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Abstract- **The problem of energy source depletion with the restricted regulation about the emissions make the need for other alternative sours of energy is a worldwide demand. The solar chimney power plant (SCPP) is an optimistic solar energy technology that produces electrical power. In this paper, a 2D analytical study is offered to evaluate the working of the SCPPs' performance with the varying ground material. Sand, concrete, asphalt, and saturated sand will be used as absorber materials in this study. The Numerical model was done with the realizable k-ε turbulence model and the discrete ordinates (DO) solar load model. The model's chimney diameter is 200 mm, collector diameter is 3000 mm, and chimney height is 3500 mm. The model's collector height is 70 mm. It gave the magnitude velocity contour, moving air temperature, pressure, and turbulence characteristics for each unique case. Based on the highest air velocity value inside the SCPP and the resulting power output, the optimal material is chosen.**

Keywords- **CFD, SCPP, solar chimney, simulation, Absorber, absorber material, saturated sand, ANSYS.**

I. INTRODUCTION

The problem of energy source depletion with the restricted regulation about the emissions make the need for other alternative sours of energy is a worldwide demand [1-6]. For this task, a new fuel was suggested to be used as an alternative source of fuel for internal combustion engine [7-11]. However, a new technology for producing a low cost and low pollutant emission has been suggested by many researchers [12-14]. In this work, the combustion process is controlled to be leaner and lower in the average temperature inside the engine cylinder. The fuel introduced into the engine cylinder was prepared in a certain form to enhance the combustion principle of HCCI combustion [15, 16]. The Egyptian state's effort to promote resources of renewable energy and connecting them to the production network and using them in national projects reinforces the importance of development and research in all energy sources, foremost among them is solar energy, which is abundantly available throughout Egypt, one of these technologies is the solar chimney. Interest in renewable energy sources has increased recently, with the state moving strongly towards green hydrogen technology and establishing many factories to produce it[17], which requires a renewable source of electrical energy. The SCPP is a fantastic invention that uses solar radiation as its energy source to power a turbine and produces electricity. However, since its creation, one of its main goals has been to produce energy both during the day and at night. Due to how the earth beneath the collector behaves as a heat storage system, it is crucial for energy absorption and heat transport. Many researchers working to improve the efficiency of the total plant by enhancing the chimney design or collector layers and area. This work focused on Spreading the operation time by using the absorber as a heat storage intermediate. The findings showed that different materials had different capacities for storing heat. Since SCPP's development, one of the goals has been to generate energy both during the day and at night. Due to its inherent properties as a heat storage system, the earth beneath the power plant is significant to the energy balance. The materials that were selected were based on their availability in Egypt, their cost, and Application possibility. Depending on their chemical structure, certain materials may store heat. For instance, water has an enormous capacity for heat storage. It also takes a long time to heat up, while metals heat up rapidly because they transmit heat effectively[18]. However, metals aren't particularly excellent at retaining heat. Materials with high specific heat are believed to hold heat well. For instance, water has an extremely high specific heat value. It thus absorbs a significant amount of energy before changing temperature. As opposed to this, sand and asphalt both have lower specific temperatures. They experience quicker temperature changes as a result.

Solar chimneys employ three well-known ideas the greenhouse effect, hot air rising, and alternatively utilizing wind turbines to turn solar energy into electricity. Using the natural convection mechanism, the hot ground raises the air temperature and forces it to flow up into the plant's chimney. The adiabatic walls cool the hot air as it travels up the chimney. The pressure difference between the chimney inlet and outlet can occur to the air density difference[19]. The pressure differential that powers the turbine might be lessened due to the friction loss within the chimney. The kinetic energy of the air that passes through the turbine powers the turbine blades and the generator, shown 'Fig. 1'.
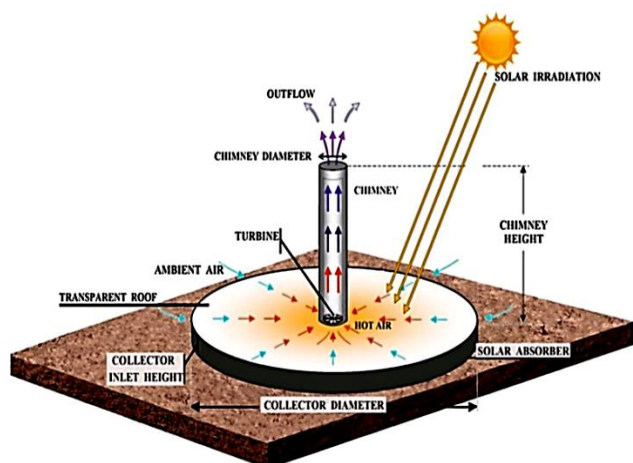
Figure1. solar chimney working principle with components [20]

A. Solar Chimney Components

a) Collector

The collector, which is the section that uses the greenhouse effect to produce hot air is constructed from glass or plastic. The air enters the chimney with no loss due to friction since the center of the collector is smoothly linked to the chimney intake. This substance permits short-wave radiation while shielding long-wave radiation from the heated ground. As a result, the airflow from the collector intake to the chimney is heated radially by the ground beneath the collector. Solar radiation is the energy that the sun emits, and solar irradiation is the quantity of solar radiation that the planet receives on a per-area basis and is measured in (kw/m2).

b) Chimney

The central component of the SCPP is a chimney. The plant's thermal engine is the tower, which is located in the collector's center. The temperature differential between the top and bottom of this tower is created. The air is moved from the bottom to the top thanks to the chimney effect. Setting the turbine in the chimney as low as possible will also help us build it more quickly[21]. The chimney can be built in a variety of ways, including:

• Free-standing tubes made of reinforced concrete.

• Steel tubes that are held aloft by cables or wires.

• Guyed steel encircled by grids of steel wires or trapezoidal Metal films can also be used to build it.

c) Turbines

The solar chimney turbine is a crucial component since it transfers the air's kinetic energy to the generator. Due to the turbine pressure drop and the plant's mass flow rate being correlated, it has a significant effect on the plant. The turbines

in solar chimneys are ducted, therefore their theoretical maximum efficiency is 100%. The airflow continues in the same direction. Solar radiation is the energy that the sun emits, and solar irradiation is the quantity of solar radiation that the planet receives on a per-area basis and is measured in (kw/m2).

B. Advantages and Disadvantages

The following section mentions the advantages and disadvantages of producing power using SCPP compared to other sources.[22]

Advantages.
a) SCPPs employ both beam and diffuse radiation.
b) Due to the absorption effect, the plant may still generate power at night.
c) Construction materials for the plant are available and inexpensive.
d) The factory can run without using height technology.
e) The facility does not operate with fossil fuels and emits no emissions. As a result, the facility wouldn't be impacted by an increase in fuel prices.
f) Solar radiation is a dependable supply in appropriate locations, such as arid regions. As a result, the electricity generated won't fluctuate as it would with systems like wind energy generating.
g) The plant's operational lifespan is prolonged (at least 80 - 100 years).
h) SCPPs don't need any cooling water.
i) Low maintenance cost.

Disadvantages.
a) SCPPs must be built on a massive scale to be economically feasible. Its magnitude results in a significant initial capital expense.
b) Throughout the day and year, the output wattage varies. The output power during peak demand periods is low while electricity production is high at low demand times.
c) c) The construction of the plant requires an enormous number of materials. Such sums could result in logistical issues.

C. Previous Researches

In 2002, Shyia analyzed an actual sample of a solar chimney with five different types of absorbing ground: aggregates, soil, sand soil, asphalt soil, and asphalt aggregate. He discovered that asphalt aggregate makes for the best absorption floor[23].

In 2011, Chaichan and Hussein investigated how chimney basement types affected the flow of air temperatures. Black pebbles, concrete, and black concrete were the three materials chosen. The outcomes demonstrate that the pebble base had the highest level of effectiveness[24].

In 2013, Pretorius Cao et al. evaluated the power outputs of six various ground types. They determined that higher ground absorptivity has beneficial impacts on yearly solar chimney power production and that moist soil and sand had the highest and lowest power outputs, respectively[25].

In 2014, Al-Azawie tested several ground materials for thermal storage experimentally and statistically and discovered that ceramic material performed well.

In 2015, Larbi et al. completed a numerical simulation of a SCPP using four soil configurations as an absorber. The study showed that the (water and Ground storage system with a diffuser) system was the suitable solution as it gave continuous energy generation with better efficiency.

In 2016, Penghua Guo conducted a thermodynamic study for a solar chimney and discovered that soil heat storage with high thermal conductivity and specific heat capacity will result in minimal variations in power production and updraft velocity over the course of a day[26].

In 2018 Kazem Bashirnezhad and others studied the effect of energy storage on the performance of solar chimney using some materials. They found that Using water and paraffin as thermal storage materials increased the efficiency by 6.2% and 22%, respectively in comparison to no absorber state. One year later, Sahraoui et al. and others made a numerical study on the influence of heat storage on the SCPP performance. Three absorber samples were used (Sand, Gravel, and Soil).

In 2021 Hasan Qahtan and others studied the influence of a basement inside collector on the effectiveness of solar chimney. They found that 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

In 2022 Pinar Mert Cuce and others Evaluate a Solar Chimney using Basalt and Bayburt Stone as Ground material on the Energy Storage. They found increasing by 70% on the mass flow rate with Bayburt stone. Erdem Cuce and others make a CFD Performance analysis for solar chimney with natural thermal energy storage materials on ground and they found that when the material is sand, the temperature rise in the system and gives better performance.

II.   SIMULATION Techniques

The simulation ran with the ANSYS fluent software. The first step is the model design [27]. The second step was
A.   *Material Properties.*

meshing, a 2D module designed and divided into 100.000 elements approximately with Height smoothing and curvature and proximity Capturing. The third step was setting up the fluent before starting the calculation. Table 2 describes the general setup for module le, materials properties, and solution methods. The simulation started with 1000 iterations and reached a good conversion as shown in 'Fig. 2'.

Table 1. SCPP simulation setup.

| Step	Settings
General setup	• Pressure-based solver • Steady-state analysis • -9.81 gravitational acceleration in (Y) direction
Model setup	• Realizable k-e, scalable wall function viscous model. • Discrete ordinate radiation model.
Materials setup	• Air properties Density (incompressible ideal gas) and the other specifications as standard. • Collector properties (glass) Density 2500 (kg/m3) CP is 750 (j/kg. k) Thermal conductivity is 1.15 (w/m. k) The absorption coefficient is 0.03 (1/m)
Solution methods	• Pressure-velocity coupling: - SIMPLEC scheme and second-order spatial discretization.
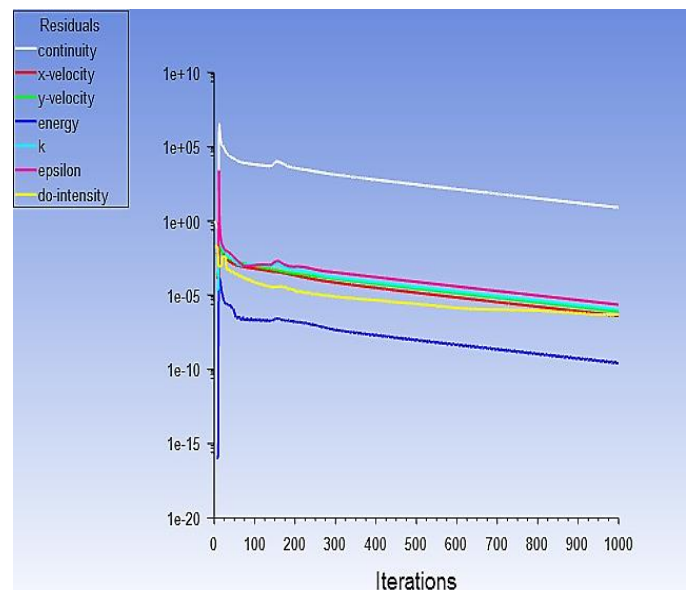
Figure2. solution conversion and iterations.

The properties of materials used in this research are described in table 1. The density, specific heat, and Thermal

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Conductivity changes in the material table for each simulation process [28].

Table 2. physical properties of used material.

NO	Material	density	Cp (specific heat) (j/kg. k)	thermal conductivity w/m-k
1	saturated sand (SS)	1922	1630	3
2	Concrete (C)	2400	1000	1.9
3	Asphalt (A)	2300	915	0.9
4	Sand (S)	1600	800	0.2

B. Simulating Assumptions

Under the ensuing presumptions, energy balance forms the basis of the mathematical model of the solar chimney [29, 30].

a) Though the performance of the power plant is transitory in nature, it is examined at steady state flow.

b) Along the collector radius, the ground temperature and collector surface both remain constant.

c) Because the Mach number is less than 0.3, the flow is incompressible and the air is an ideal gas. The pressure-based solution method is what we employ.

d) There is complete symmetry with the direction of the flow beneath the collector.

e) Between two parallel plates is where the flow under the collector occurs.

f) The heat radiated to the chimney is disregarded since the collection area exceeds the surface area of the chimney.

g) The air velocity at the wall boundary is equal to zero and the absorber surface's roughness is set to zero to simplify the solution.

C. Working and Boundary Conditions

The boundary condition is the key to this simulation and other similar simulations, the conditions described for the collector inlet and outlet, absorber, collector surface, chimney wall, and interior fluid flow as described in table 3.

Table 3. Working and boundary conditions.

position	condition
Ambient	Tair = 300 k, solar intensity = 1000 w/m2 (assuming these conditions are constant along the day time as the simulation is running as steady not transient)
Inlet	Pressure inlet, T= 300, P= 0
Outlet	Pressure outlet, T= 300, P= 0
Absorber	Wall, mixed thermal condition h= 10 / T=300, opaque
Collector	Wall, radiation thermal condition h= 10 / T= 300, semitransparent radiation model with direct irradiation 1000 w/m2, in the negative direction of (Y) beam.

| Chimney	Wall, heat flux =0, opaque

III.   RESULTS

After the solution process is completed, we get the results for the different cases we study. A result comparison will occur between the four materials for the values of pressure, velocity, temperature and T.K.E.
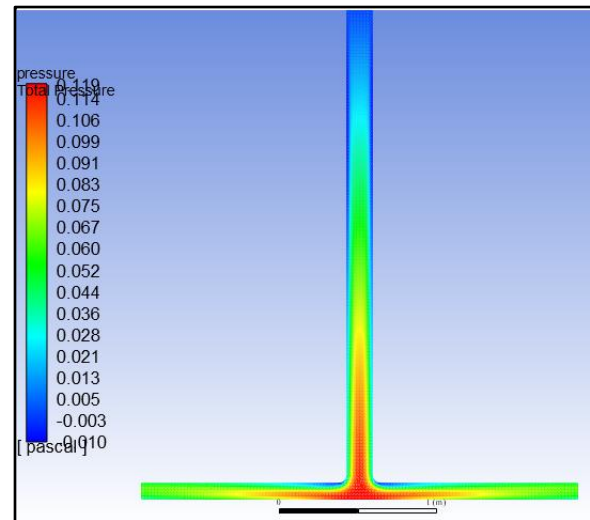
A. Pressure Scheme Comparing

The following schemes shown in 'Fig. 3', show the distribution of total pressure along the chimney. It is found

that the total pressure increased at the center of the collector as a result of the kinetic energy of airflow collected there, this increase in pressure magnitude plays an important role in the generated power from turbines. The varying materials affected the magnitudes positively but still gives the same suitable distribution. The variable values for each material play the role of making the power output different from each material to another.
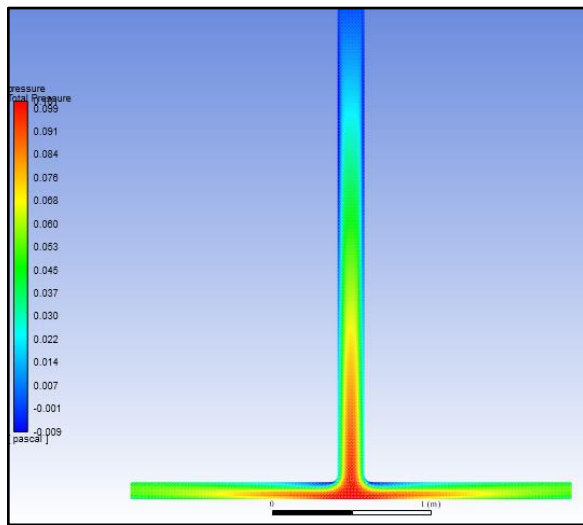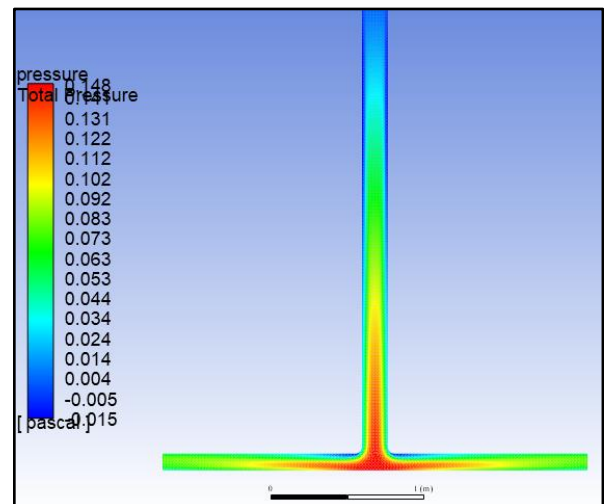

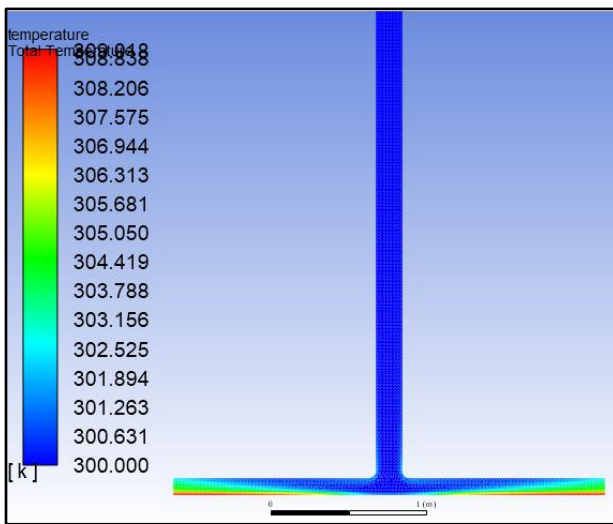(a). Sand

(b). asphalt
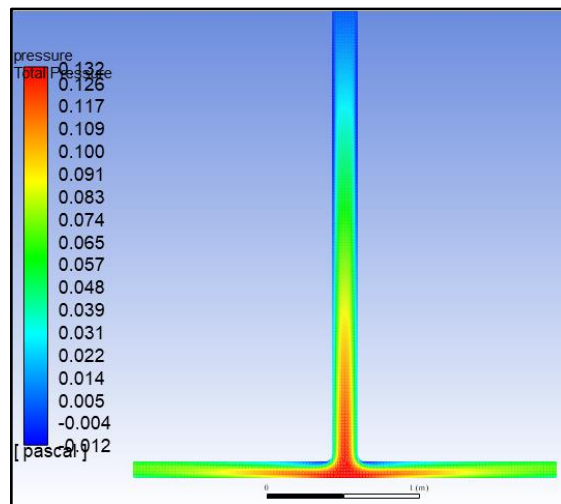
(c). concrete

(d). saturated sand

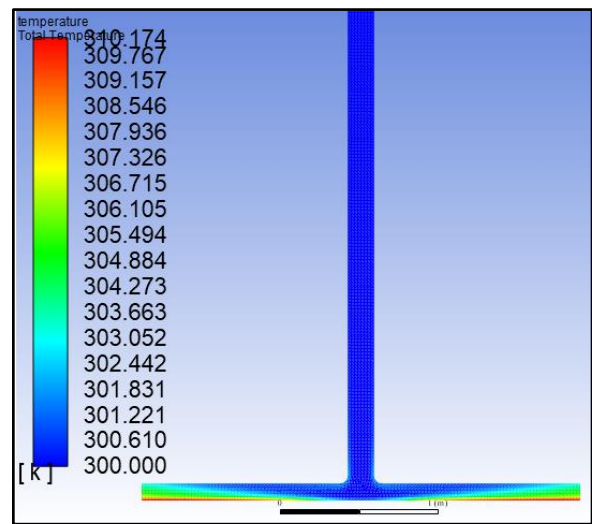**Figure 3. Pressure scheme comparing for used materials.**

B. Temperature Scheme Comparing

Results shown in 'Fig. 4'shows the temperature distribution for each case of absorber material, it is founded that the air temperature increased along the collector diameter affected by the hot absorber and then started cooling again to move up along the chimney. In the case of saturated sand, it gives the highest ground temperature as the
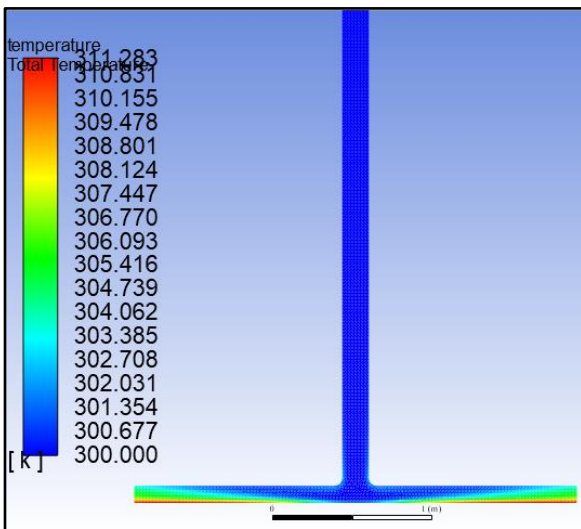
highest absorbing properties. The temperature difference between ambient air and collector air is increased due to ground materials absorbing characteristics.
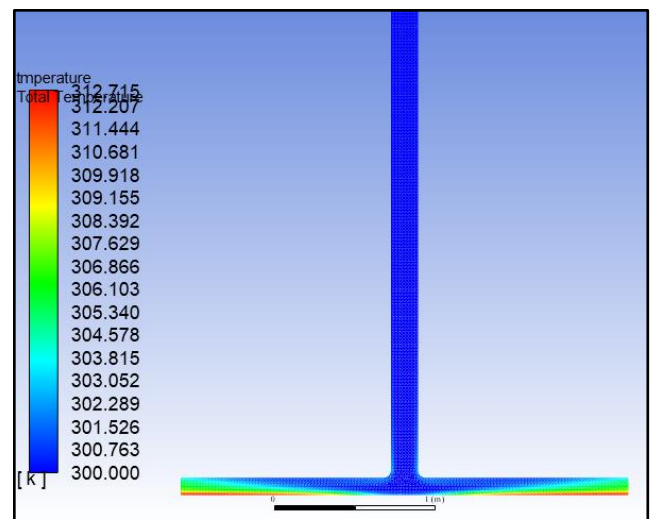

(a). Sand
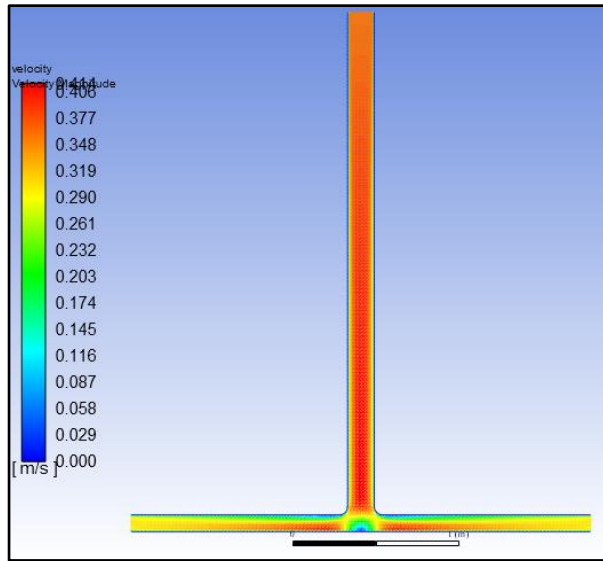

(b). asphalt

(c). concrete

(d). saturated sand

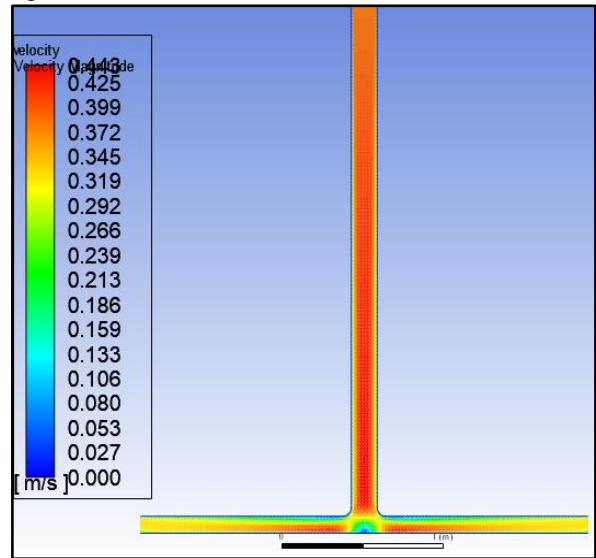**Figure 4. temperature scheme comparing for used materials.**

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C. *Velocity scheme comparing*

According to the following results in 'Fig. 5', It has been established that the magnitude velocity's substantial value always appears at the bottom of the chimney and that the

magnitude velocity values outside of the chimney are relatively faint. The magnitude velocity is measured as 0.414 m/s for sand, 0.443 m/s for asphalt, 0.465 m/s for concrete, and 0.0493 m/s for saturated sand. The magnitude velocity changes from one absorber to the next.

(a). Sand

(b). asphalt
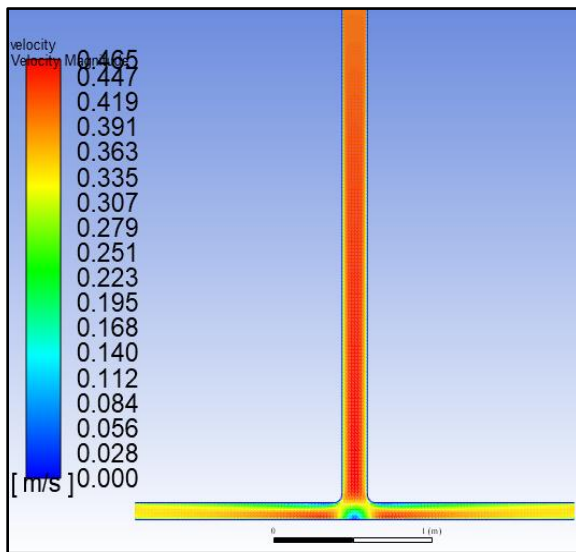
(c). concrete

(d). saturated sand

Figure 5. Velocity scheme comparing for used materials.

The following table 4 includes all results for this simulation. And here are some notes for these results.

i. The higher the collector temperature, the lower the minimum density. This is normal as the gas gets lower density with more temperatures and moves up.

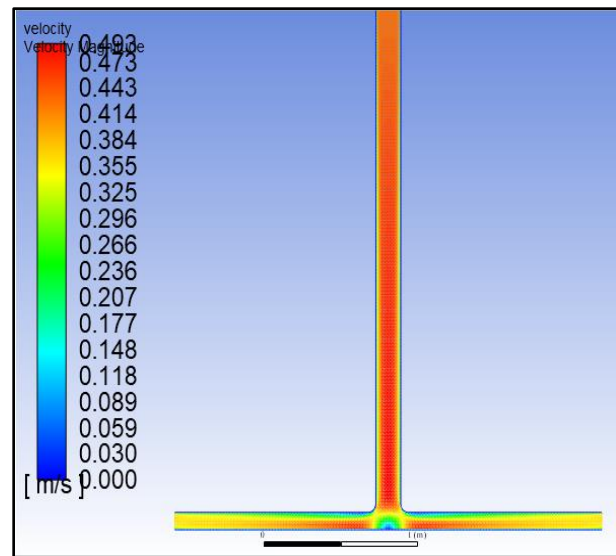ii. Turbulent kinetic energy increased with more mass and volume flow rate which can use to increase the output power from the turbine.

iii. The higher collector temperature occurs due to higher ground thermal properties which rises the temperature of more air volume and give more output power.

iv. Saturated sand gives the best performance as a ground material as it gives the highest power along the day as shown in 'Fig. 6'.

Table 4. all results for studied materials.

| Material	Saturated Sand	Concrete	Asphalt	Sand
Pressure (pa)	(-0.015 - 0.148)	(-0.012-0.132)	(-0.010 - 0.119)	(-0.009 - 0.101)
MAX Temperature (K)	312.715	311.283	310.174	309.018
MAX Velocity (m/s)	0.493	0.465	0.443	0.414
Density Range (kg/m3)	(1.129 - 1.177)	(1.134 - 1.177)	(1.138 - 1.177)	(1.143 - 1.177)
T.K.E (m2/S2)	0.006	0.005	0.005	0.004
Mass Flow Rate (kg/s)	0.079	0.075	0.071	0.067
Output power (KW)	2.09690	1.75953	1.52142	1.24176
Overall efficiency	0.0714	0.0628	0.0542	0.0428
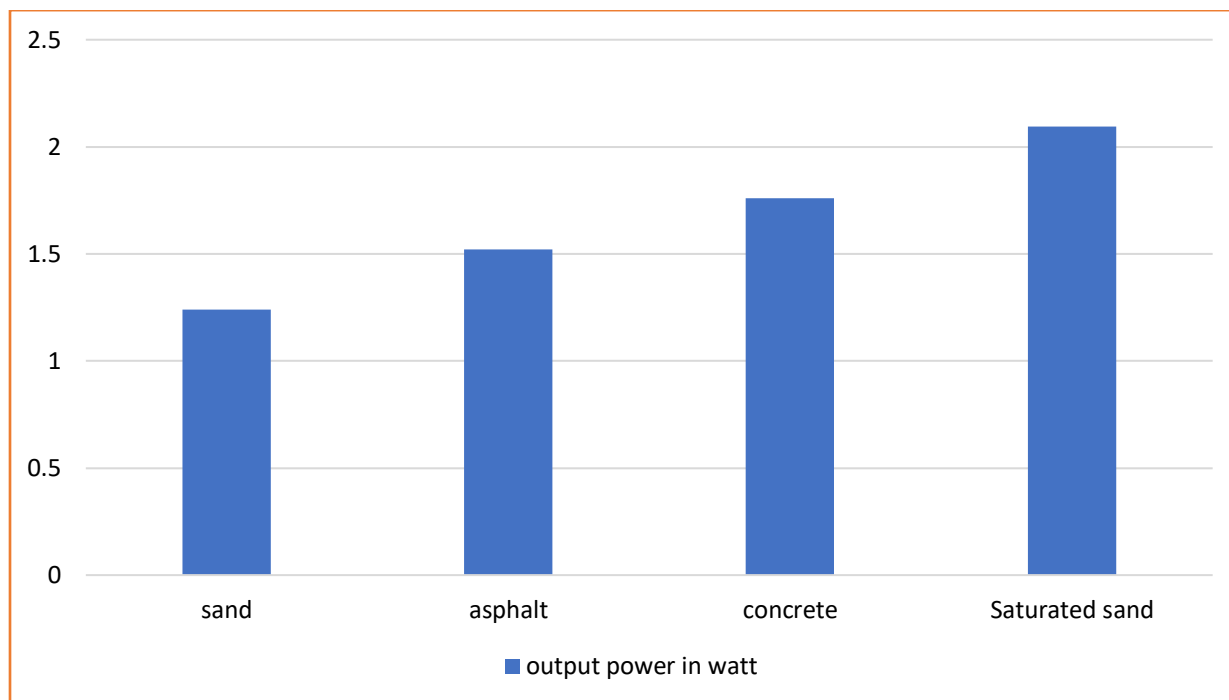
Figure 6. output power chart.

IV. VALIDATION

As shown in in table 5. There is a remarkable convergence in results between this study and other studies that highlights the effect of absorber material on the overall planet efficiency. Asphalt and concrete presented better performance than sand but saturated sand is the pest solution and valid to apply in physical or social world. The little pit difference is caused by the difference in model parameters, as it known that solar chimney achieves more performance with large scales.

Table 5. cobbering between this study and other results

Material	Efficiency (other studies)	Efficiency (this study)
sand	0.049	0.042
asphalt	0.059	0.054
concrete	0.066	0.062
Saturated sand	0.069 (for saturated gravel)	0.0714

V. CONCLUSION

In this work, multiple absorber material performances with diverse thermal properties are presented. The most effective material for absorbing solar radiation and storing heat was studied among four locally accessible materials in Egypt. According to the analytical investigation, saturated sand performed better at converting solar radiation into thermal energy and producing buoyant air in the system. The air velocity reached 0.493 m/s in the case of saturated sand which, respectively increased the power output, saturated sand has the advantage of water absorptivity as its content of water, the limitation of using water as an absorbing surface is the mechanical design for a such system which prevent the vaporizing and cost of such system is very high. Instead of this system, the water content in saturated water plays this role with low cost and simple design.

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