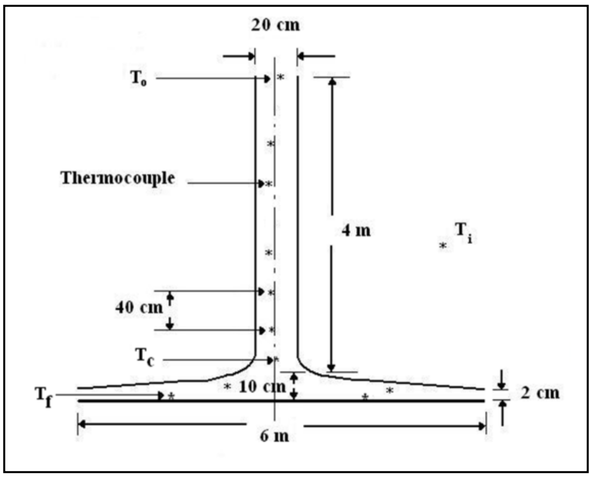

Fig. 2. Schematic diagram of the solar chimney and thermocouples distribution.

In order to measure air temperatures in different areas of the air chimney, several thermocouples type K were used. Six of these thermocouples were fixed under the transparent lid and distributed regularly around the chimney as Figure 2 shows. Six thermocouples were used to measure the temperature of the air rising through the chimney and distributed at equal distances (Fig. 2). The first thermal temperature in the group represents the combined air temperature (TEC). The temperature of the air entering the chimney (TA) was measured outside the chimney in the shadow. The temperature of the basement was measured by three thermocouples distributed evenly. The average of these thermocouple readings was taken as (Tv). Figure 3 shows a photograph of the solar chimney used in the study.

The air flow measuring device has eight (8) blades type Homis anemometers; it is equipped with a 50 mm dia. fan. The device was calibrated and the wind sped was taken into concentration during calibration. An apogee meter pyranometer was used to measure the solar radiation during the testing period.

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Experiments were conducted in the spring of 2017 in the atmosphere of the Baghdad-Iraq; the spring period in this city is characterized by continuous dust storms and the amounts of dust and pollen suspended in the atmosphere at the highest values compared to the other seasons. Experiments were conducted on three cases:

Fig. 3. The solar tower's prototype

The first case: When the chimney is completely clean and no dust was accumulated on it, to make sure of this, a blower was used three times during the night to prevent the deposition of suspended dust on the solar collector. The heated air temperature resulted from this chimney was coded (T_{cleen}).
Second: the dust was left to accumulate on the solar collector for a week, and the temperature readings were then measured. The heated air temperature resulted from this chimney was coded ($T_{Polluted}$).
Case 3: The solar collector was cleaned by washing it with water only in the morning of each measuring day. The heated air temperature resulted from this chimney was coded (T_{Washed}).

For each case, the readings were measured for three consecutive days, provided that the atmosphere is bright and without clouds and take the arithmetic average of the readings to ensure the fairness of the repeatability and reduce the uncertainty to the minimum.

A. The Solar Chimney Performance Calculations

The solar chimney system consists of three main parts: the transparent collector, the chimney, and the turbines. Wind turbines were not used in this study for technical reasons related to the budget. Therefore, the solar chimney was concentrated on the thermal energy generated in the different parts of the solar chimney. The main function of the solar chimney is to convert the heat stored in the air and ground into kinetic power. The efficiency of the system is supported by the equation:
Total system efficiency

$$= \eta_{coll} \cdot \eta_{tower} \cdot \eta_{turbine} \quad \text{... (1)}$$

As there was no turbine used in this study, the focus was concentrated on the collector efficiency which can be calculated by the equation:

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

Ptot - depends on the air density differences resulted from heating the air inside the collector area, and it is calculated by the equation:

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

From P_{tot} equation it is clear that increasing the solar tower height increases the P_{tot}. The solar energy, which is the input energy, can be calculated by:

$$\dot{Q} = I_h \, . A_c \quad \text{... (4)}$$

This efficiency was used to compare between the three studied cases.

III. Results and Discussions

The general idea of the solar chimney is to transfer the solar energy found in the solar radiation through a transparent cover. This energy is absorbed by the earth, causing it to be heated. A large part of the energy stored in the earth will move into the surrounding air through the open surrounding and let it out through the chimney [56, 57]. Unlike other solar systems, such as solar concentrating power stations, which require direct solar radiation, the solar chimney system can benefit from direct and diffuse radiation. So, the solar chimney works in the clear or cloudy or dusty days [58, 59].

Fig. 4 shows the solar intensity distribution with daytime. Because of the use of one solar chimney in the experiments for the reasons given earlier, the intensity of solar radiation, which varies from day to day, will play an important role in the output of the solar chimney. The first experiments were carried out on a completely clean chimney, and a clean transparent plastic cover was used for this purpose. To make sure that no dust accumulated on it, it was blown several times during the day by an air blower. Measurements of this chimney were taken for the period from March 11 to 13. Solar radiation in these days is high compared to many countries of the world, as Iraq is located near the solar belt region. After taking the required readings, the suspended dust in the atmosphere was allowed to deposit on the transparent envelope for ten days, after this period, measurements on the polluted chimney were taken. The solar radiation readings were measured for the period from 22 to 24 March. It is noted from the figure that solar radiation during the measurement days was clearly lower than the clean chimney readings, because of the increase of suspended dust and pollen concentration in the atmosphere during this period. The atmosphere during the subsequent period was shinier and clean, in which the solar radiation of the washed chimney was measured from 27 to 29 March. It is noted that the intensity of solar radiation increased during the 20 days period of experiments, which means that this country is very suitable for the use of solar applications all without any doubt in success.

The difference in temperature between the solar collector and the ambient air reached 22°C at 1 PM. in spite of the limited measures of the collector studied. It is this difference in temperature that generates the driving force of airflow and can be expressed by the effect of the greenhouse effect because of the solar collector.

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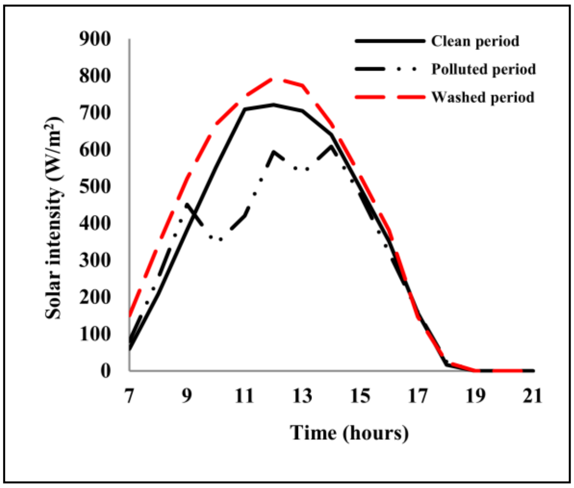

Fig. 4. the solar intensity distribution through the measuring period

The air temperature difference between the chimney and the surrounding air causes pressure differentials and the movement of hot air to the top out through the chimney orifice. Fig. 6 shows the average air velocity out of the chimney nozzle for three studied cases. The explicit relationship between temperature and the velocity of air outside the chimney is cleared. Ref. [61] indicated that to achieve the highest natural convection rate of the chimney needs to have many modifications to the compound relationship between the collector and the chimney orifice in actual conditions.

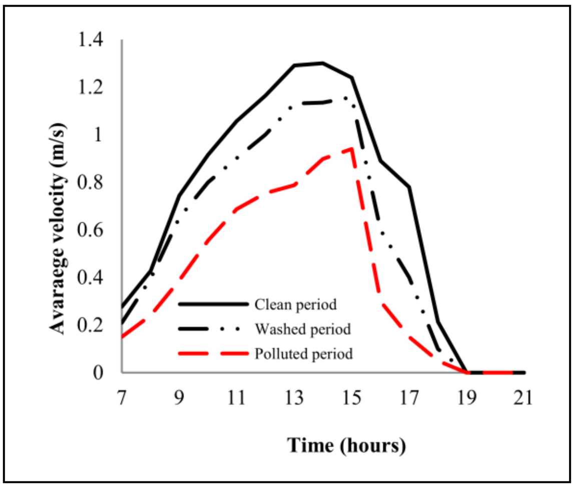

Fig. 6. The average air velocities distribution through the day

The output power of the chimney depends on the speed and temperature, for this reason the clean chimney had the highest level, as Fig. 7 declares. As for the polluted chimney, the resulting power was the least. This means that the power of this system will be greatly affected by the accumulation of dust and should be cleaned continuously and at intervals that converge and diverge according to season. In the spring and autumn of Baghdad, dust storms intensify and increase the pollutants deposition, so the cleaning period should be more frequent than winter and summer seasons.

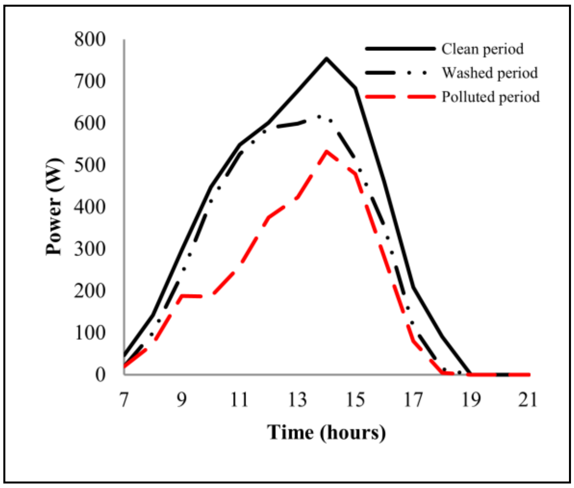

Fig. 7. The studied chimneys output powers distribution through the day

Fig. 8 shows the studied solar chimneys efficiencies during the day. The more transparent and cleaner the collector, the higher system efficiency will be achieved. Although the components of the solar chimney are simple, the cleanliness of the solar collector has the greatest impact on the resulting efficiency. Working in dusty atmosphere and allowing the accumulation of dust, even for a short period such as ten days in this case, caused a significant reduction in efficiency, as the figure indicates.

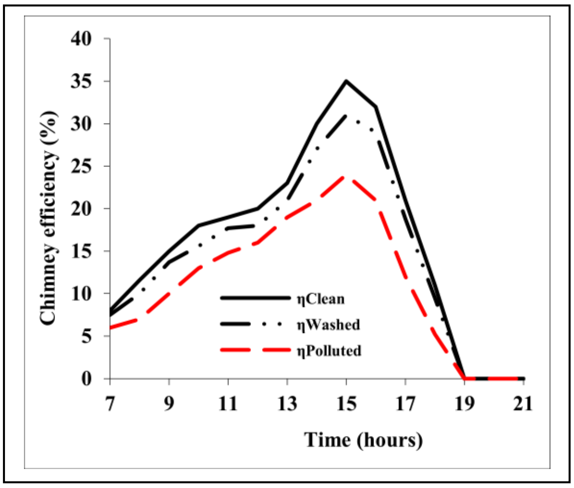

Fig. 8. The solar chimneys efficiencies distribution during the day

IV. CONCLUSIONS

In this study, a prototype of solar chimney was constructed to investigate the effect of the accumulation of dust on the chimney's collector on the performance of the chimney, in the area of the city of Baghdad-Iraq. For this purpose, the solar radiation, ambient temperature, resulting power, and system efficiency were also studied. The results showed that the rise of dust in the atmosphere causes a reduction of the solar radiation coming to the system, as well as its accumulation obscures the sunlight and reflected in a significant decrease in the system performance. The process of washing the system

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from the top proved to be insufficient as the dust and contaminants can stick to the bottom of the transparent collector and reduce the penetration of solar radiation, and then decrease the performance and efficiency of the system. Cleaning the solar collector is necessary to restore some of the efficiency lost due to accumulation of dust and air pollutants. This cleaning should be done at intervals that converge or diverge depending on the conditions of the dust in the air. To insure that the solar chimney has the highest performance and efficiency, it is preferred to clean the collector at intervals of not more than two weeks after while it must be cleaned directly after each dust storm.

Notation

A_c collector area
H tower height
I_h Average solar intensity
P_{tot} Pressure difference produced between collector outlet and ambeint ait
$\dot{Q}$ 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
$\eta_{turbine}$- Turbine efficiency.

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