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# The application of artificial neural networks to predict the performance of solar chimney filled with phase change materials

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ABSTRACT

In this study, the effects of phase change material on a solar chimney were studied both experimentally and numerically. Paraffin wax, as a phase change material, was installed inside the small constructed solar chimney in the campus of the University of Tehran with 1.5 m collector radius, 3 m chimney height and 20 cm chimney diameter. The goal of the paper was to illustrate the application of a properly constructed Artificial Neural Network model to predict the performance of the solar chimney, filled with phase change material. The parameters $T_A$ and $T_{air}$ were reported as the input and output data, respectively. Then, a multi-layer neural network using MATLAB software was employed to find a relationship between the inputs and outputs. The process had eight inputs and four outputs, and it was shown that the trained network was well-suited for the problem modeling. Comparing the results with the experimental data indicates the accuracy of the analysis. As a result of the research, the correlation between the predicted values by the network and the experiments, for all outputs, was more than 99%. Moreover, the average value of the relative errors for all outputs were less than 3%.

## 1. Introduction

The concept of the solar chimney was firstly expressed by Hanns Gunther [1]. According to this concept, Schlaich et al. [2] constructed the first Solar Chimney Power Plant (SCPP) in Manzanares, Spain. In 2009, Petela [3] presented a thermodynamic model of SCPP, which was based on the energy and exergy analysis. A mathematical model based on the thermodynamic cycle and meteorological data was developed for solar chimney at the high latitudes by Bilgen and Rheault [4]. They concluded that the overall thermal performance of the SCPP at the high latitudes for the horizontal collector fields was better than the others.

In 2011, a small scale of the solar chimney was built by Kasaeian et al. [5]. They optimized some geometric parameters such as the collector entrance size, which had a noticeable impact on the system efficiency. They also studied some geometric parameters of the solar chimney (SC) to analyze the temperature distribution and air velocity, numerically [6]. Later, the obtained data were compared with the obtained experimental results of the solar chimney of Tehran and the climatic effects on the pilot were investigated [7]. Hurtado et al. [8] presented a numerical model to evaluate the thermodynamic behavior of an SCPP. The research was based on the Manzanares pilot; also they used soil as the absorber to store the thermal energy. Cao et al. [9] designed a sloped solar chimney with the height and angle collector of 252.2 m and 31°, respectively. The aim of the research was to investigate the feasibility of producing 5 MW monthly power. In another work, they combined a geothermal plant with an SCPP in the form of a theoretical model. Cao et al. [10], in another study, analyzed a combined model and compared this with two other models consisting full solar system and the full geothermal system.

Ming et al. [11] evaluated the performance of an SCPP using energy storage layer. Another study was carried out for modifying solar chimney power plant to generate fresh water in some cities of China [12]. Tan and Wong investigated the effect of the ambient air velocity on the performance of solar chimney power plant [13]. A research, based on the Manzanares pilot plant, was done by Xu et al. [14]. They evaluated the impact of solar radiation and the turbine pressure drop to present a mathematical model of flow and heat transfer in the SCPP. Hamdan [15] proposed a mathematical thermal model using the Bernoulli Equation with the buoyancy effect for the airflow inside an SCPP. A small solar chimney was constructed by Ghalamchi et al. [16] in the campus of University of Tehran, Iran. The chimney was built with 3 m height and 20 cm in diameter, also the collector diameter and entrance size were 3 m and 6 cm, respectively. Nasirivatan et al. [17] investigated the effect of Electro Hydro Dynamic (EHD) on a solar

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chimney to increase the fluid velocity. According to this study, Ghalamchi et al. [18] evaluated the wind corona effect on the SC, by using different electrode layouts consisting of radial, symmetric and parallel.

Guo et al. [19] investigated the annual performance of an SCPP to obtain the optimal turbine pressure drop of the system. A mathematical model was proposed by Hosein and Selim [20] to evaluate the operation of a solar chimney, which was used for natural ventilation. They studied some geometrical and operational parameters to analyze the Air Change rate per Hour (ACH) inside the system. Li et al. [21] analyzed the effect of Thermal Conductivity Enhancers (TCEs) on the energy storage layer inside a solar chimney. Ayadi et al. [22] investigated the performance of a solar chimney for different collector roof angles. They found that the collector roof angle was an important parameter to enhance the airflow velocity inside the SCPP. Li and Liu [23] investigated the thermal behavior of a solar chimney with Phase Change Material (PCM). They studied the SC performance for different heat fluxes. Bin et al. [24] analyzed the effect of various thicknesses of the air gap and $Na_2CO_3 \cdot 10H_2O$ on the temperature distribution inside the chimney experimentally. They measured some parameters such as air velocity, air mass flow and heat gain to investigate the impact of the latent heat storage on the system improvement.

Kalogirou et al. [25] used an artificial neural network to predict the long-term performance of forced circulation solar domestic water heating systems. They demonstrated that this method had more advantages than the conventional algorithmic methods [26]. Fadare [27] developed an ANN model to predict the solar energy potential in Nigeria. The model was designed using the neural toolbox of MATLAB, where the geographical and meteorological data of some cities in Nigeria were used as the inputs to the network. A model, based on using the ANN and ANFIS, was presented by Amirkhani et al. [28]. The research was based on the built pilot in the campus of University of Zanjan, Iran. The comparison between the ANFIS model and the experimental data showed a good agreement between them. An Artificial Neural Network/Genetic Algorithm (ANN-GA) was applied by Yuce et al. [29], to optimize the energy management in the domestic sector. The solution showed a reduction in the grid energy usage for a house. Nowak and Rusin [30] applied the ANN to control a steam turbine heating process. The method was based on two ANN models, working in series.

Using LHS system solar chimney is one of the new noteworthy fields. The latent heat storage system improves the performance of solar chimney. In the previous works, the researchers investigated the effect of some parameters such as heat flux, the thickness of PCM, and the types of phase change materials. In our previous study in [31], two parameters including temperature and velocity were measured to evaluate the Latent Heat Storage (LHS) effect on the SC. The experimental data were analyzed for two cases, with and without PCM (paraffin wax), in the SC collector. We used paraffin wax (C20) as a PCM, because of its low price and availability. Since there has been conducted a few works on the application of the ANN in the SCPP from the process and heat transfer points of view, this research has been conducted in order to monitor the temperature in the SCPP. Also, presenting experimental data on the application of phase change materials in solar chimney, is the other novelty point. To find the best relationship between the inputs and outputs, a multi-layer perceptron neural network is utilized. The required data for the neural network training are gathered from the experiments. The structure of the network has been constituted after some trial and error, and then, the selected structure is run several times. If the network is well-trained, the results must be very close in the multiple runs. Then, the best outcomes of the trained networks are reported.

## 2. The experimental procedure

The experimental data were analyzed for two cases, with and without PCM (paraffin wax), in the SC collector. Here, a brief description is presented to explain the experimental part of this study.

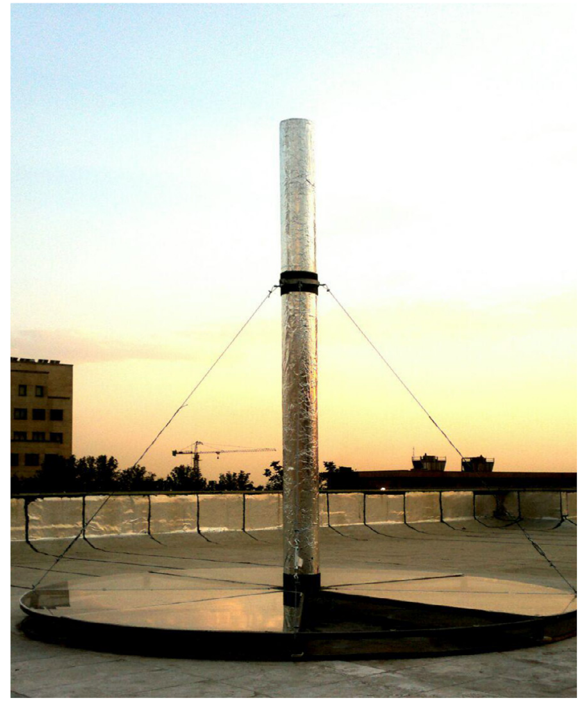

**Fig. 1.** Schematic of the constructed SC.

### 2.1. Setup description

The constructed solar chimney consisted of a collector with 1.5 m radius, and a 3 m tall chimney was used to investigate the effect of the PCM on the thermal efficiency. Also, the collector entrance size and the angle of the solar collector are 6 cm and zero, respectively. The schematic of the set-up is shown in Fig. 1. The chimney was built of a polypropylene pipe with 4 mm thickness and 10 cm radius. The collector was made of steel sheets and chipboard pieces, and covered by glasses. Table 1 illustrates the main geometrical parameters of the SC.

### 2.2. Latent heat storage system

A latent heat storage (LHS) system was applied to optimize the solar chimney s thermal performance. The PCMs have a high potential for heat storage with a small change in the temperature during the cloudy days and nights. When the temperature decreases, the process of phase change starts and the latent heat of the phase change materials is released, so it would lead to warming the air in the absence of sunlight. This process causes improving the system efficiency, significantly. In this research, paraffin wax (C20) with “Merck code 107150” was selected as the PCM. The melting point and heat of fusion of the PCM were 45 °C and 189 KJ/Kg, respectively. The aluminum foils packs of PCM with 1 cm thickness was installed inside the collector. Since the collector slope was zero, there were the same pressure in all directions and the same thickness inside the container of PCM. Some thermophysical properties of C20 are shown in Table 2.

**Table 1**
The solar chimney‘s geometrical parameters.

| Parameter | Size (m) |
|---|---|
| Chimney radius | 0.10 |
| Collector radius | 1.50 |
| Collector height | 0.06 |
| Chimney height | 3.00 |