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Difference of Solar Chimney System Chimney Designs and Numerical Modeling in Collector Surface Areas

Adem YILMAZ, Sinan ÜNVAR, Ali Serkan AVCI, Bünyamin AYGÜN

Abstract - In this study, numerical analysis in different designs has been developed for performance analysis of solar chimneys. The temperature and velocity values that affect the efficiency of solar chimney were analyzed for different chimney designs and collector surface areas. For chimney designs, 45^o inclined, 75^o cone and 75^o V flue types were compared with the standard 90^o flue type. In addition, the effects of collector surface area and chimney height on the system were investigated for vertical chimneys. The simulation of the Solar Chimney was performed with the Energy 2D program based on computational physics. In the simulations obtained, it was found that the chimney slope increased the air velocity value at the chimney inlet but no increase value was observed for the cone, V type and 45^0 inclined chimney types which is one of the most important parameters in determining the turbine power value. It was analyzed that the increase in collector surface area significantly increased the temperature and velocity values of the air flowing from the collector mouth inlet to the center. As a result, when the different chimney designs were compared, the most important factor affecting the performance of the solar chimney was the chimney length and the collector surface area.

Index Terms Solar energy, solar chimney, numerical modeling.

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1 INTRODUCTION

TODAY, as a result of expanding economic growth and rapidly increasing quality of life, it is seen that there is a rapid increase in demand in all areas of the energy sector in our country. Referring to the figures Developments G20 countries in 2015 between China and the fastest growing electricity demand growth rate in Turkey is the third country after India, which is designated as an annual average of 5.5% over the last 13 years. National Renewable Energy Action Plan within the scope of Turkey's total energy consumption for 2023 is estimated at 1.2 trillion MWh and is expected to be met from renewable sources 252 billion portion of this consumption Mwh [1].

- Adem YILMAZ, Batman University.Batman, Turkey, E-mail: adem.yilmaz@batman.edu.tr
- Sinan ÜNVAR, Ağrı İbrahim Çeçen University, Ağrı, Turkey, E-mail: sunvar@agri.edu.tr
- Ali Serkan AVCI, Batman University, Batman, Turkey, E-mail: aliserkan.avci@batman.edu.tr
- Bünyamin AYGÜN. Ağrı İbrahim Çeçen Üniversitesi, Ağrı, Turkey, E-mail: baygun@agri.edu.tr

Although solar and wind power generation from renewable energy sources is rapidly increasing, fossil fuels continue to account for the majority of global total final energy consumption. As of 2016, modern renewable energy sources (excluding the use of traditional biomass) account for about 10.4% of total final energy consumption. The largest portion of these energy sources is electricity generation with 5.4% and most of them are hydroelectric energy (3.7%). In 2017, 2.9 billion kWh of electricity was generated from solar energy in our country. As of the end of June 2018, the total installed capacity of 4,703 MW unlicensed and 23 MW licensed PV solar power plants in Turkey is 4,726 MW [2].

Devices that convert solar radiation into electricity by various methods are called solar energy production technologies. Solar chimneys is a system that develops and increases efficiency among these technologies. The solar chimneys, which consist of a large collector greenhouse and a central chimney, produce hot air by the sun (direct and diffuse ray) under a large glass collector. The heated air moves towards the chimney in the center of the collector and is drawn upwards. This traction drives the wind turbine installed in the chimney. Kinetic energy is converted into mechanical energy and thus electrical energy is obtained. Recently, the fact that solar chimney power plants are suitable for generating electricity in deserts and regions rich in solar radiation, producing electricity 24 hours a day, not needing cooling water, and ecological damages make these systems advantage. The most important disadvantage of the system is that its overall efficiency is relatively small. For example, considering the commercial application of a solar chimney power plant with an output power of up to 100 MW, the chimney should be approximately 1000 m and the collector diameter should be several kilometers [3].

Many studies have been done in the literature about theoretical modeling and simulation of solar chimney power plants. The data obtained in some studies were compared with the results of the experimental study.

Hannes et al. presented a solar chimney plant with an inclined collector area and a model showing the general condition of humid air [4]. Kiwan et al. produced distilled water by direct evaporation of water using the same geometry as a conventional solar chimney plant. Mathematical model has been developed and theoretical analysis has been done for the proposed system [5]. Toghraie et al. examined the effects of geometric properties on solar chimneys numerically [6]. Rabehi et al. presented the numerical simulations and design of the solar chimney power plant adopting the fan model in this study [7]. Ayadi et al. emphasize the effect of chimney height on local characteristics of air flow in solar chimney power plant [8]. Najm and Shaaban presented a detailed numerical survey of solar chimney power density under different operating conditions [9]. In addition, Das and Chandramohan developed a 3D numerical model to estimate and analyze the flow and performance parameters of the solar chimney plant [10].

In this study, efficiency of 4 different chimney types were analyzed. For each simulation, the same ambient conditions and material properties were chosen except for the chimney designs. Temperature and velocity values were evaluated to evaluate system performance.

2 METHODOLOGY

Simulation of Solar Chimney; The Energy2D program, based on computational physics, was simulated using three modes of heat transfer (conductivity, convection, and combining with radiation and particle dynamics). The Energy2D runs very fast on most computers and eliminates the switches between preprocessors, solvents and processors typically required to perform computerized fluid dynamics simulations. It allows you to design "computational experiments" to test a scientific hypothesis or solve an engineering problem without resorting to complex mathematics [3].

In this study, temperature and velocity parameters were investigated. For all simulations, the irradiation values are fixed and the instantaneous solar irradiation value is taken as 600 W / m^2. According to this; ambient air temperature was determined as T_0 = 273K. Since the chimney wall was assumed to be insulated, the chimney was considered adiabatic. The collector glass surface is selected as translucent and the convection limit between ambient air and air is taken into consideration. The defined physical boundary condition values are given in Table 1.

TABLE 1
PHYSICAL PROPERTIES OF MATERIALS

Physical Property (Unit)	Collector	Ground	Chimney
Density (kg/m^3)	2700	1441	2100
Thermal conductivity (W/mK)	0.96	0.5	1.4
Self heat (J/kg.K)	840	830	880
Absorption Coefficient (1/m)	17	0.5	0.5
Transmission Coefficient (1/m)	1	0.1	0.1
Emission (Radiation Power)	0.9	0.89	0.71

In order to calculate the output power of Solar Chimney Systems, it is necessary to calculate the speed and temperature values together with the physical quantities in the system. In addition, the type of flow should be determined. When the turbulent flows are examined, in natural convection, the power of the flow caused by the buoyancy force is measured by the Rayleigh number:

$$Ra = \frac{g\beta\Delta T L^3}{\vartheta_a} = Gr \times Pr \qquad (1)$$

Here, ΔT is the maximum temperature rise in the chimney. a, β and L are thermal diffusivity, thermal expansion coefficient and collector height respectively. Gr and Pr indicate the Grashof number and Prandtl number respectively. After the preliminary calculation, the number of Ra was found to be higher than 10^9. Therefore, it is considered that the turbulent mathematical model is suitable for defining the flow within the prototype. Pressure drop in solar chimneys;

$$\Delta p = \frac{1}{2}\rho V_{t,max}^2 \qquad (2)$$

Where $V_{t,max}$ is the maximum air velocity in a chimney without a turbine. Equation. (12) and (13) are used to calculate the turbine power output and collector efficiency respectively [11].

$$P = \eta_t \Delta P_t Q_v \qquad (3)$$

$$\eta_{coll} = \frac{c_p \dot{m} \Delta T}{\pi r_{coll}^2 I} \qquad (4)$$

η_t is turbine efficiency, ΔP_t is turbine pressure drop, Q_v volume flow rate m is the mass flow rate, ΔT, temperature increase through the collectorThe r_{coll} collector radius I is solar radiation. Turbine efficiency was taken as 0.8 [12].

3 RESULTS AND DISCUSSION

Chimney types were examined for performance analysis of Solar Chimney. For each design (45° inclined, 75° cone type, 75° V flue types and standard 90° flue type) temperature and speed values are discussed. The most suitable chimney type in terms of system efficiency was investigated by simulating with Energy 2D program. In the simulations, the material structure of the chimney and collector and the ambient conditions are the same. However, although different types of chimney slopes and designs are selected, collector length, collector inlet port, chimney inlet diameters and chimney lengths are equal. Table 2 shows the physical quantities of the solar chimney.

TABLE 2
SCPP DIMENSIONS

Physical Properties	Length (m)
Chimney length	7
Diameter of chimney	1.2
Chimney wall thickness	0.2
Height of the chimney center from the ground	6.3
Collector diameter	2
Wall thickness of collector	0.1
Height of collector center from ground	2.8

Figure 1 shows the simulation image of the chimney type with 45° slope. In the simulation, an increase was observed in the temperature values opposite to the slope side. This is due to the heated air flow as the wind is drawn further in the direction of inclination.

Figures 2 and 3 show the velocity and temperature values of the 45 ° inclined chimney type. The highest temperature values were observed at T1 and T2 points opposite to the slope. The maximum temperature is 39.3 ° C. As the flue inlet temperature (T3) remains in the shade area against solar radiation, the temperature values are relatively low at this point, the max temperature value is 17.2°C. The highest speed was observed at the A4 and A3 speed points in the opposite direction of the slope. The max speed value at point A4 is 0.04 m / s. The simulation of a cone-type chimney with a slope of 75o is shown in Figure 4. With this design, it was desired to further increase the vacuum effect for the chimney which gradually shrinks upwards. When the temperature and velocity of the cone type chimney with a slope of 75 o was examined, the highest temperature value was observed to be 26.3 °C at T2 points.

For the flue inlet temperature (T3), the max temperature value is 14.1oC. The maximum speed value at the chimney inlet (A1) is 0,043 m / s. Temperature and speed graphs for this simulation are shown in Figures 5 and 6.

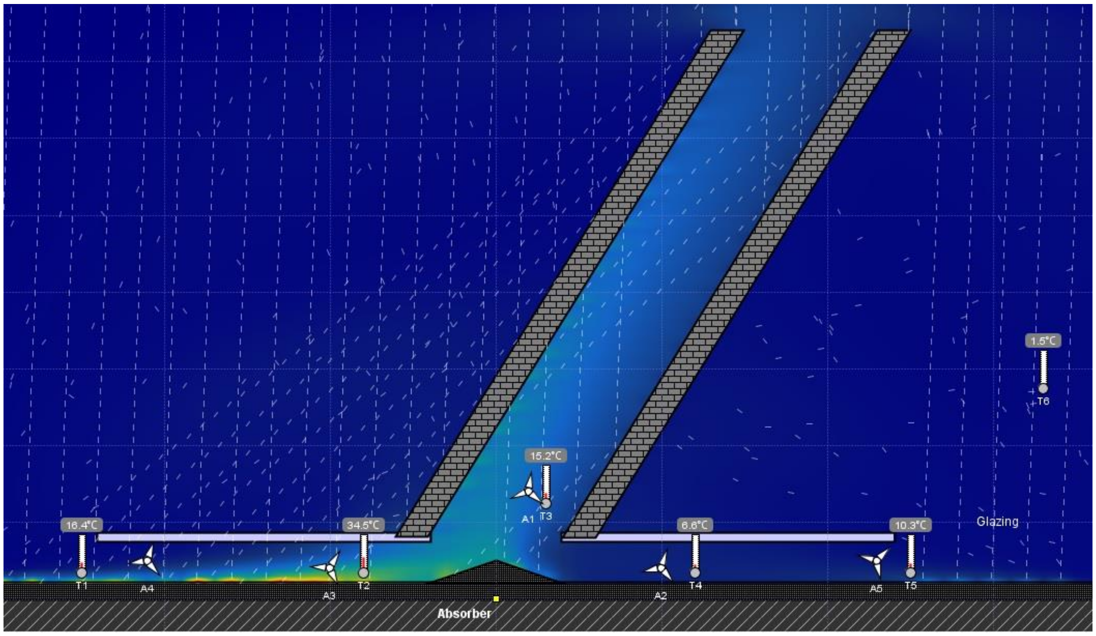

Figure 1. 45º inclined chimney type simulation.

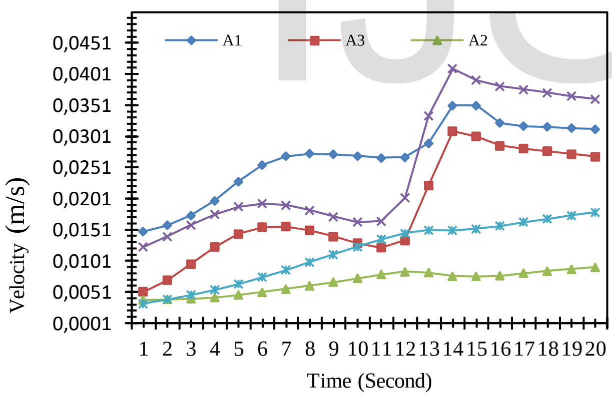

Figure 2. Velocity values of chimney type inclined to 45º.

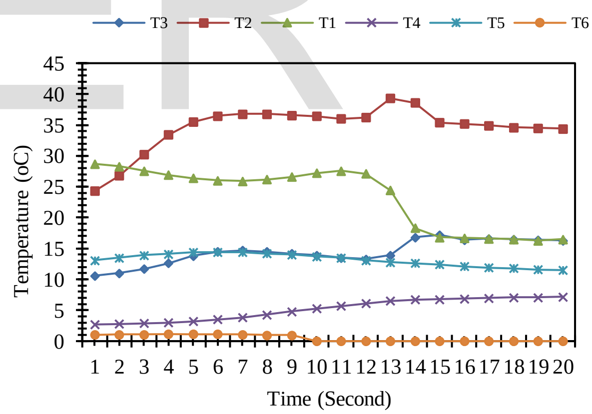

Figure 3. Temperature values of chimney type inclined to 45º

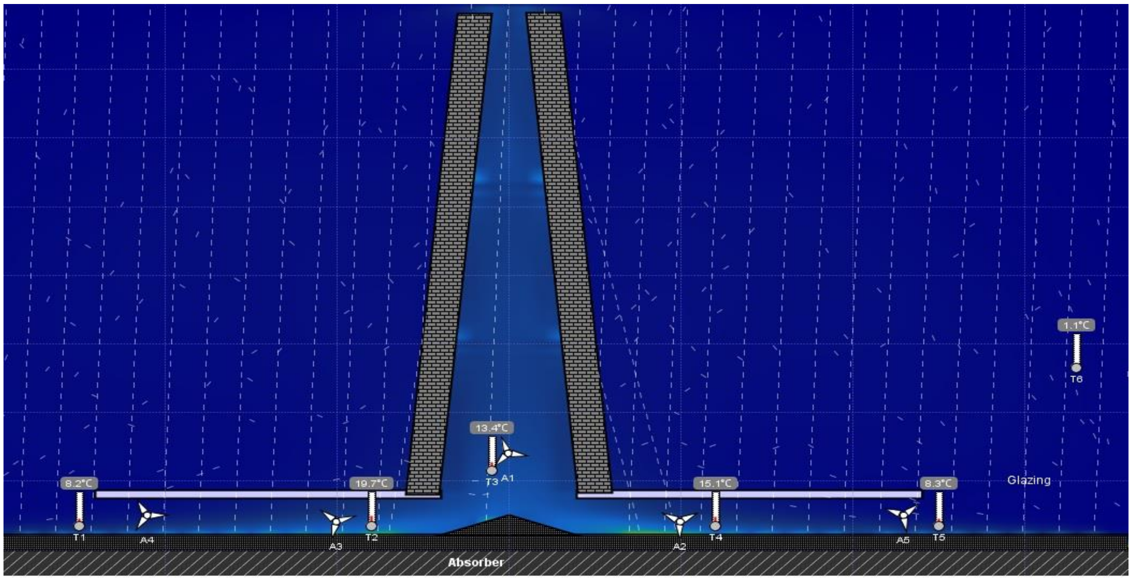

Figure 4. Simulation of conical chimney type with inclination of 75°.

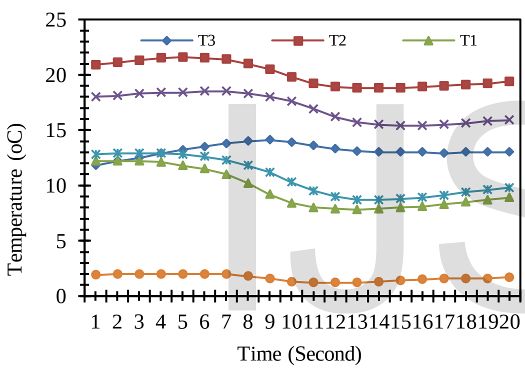

Figure 5. Temperature values of V type chimney inclined to 75°.

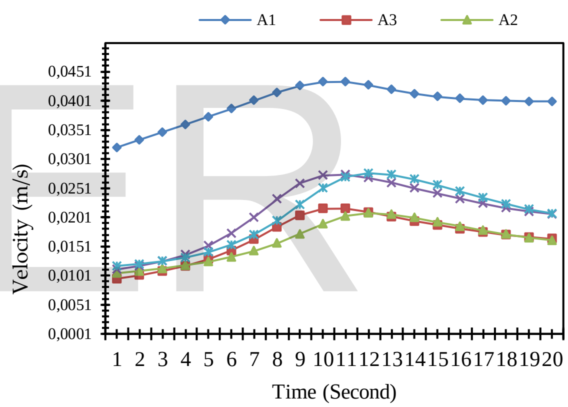

Figure 6. Velocity values of V type chimney with inclined 75°

The simulation of the V-type chimney with a slope of 75° is given in Figure 7With this simulation, the design of the chimney expanding upwards was investigated.

The highest temperature values of the V-type chimney with a slope of 75° were observed in the region from the collector inlet to the chimney. The maximum temperature for the flue inlet temperature (T3) is 17.4 ° C. The temperature rise at this point is due to radiation as shown in the simulation.

Although the temperature value increases at the entrance of the chimney, the speed value shows a ease. The maximum speed value at this point (A1) is

0.038 m / s. Temperature and speed graphs for this simulation are shown in Figures 8 and 9.

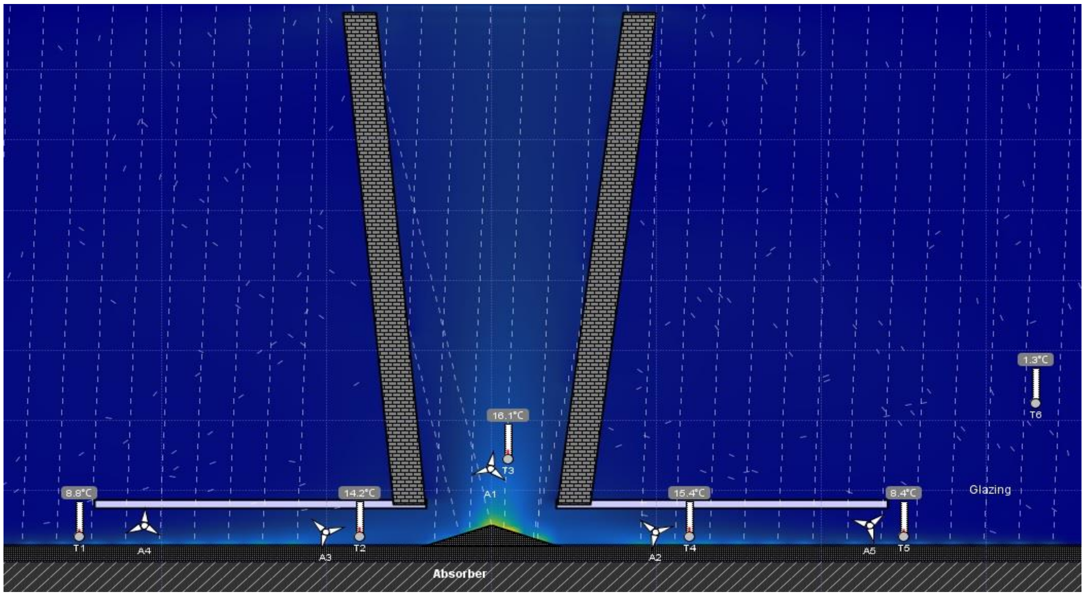

Figure 7. Simulation of V-type chimney with inclined 75° m/s.

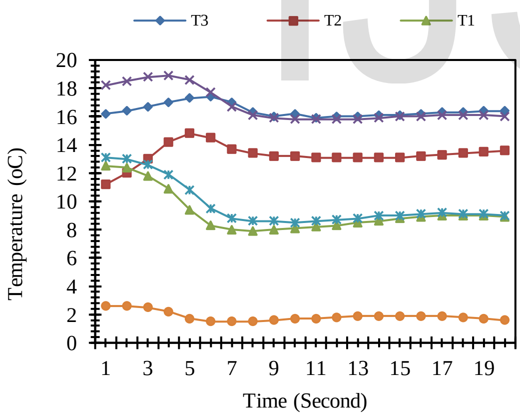

Figure 8. Temperature values of 75 o inclined chimney type.

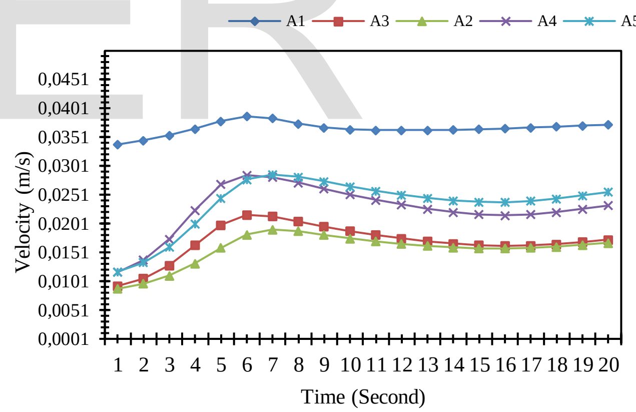

Figure 9. Velocity values of75o inclined chimney type.

The simulation of the 90 ° flue type is shown in Figure 10With this simulation it is possible to examine the performance analysis of inclined flue types with the standard flue type.

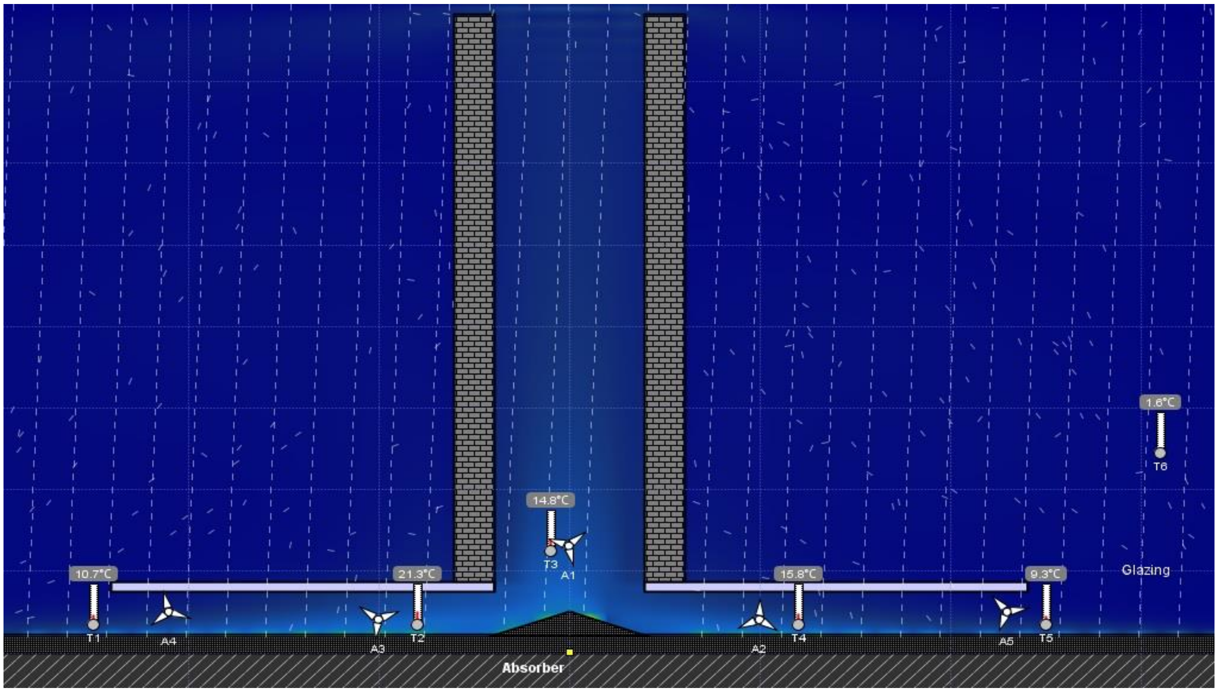

Figure 10. 90 ° flue type simulation.

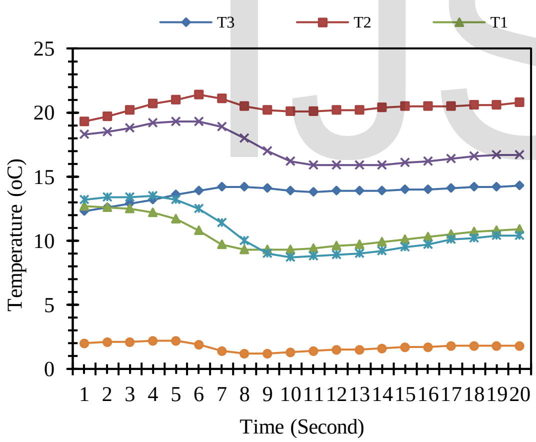

Figure 11. Temperature values of V type chimney inclined to 75°

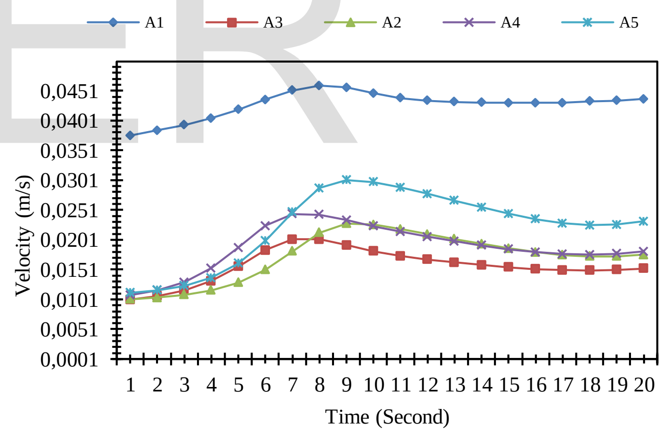

Figure 12. Velocity values of V type chimney with inclined 75°.

Temperature and speed graphs of the 90 ° flue type simulation are shown in Figures 11 and 12. When these parameters are examined, it is seen that the highest temperature value is at T2 and T4 points as in other simulations. The maximum temperature for the flue inlet temperature (T3) is 14.3 ° C. The maximum speed value at the flue inlet (A1) is 0.045 m / s. This value gives the highest speed value compared to other simulations.

4 CONCLUSIONS

Solar chimney power plants promise huge energy generation capacity in areas with high solar radiation. In addition, it is expected to make positive environmental and economic contributions to the reduction of fossil fuel use through the use of solar energy.

In the simulations obtained, it was analyzed that the chimney slope increased the air velocity value at the inlet of the chimney and the increase in the collector surface area significantly increased the temperature and velocity values of the air flowing from the collector opening to the center. As a result, when the different chimney designs were compared, the most important factor affecting the performance of the solar chimney was the chimney l ength and the collector surface area.

In addition, water bags can be placed on the floor by making thermal storage and the floor can be painted black in order to increase the efficiency and the system to work at night time. By combining transparent photovoltaic and many other innovative methods as a solar collector, a hybrid power generation system can be designed.

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