Journal of Mechanical Research and Application (JMRA), Vol. 14 No.3, 1403 (2024),1-12

JMRA
Journal of Mechanical Research and Application
ISSN: 2251-7383, eISSN: 2251-7391

Evaluation of the magnetic field effect on stepped solar still efficiency

Kimya Samadi[1], Hamidreza Goshayeshi[1*], Vahid Nejati[1], Seyed Reza Saleh[1],Issa Chaer[2]

[1] Department of Mechanical Engineering, Mashhad Branch, Islamic Azad University, Mashhad, Iran

2 The School of Built Environment and Architecture, London South Bank University, SE1 0AA, London, United Kingdom

Abstract

This study focuses on improving the performance of a stepped solar still by investigating the effect of a magnetic field applied by a solenoid using a numerical solution method and experimental work. The calculations and experimental work in this study are based on a stepped solar still with seven steps. The effects of the applied magnetic field generated by the solenoid are investigated in terms of flow streamlines, contour plots of x-velocity and y-velocity, both in ignoring and considering the influence of magnetic field intensity. Two different combinations of NI (N is the number of solenoid turns, and I is the electric current intensity) are examined with values of $2.5 \times 10^5$and 10×10^5.In experimental work to increase the daily production rate of fresh water, the stepped solar still has been tested and optimized in various configurations including 1) Simple configuration, 2) utilizing a solenoid with turns of 275 3) utilizing a solenoid with turns of 1000.In computational fluid dynamics method, for the applied magnetic field with $NI = 10 \times 10^5$,it has been observed that the evaporation rate reaches its maximum value in all stages of the solar desalination water slide, resulting in an increased water evaporation rate in the solar still. The evaporation rate has approximately reached the maximum value of 1.02×10^{-1} (kg/s) in all parts of the solar still. In experimental work the solar still's efficiency from 55.2% in mode 1 has reached 72.9%,74.3%.

Keywords: Solar Still, Magnetic Field, Solenoid, Computational fluid dynamics method, efficiency, NI

Introduction

Today, there is a crisis in limited access to freshwater resources due to population growth in the world. The global population growth rate has been increasing in recent years [1]. Water scarcity and pollution of underground water resources have created serious problems, particularly in developing countries, impacting all aspects of life. Human activities, the use of fossil fuels, and depletion of surface and under groundwater have further aggravated the environmental crisis. The demand for clean water is growing every day [2]. Providing clean drinking water for people has become a serious problem for governments worldwide [3].

In Iran water is still not treated in many rural areas which use aqueducts, springs and wells for water supply. Also, saline water is increased due to depletion of underground water supplies. some areas which access to sea water don't access to water filtration networks. Therefore, solar stills would be an effective solution which uses solar radiation for water desalination. Solar still is a water desalination device which is based on evaporation and condensation process that is results as natural rain.[4]

Since water desalination process doesn't offset the ancillary costs, currently most studies focus on enhancing the efficiency of water desalination units and increasing freshwater production using conventional methods.[5] For example, Dubey et al. [6] conducted a thermo-exergo economic analysis of double slope solar still with $2m^2$ area which was augmented with ferrite ring magnets and a blackened galvanized iron sheet. Adibi et al. [7] investigated the enhancement of the performance of a stepped solar still using hybrid phase change materials with the appliance of a magnetic field.

Goharkhah et al. [8] investigated the effect of a magnetic field on the hydrodynamics and heat transfer of a magnetic ferrofluid flow in a porous finned heat pan. In this research the heat transfer rate successfully increased by up to 35%. Assad Rahman et al. [9] developed a physical model of a solar still by applying a magnetic unit and a double-layered water-cooled glass cover. They found the highest efficiency of approximately 32.55% and a 50% improvement in freshwater production compared to the conventional solar still. They identified the presence of a magnetic field as a factor contributing to the enhanced performance of the solar still. Divagar et al. [10]

conducted a thermodynamic analysis of a single-slope solar still unit which was equipped with graphite plates and ferromagnetic blocks. The study focused on investigating the system's performance under seasonal weather conditions. The results of these researches showed that appalling magnetic field on solar desalination systems lead to improvement the heat transfer coefficient, solar still efficiency and water productivity.as mentioned before, utilizing User-Defined Function (UDF) coding in Fluent software can simulate the operation of a cascade Stepped solar still under the influence of a magnetic field created by an internal solenoid. In experimental work to increase the daily production rate of fresh water, the stepped solar still has been tested and optimized under the influence of a magnetic field which was created by a solenoid with different turns. Comparison of the magnetic field effect on stepped solar still efficiency with computational fluid dynamics and experimental work is given below.

1. Schematic Model Design

Figure 1 illustrates a two-dimensional schematic design of a stepped solar still. It represents a stepped solar still with a length of L and left wall heights of $\boldsymbol{H_l}$ and right wall heights of $\boldsymbol{H_r}$. The bottom wall corresponds to the cascaded section of the stepped solar still being leak sealed, and it is covered with a glass cover. The stepped solar still consists of 7 cascades, each with a height of 30 millimeters, a width of 110 millimeters, and a length of 840 millimeters. The solenoid of interest is positioned inside the stepped solar still, specifically on top of the cascades as indicated in Fig. 1, at a distance of $\boldsymbol{X_C}$ from the left wall and $\boldsymbol{Y_C}$ from the bottom wall. The values of temperature on the upper wall are indicated by $\boldsymbol{T_g}$ and the values of temperature on the lower walls is indicated by $\boldsymbol{T_w}$.

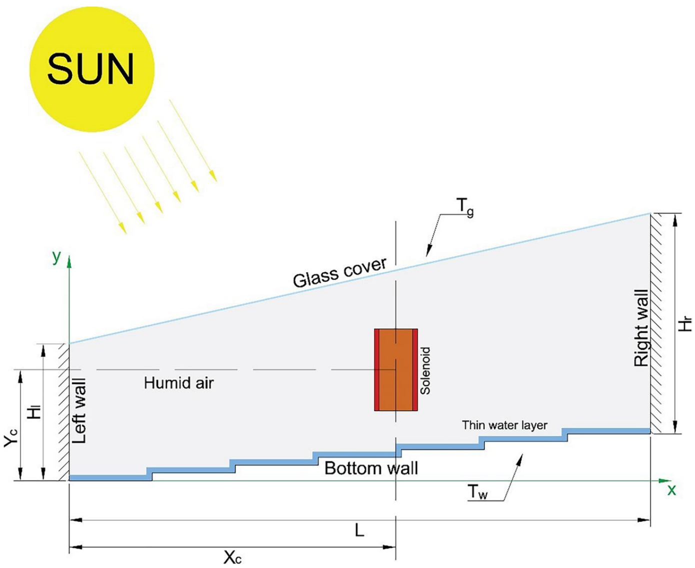

Fig. 1 Schematic diagram and coordinate system of a stepped solar still

2. Numerical Method

The governing equations are solved using the Finite Volume Method, and the corresponding boundary conditions are applied in this study. The Fluent software is utilized to discretize and solve the governing equations of conduction and convection using the second-order upwind scheme. The velocity-pressure coupling is achieved using the SIMPLEC algorithm. The discretized system of equations is considered converged when the residuals reached a value below 10^{-6}. To account for the magnetic field impact, in addition to using Equations and calculating magnetic field intensity, the term related to the Kelvin body force has also been computed. This calculation is performed using the UDF capability in the FLUENT software.

3.Computational Fluid dynamics results

The impact of magnetic field which is applied by solenoids on the water production rate and heat transfer coefficient improvement in a stepped solar still is examined. The analysis is evaluated for two states: one without the magnetic field and the other with two different intensities of the magnetic field which applied by NI=2.5*10^5 and NI=$5 * 10^5$.Fiqure2-4 illustrates the contours of stream function, x-velocity and y-velocity with states without the magnetic field and with two magnetic field intensifies. the coli turns are represented by N and the electrical current is represented by I.

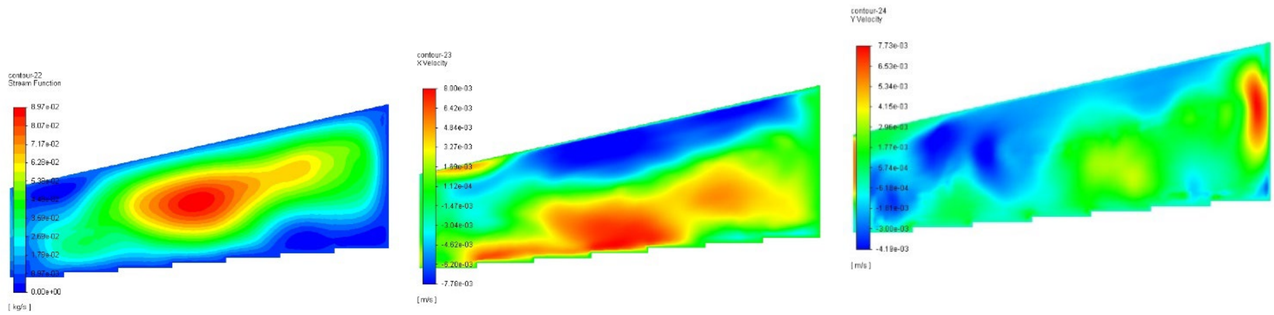

Fig2.Contours of stream function,x-velocity and y-velocity for NI=0

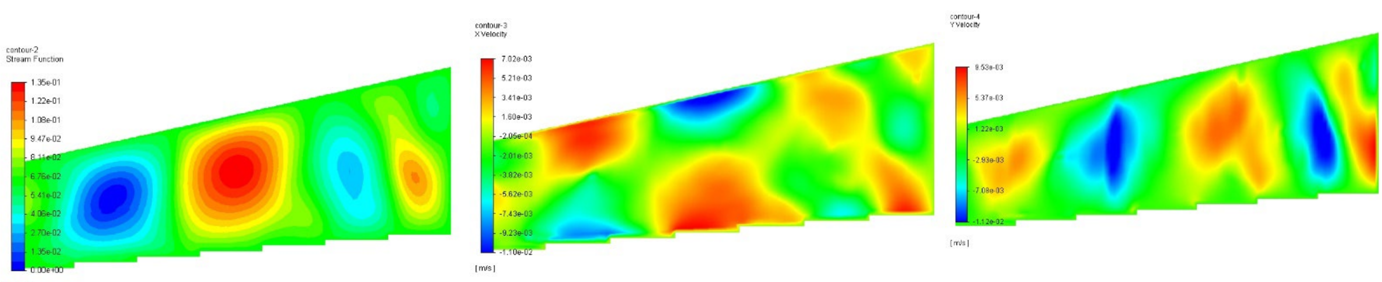

Fig3.Contours of stream function,x-velocity and y-velocity for NI=2.5*10^5

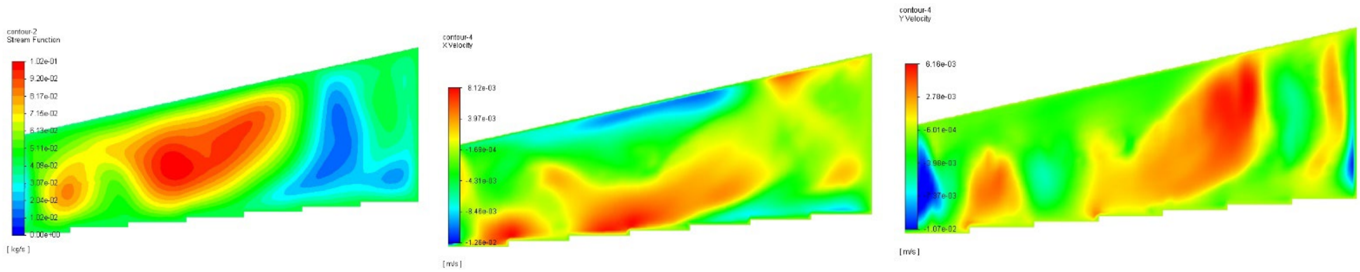

Fig4.Contours of stream function, x-velocity and y-velocity for NI=5*10^5

in the state NI = 2.5 × 10^5 with an increase in the value of NI, the eddy currents are reinforced or strengthened. In this case, due to the boundary forces directed upward, the flow separates near the middle of the lower wall, resulting in the formation of a vortex contour with four vortices. Noticing the contours related to the velocity in the x-direction, and velocity in the y-direction, it is important to note that velocity plays a significant role. The higher the velocity, as illustrated in this research by utilizing the effect of applying a magnetic field, the faster the evaporation process occurs.

As demonstrated in the velocity contour in the x-axis direction, the velocity at the first, second, fourth, and sixth steps exhibits extrema. Convective heat transfer is likely more prominent in those regions, leading to increased water evaporation.

As demonstrated in the state of NI = 10 × 10^5,the maximum value in the flow function corresponds to 1.02 × 10^{-1} Kg/S, clearly associated with the vortex in the fourth and fifth steps. It can be stated that in this region, considering the effect of the applied magnetic field, the maximum level of evaporation occurs, and it further develops in subsequent steps.

4. Experimental Set up

Fig. 5 illustrates the desired step solar still. The device casing is constructed from a 0.25-millimeter-thick sheet of galvanized steel. This new design included preheating pipes that are placed at the top of the stepped solar still. These connection pipes which are located between the tank and the device, are shown in Fig. 5. The modified desalination system contains 28 steps in three different stepped surfaces built on 2 mm thickness iron sheet. The step dimension is 840 mm*30 mm*110 mm.

In this experiment, a 3-millimeter-thick glass with a 15-degree slope is installed on the top surface of the device. This glass not only allows sunlight to pass through but also aids in the condensation of the vapor produced.

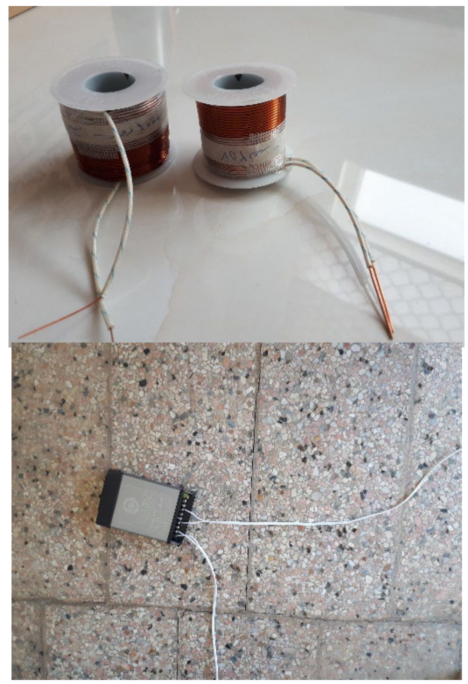

Fig.5 Stepped Solar Still Fig.6 275 and 1000 turns solenoids Power supplies for them

In the presence of a magnetic field, when the magnetic field is created by solenoids with 275 and 1000 turns, the magnetic field strength for a solenoid with several turns N could be calculated as Equation 2. In this experiment, the magnetic field is applied with two solenoids at different turns of 275 and 1000. μ_0 is the permeability constant, which represents the magnetic permeability.

$$q'' = h\Delta T \quad (1)$$

$$B = NI\mu_0 \quad (2)$$

$$\text{Where, } \mu_0 = 4\pi * 10^{-7} \quad (3)$$

The solar still efficiency could be defined as below:

$$\eta=\frac{V_F^T \rho h_{fg}}{H} \quad (4)$$

Where, $h_{fg} = 2450 \frac{KJ}{Kg}$

$$H=A_s*\int I_T(t)dt=A_s*\Sigma I_{\mathrm{T}}(t_{\mathrm{i}})\Delta T \quad [11] \quad (5)$$

The experiments were conducted under various conditions, including 1) Simple state 2) In conjunction with solenoid with 275 turns 3) In conjunction with solenoid with 1000 turns. Fig. 7 indicates the first experiment conducted on June 28th, 2023. The experiment took place on a clear and sunny day using a conventional stepped solar still. Fig. 8 indicates the results of the experiments conducted using a stepped solar still with a solenoid having 275 turns on July 7th, 2023. Fig. 9 indicates the results of the experiments conducted using a stepped solar still with a solenoid having 1000 turns on July 9th, 2023.

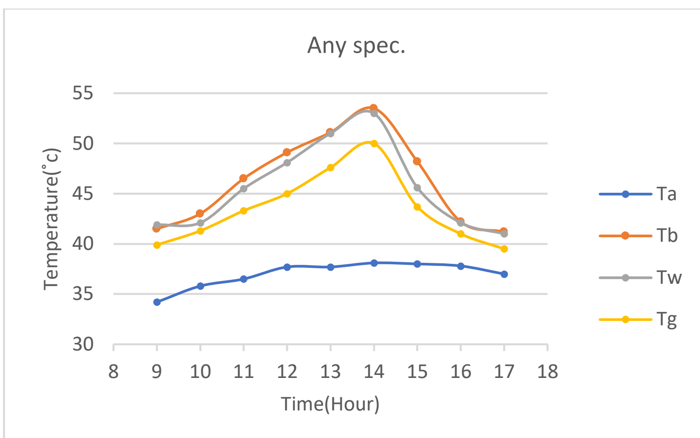

Fig 7. Temperature of air, glass coating, water, and heat transfer coefficient in state 1

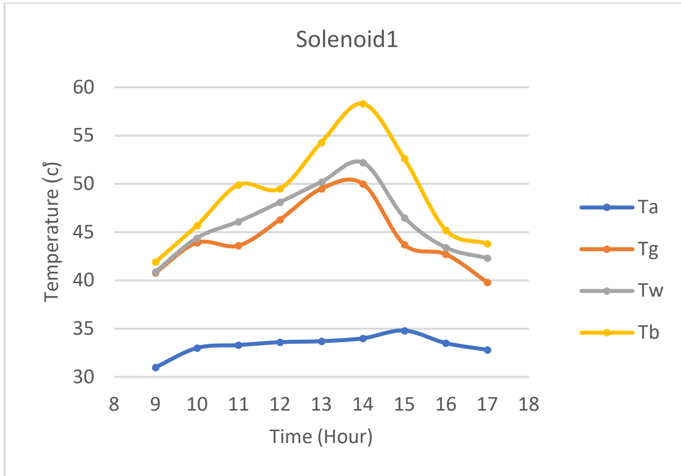

Fig 8. Temperature of air, glass cover, water, and heat transfer coefficient in state 2

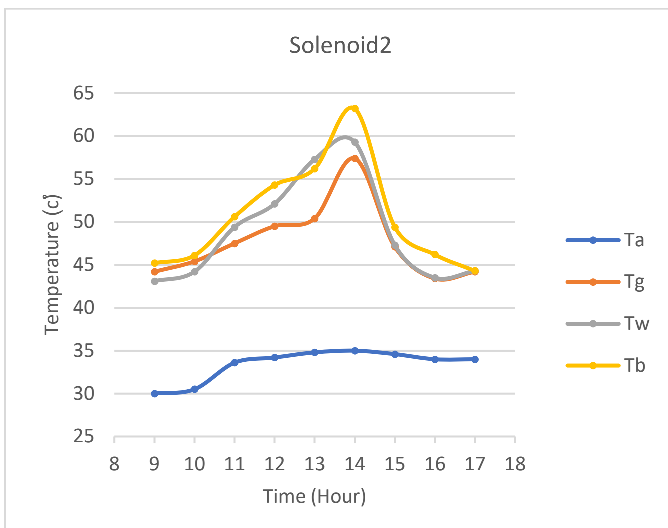

Fig 9. Temperature of air, glass cover, water, and heat transfer coefficient in design 4

Experiments were carried out on the stepped solar still in the presence of a magnetic field applied using a solenoid with 275 turns on clear and sunny days, July 7th and

9th, 2023. Similarly, a solenoid with 1000 turns, connected to the power supply and city electricity at its two ends, was placed in the staircase section of the solar water desalination device. To ensure safety in the presence of humid air inside the device, the solenoid was properly sealed to prevent electric shock hazards. the best results for the temperature of air, glass coating, water, and heat transfer coefficient are presented.
experimental results indicate that as the intensity of the magnetic field increases, more heat is transferred to the water, leading to an enhanced rate of desalinated water production.in other word the larger the coil turns of solenoid, the stronger the magnetic field and leads to an enhanced rate of desalinated water production.

5.Conclusion

In the present research, the impact of applying a magnetic field using two solenoids on the convective heat transfer is evaluated by computational fluid dynamics analysis and experimental work.

-The convective heat transfer enhancement due to the magnetic field depend on time.

-In addition to the primary vortices which are generated due to buoyancy forces, the magnetic field has produced additional vortices.

-The convective heat transfer is increasing functions of the magnetic field intensity that is related to the amount of NI variations.

-For the magnetic field with NI = 0, 2.5×10^5,10×10^5, heat transfer rate can be augmented up to 53% respectively.

- The use of magnetic field, which is applied by two solenoids, leads to an improvement in the stepped solar still efficiency compared to design1.When magnetic field is applied by two solenoids with 1000 and 275 turns, the solar desalination unit efficiency respectively, is estimated about 72.9% and 66.3%.

In conclusion, further research can be conducted using permanent magnets with different shapes to access their impact on improving the performance of these devices. Also, the impact of nanofluids and PCMs can be investigated for efficiency improvement. The arrangement and number of magnets can also be investigated to enhance their functionality.

References

1. Shahzad, M.W., et al., Demystifying integrated power and desalination processes evaluation based on standard primary energy approach, *Therm. Sci. Eng. Prog.,*2022, vol. 27, p. 101153.

2. Mevada, D., et al., Investigation and performance analysis of solar still with energy storage materials: An energy-exergy efficiency analysis, *Case Stud. Therm.*

Eng., 2022, vol. 29, p. 101687.

3. Al-Harahsheh, M., Abu-Arabi, M., Ahmad, M., and Mousa, H., Self-powered solar desalination using solar still enhanced by external solar collector and phasechange material, *Appl. Therm. Eng.,* 2022, vol. 206, p.

118118.

4.Toosi, S.S. A., Goshayeshi, H.R., and Heris, S.Z., Experimental investigation of stepped solar still with phase change material and external condenser, *J. Energy Storage,* 2021, vol. 40, p. 102681.

5. Goshayeshi, H.R., and Safaei, M.R., Effect of absorber plate surface shape and glass cover inclination angle on the performance of a passive solar still, *Int. J. Num.*

Methods Heat Fluid Flow, 2020, vol. 30, no. 6,

pp. 3183–3198.

6. Dubey, M., & Mishra, D. R. (2020). Thermo-exergo-economic analysis of double slope solar still augmented with ferrite ring magnets and GI sheet. *Desalination and Water Treatment*, *198*, 19-30.

7. Toosi SSA, Goshayeshi HR, Heris SZ (2021) Experimental investigation of stepped solar still with phase change material and external condenser. J Energy Storage 40:102681.

8. Ashjaee M, Goharkhah M, Khadem LA, Ahmadi R (2014) Effect of magnetic field on the forced convection heat transfer and pressure drop of a magnetic nanofluid in a miniature heat sink. Heat Mass Transf 51:953‑964. https:// doi. org/ 10. 1007/s00231- 014- 1467-1.

9. Al-Hilphy ARS (2013) Development of basin solar still by adding magnetic treatment unit and double glass cover provided with water. Am J Eng Appl Sci 6(3):286‑296. https:// doi. org/ 10. 3844/ajeas sp. 2013. 286. 296

10. Dhivagar R, Mohanraj M, Raj P, Gopidesi RK (2021) Thermodynamic analysis of single slope solar still using graphite plates and block magnets at seasonal climatic conditions. Water Sci Technol 84(10‑11):2635‑2651. https:// doi. org/ 10. 2166/ wst. 2021. 156

11.Design, Construction and Experimental investigation of the performance of an improved inclined solar still. Mechanical Engineering of Tabriz university (3)52(237-246).