Proceedings of the 6th International Conference on Energy Harvesting, Storage, and Transfer (EHST'22)
Niagara Falls, Canada – June 08-10, 2022
Paper No. 136
DOI: 10.11159/ehst22.136

Performance Improvement of Nanofluid Based Direct Absorption Solar Collector (DASC) by Pulsating Flowrate

Mehran Bozorgi[1]*, Kasra Ghasemi[1], Mohammadreza Mohaghegh[1], Syeda Humaira Tasnim[1], Shohel Mahmud[1]
[1] School of Engineering, University of Guelph, Ontario, Canada
mbozorgi@uoguelph.ca*, kghasemi@uoguelph.ca, mohaghem@uoguelph.ca, stasnim@uoguelph.ca, smahmud@uoguelph.ca

Abstract **–** Solar energy systems have been recognized as a significant component of HVAC systems during the last two decades, providing thermal and electrical energy for a variety of applications. Meanwhile, nanofluid-based Direct Absorption Solar Collectors (DASCs) hold great potential for converting solar radiation to thermal energy in energy systems since nanoparticles significantly improve the energy-absorbing potential of the base fluid. The primary impediment to commercializing these collectors is the sedimentation and agglomeration of nanoparticles over an extended period of time. The novel design of direct absorption solar collector was modelled in this study by COMSOL software using water and silver nanofluid as the working fluid and the effect of pulsating flowrate on the DASC's performance was investigated in order to increase efficiency and reduce nanoparticle sedimentation and agglomeration. According to the results, collector efficiency can be increased by using pulsing flowrates, and this improvement is much more pronounced when nanofluid is employed as the working fluid, increasing efficiency to 84.2 percent. The energy efficiency of the DASC rises by 5% and 3% with pulsing flowrates for silver nanofluid and water, respectively. Thus, using pulsating flowrate in the direct absorption solar collector can grow thermal efficiency while simultaneously preventing nanoparticle deposition and aggregation in the collector. The findings of this research can pave the way for the use of nanofluid-based direct absorption solar collectors in a variety of energy systems.
Keywords**:** Solar Energy, Direct Absorption Solar Collector, Pulsating Flowrate, COMSOL, Silver Nanofluid

1 Introduction

As the world's population is increasing and society's energy demands keep rising, the usage of renewable energy might be considered an important topic for scholars. Solar energy is a viable alternative to fossil fuels because of its widespread availability and the fact that it can be produced without causing any environmental negative effect. Solar collectors, among other solar energy systems, may contribute significantly to HVAC systems by converting solar radiation to thermal and electrical energy. Additionally, by removing the absorbing plate in Direct Absorption Solar Collectors (DASCs), thermal resistance is reduced significantly and solar energy is directly absorbed by the working fluid [1]. As a result, several researchers investigated the use of various types of nanofluids in DASCs in order to increase the energy absorption capacity of working fluids.

Otanicar et al. were pioneers in this discipline. They investigated the characteristics of carbon nanotubes, graphite, and silver nanofluids to determine their suitability for usage in DASCs. According to their findings, raising the concentration of the nanofluid boosts the solar collector's efficiency [2]. In numerical research, Tyagi et al. used the Rayleigh technique to investigate the characteristics of aluminium nanofluid and discovered that the nanoparticles enhance the absorption of incoming radiation by more than nine times that of pure water [3]. Ladjevardi et al. solved mass, momentum, and energy equations together to predict DASC performance by using graphite nanofluid. They reported that there is a volume fraction of 0.000025 % in which more than half of the irradiation energy can be absorbed for merely 0.0045 $/L of the additional cost [4].

Karami et al. conducted separate research on the characteristics of carbon nanotubes, carbon nanoballs, and copper oxide nanofluids. These nanoparticles can considerably enhance the thermal and radiative characteristics of the base fluid [5]–[7]. Furthermore, Karami et al examined the effect of using PVP coated silver nanofluid, hybrid Fe2O3 with SIC nanofluid, and nano-diamond fluid in DASC, experimentally. They solved the first and the second law of thermodynamics to determine the energy and exergy efficiency of solar collectors. Also, they obtained some empirical correlations to predict the collector's efficiency in different conditions [8]–[10]. On the other hand, Siavashi et al. observed that while nanoparticles at low concentrations can boost collector efficiency, their presence at high concentrations might result in poor performance. Additionally, they demonstrated that the absorber plate significantly increased collector performance, particularly when the working fluid was pure water [11].

Turkyilmazoglu analysed the performance of DASC with two different boundary condition of bottom surface analytically [12]. Jyani et al. investigated the influence of turbulence and laminar flow on the collector's efficiency and discovered that transitioning from laminar to turbulence flow enhanced energy efficiency by 3% [13]. Guo et al. studied the optical properties and light-to-heat conversion performance of Ti_3C_2/[BMIM]BF_4 to use in DASCs. They found that Ti_3C_2/[BMIM]BF_4 nanofluids have great potential for absorbing solar radiation and can increase the DASC's efficiency [14].

Alqaed et al. analysed the application of CuO nanofluid based DASC in HVAC system in three cities with different climate in Suadi Arabia. According to their results, they found that in Sharorah, energy savings in the presence of CuO were determined to be 18,730 kWh 19,440 kWh, and 20,430 kWh for 25, 50, and 100 ppm, respectively [15]. Vakili et al. forecasted the performance of a low-temperature DASC improved with nanofluids, by developing an artificial neural network (ANN) adaptive neuro-fuzzy inference system (ANFIS) model. Additionally, they demonstrated that the ANFIS model's output coincides well with the experimental results from their prior work [16].

The nanofluids-based DASC has an important impediment which is the sedimentation of nanoparticles in the long-term period which overshadows the collector's performance. In this paper, a novel approach is applied in direct absorption solar collectors to enhance their performance and prevent sedimentation of nanoparticles in the collector by using pulsating flowrate. This research can be considered pioneering in this field by integrating flowrate with the pulse in this type of solar collector engendering more prevalence of using this type of solar collector in energy systems.

2 Methodology

2.1 Schematic of the Problem

Radiation is the primary heat transfer mechanism in Direct Absorption Solar Collectors (DASCs). According to figure 1, working fluid flows between clear glass and a totally insulated aluminium surface. By absorbing incident solar irradiation, the temperature of the working fluid rises.

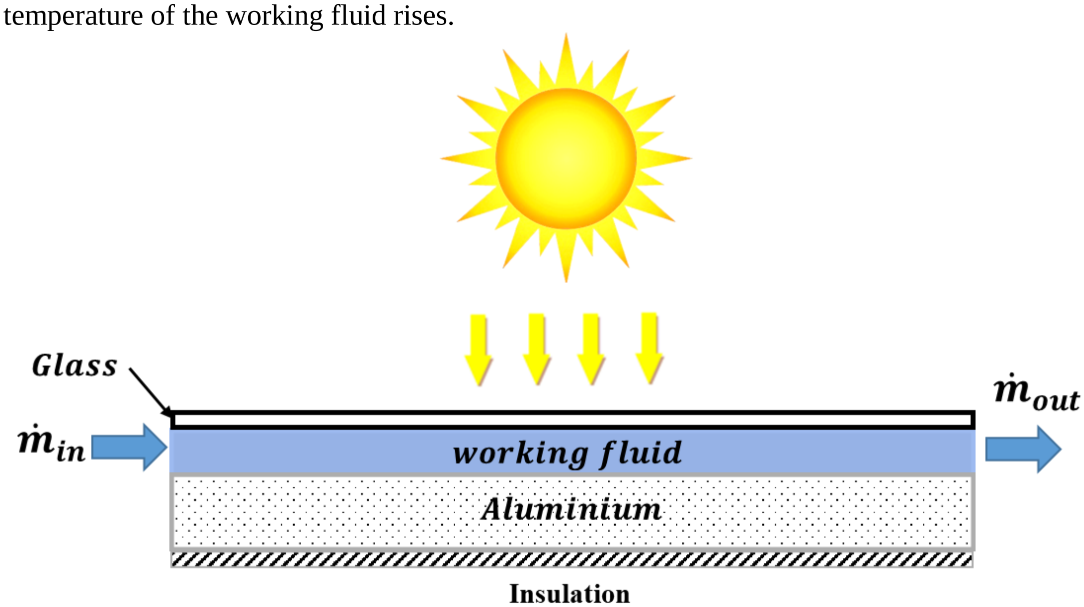

Fig. 1: Schematic of the Direct Absorption Solar Collector (DASC)

In this research, the solar collector is modelled in 2-D including conduction, convection, and radiation heat transfer. The solar radiation is constant and equals to 700 W/m^2 during simulation time. The dimensions and parameters of the problem are illustrated in table 1.

Table 1: Parameters of the problem

Parameter	Description	Value
H_f	Thickness of working fluid	1 cm
H_b	Thickness of bottom	2 cm
H_g	Thickness of glass	4 mm
$A = L^2$	Collector area	60×60 cm^2
G	Solar radiation	700 W/m^2
h_{air}	Convection heat transfer coefficient	10 W/m^2K
T_{inf}	Ambient temperature	298.15 K

2.2 Nanofluid

In this study, silver nanoparticle coated with PVP (Polyvinylpyrrolidone) has been used as the main particle of deionized water-based nanofluid. The nanofluid's concentration is 1000 ppm and its thermal conductivity is compared with deionized water in figure 2. By applying the transient hot-wire method and using the KD2 Pro device with TR-1 sensor kit (KD2 Pro, Decagon devices Inc., USA), the thermal conductivity of the base fluid and nanofluid were measured. According to the results, the thermal conductivity of water and 1000 ppm PVP coated silver nanofluid are 0.54 and 0.6 W/mK respectively in 25°C. Whereas, these quantities are increased to 0.594 and 1.098 W/mK in 55°C.

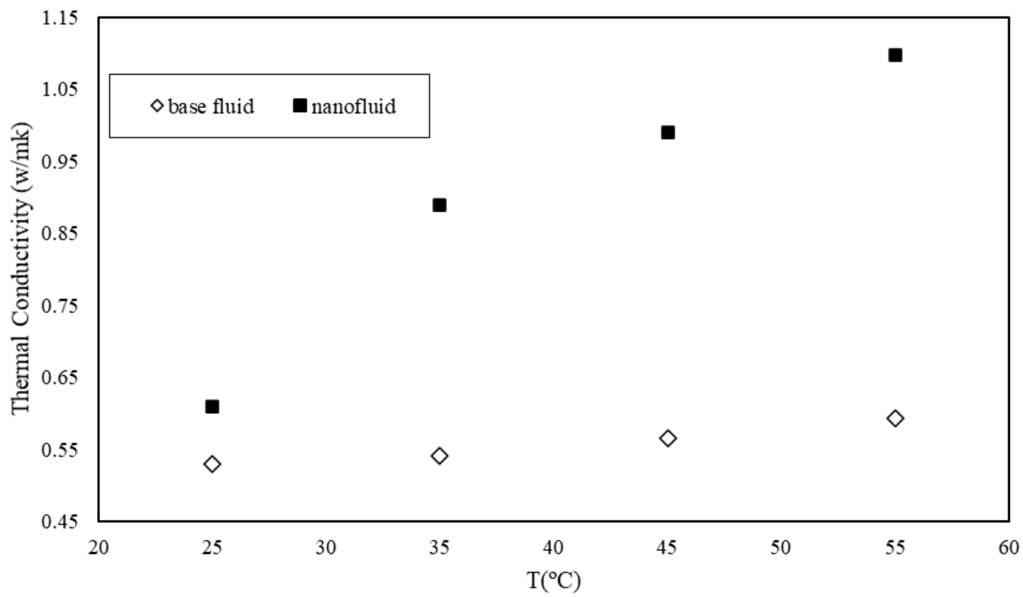

Fig. 2: The comparison of thermal conductivity of water and nanofluid in different temperature

2.3 Pulsating Flowrate

The primary goal of this work is to simulate pulsing flow in DASC in order to improve its thermal performance and prevent nanoparticle sedimentation and aggregation. Thus, the velocity of inlet fluid into the DASC has a specific expression which is displayed in equation (1).

$$u_{inlet} = u_0 \sin(a\pi t) + 2u_0 \quad (1)$$

In equation (1), a=0.05 and u_0 is reference velocity which equals to 0.00075 m/s. Figure 3 depicts the velocity amounts in a 900-second period.

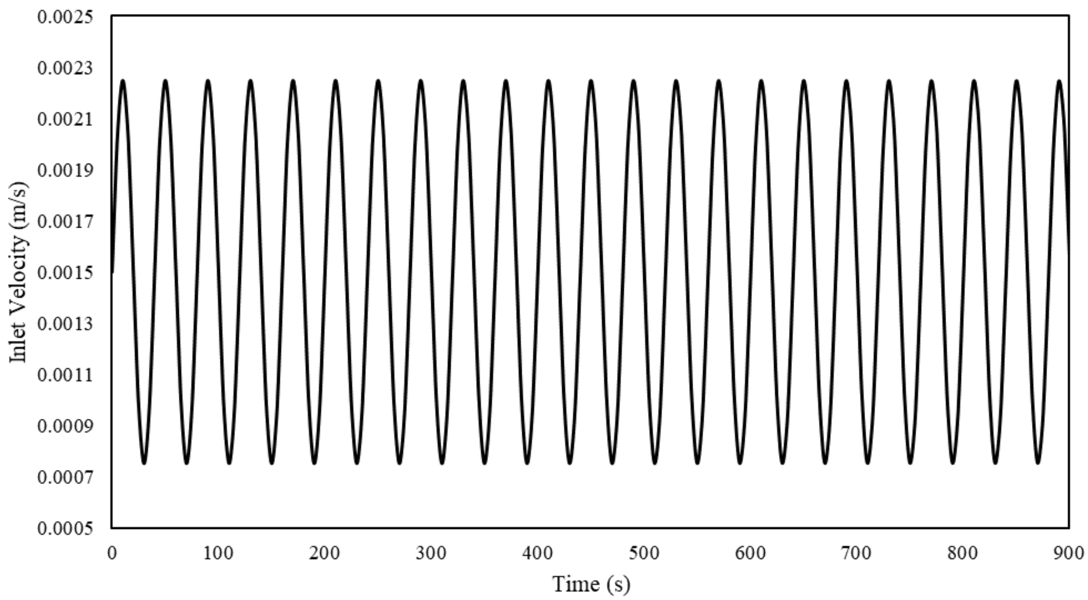

Fig. 3: Inlet velocity values

2.4 Governing Equations

The energy efficiency of the collector, which is the most significant output parameters of simulation, can be calculated by equation (2).

$$\eta = \frac{\dot{m} C_p \Delta T}{GA} \tag{2}$$

Based on the DIN EN 12975-2 which is the test standard of the flat plate solar collectors, the test period of collector to reach the steady state condition will be about 15 minutes (900 seconds) [8]. So, the results of the project will be presented in this period.

3 VALIDATION

In this project, the simulated results by COMSOL software, is compared with experimental research in this field [8].Figure 4 shows the output temperature of working fluid in the direct absorption solar collector for both experimental and numerical research. Based on the figure 4, although COMSOL modelling simulation provides higher temperature rather than experimental results, but the average error is about 0.5% which is acceptable. This discrepancy can be caused by changes in ambient temperature, wind velocity, and other parameters during experimental tests.

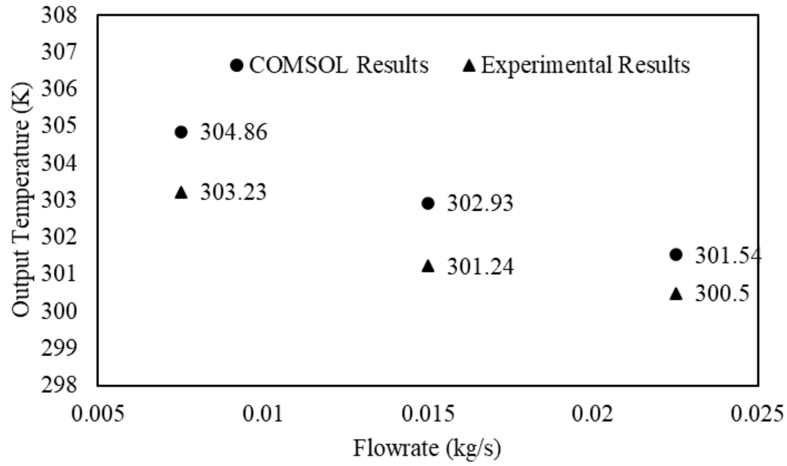

Fig. 4: comparison experimental and COMSOL results

4 Result And Discussion

To analyse the behaviour of efficiency at different conditions, efficiency of the collector is calculated based on T*. According to the equation (3), T* depends on the difference between inlet temperature of working fluid and ambient temperature.

$$T^* = \frac{T_{in} - T_a}{GA} \quad (3)$$

The efficiency of DASC is depicted in terms of T* for water and 1000 ppm PVP-coated silver nanofluid with pulsating and steady flow rates in Figure 5. According to the results, when T* increases, heat losses to the ambient rise, and efficiency decreases noticeably in all circumstances.

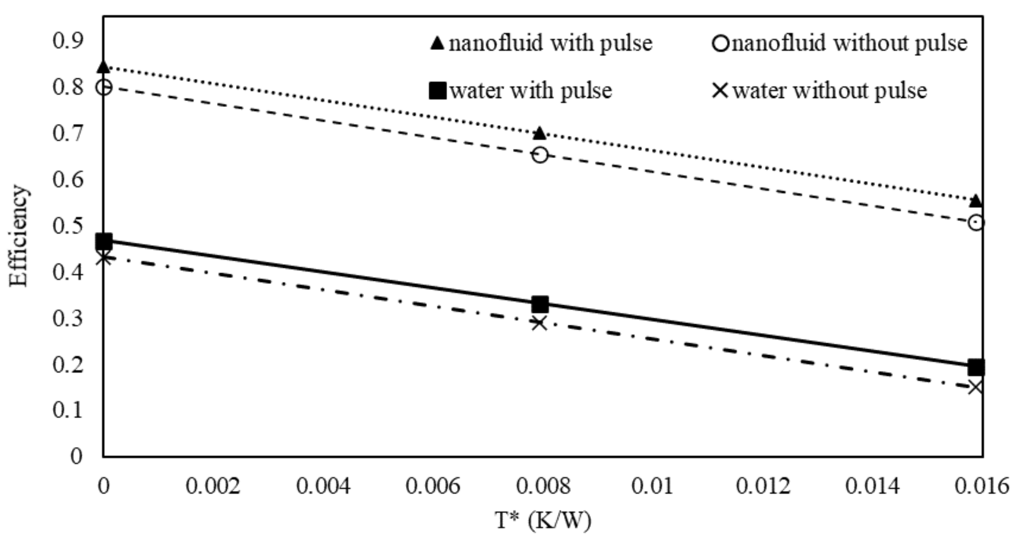

Fig. 5: Collector efficiency in terms of T* for water and nanofluid

Based on figure 5, the use of PVP-coated silver nanofluid in DASC can significantly boost the collector's efficiency. The addition of nanoparticles in the working fluid increases the absorption capacity of the base fluid, therefore raising its temperature. By replacing 1000 ppm PVP-coated silver nanofluid instead of water as a working fluid, the DASC's efficiency rises from 46.6 to 84.2 %. Furthermore, pulsating flowrate has a prominent impact on the energy efficiency. For both water and nanofluid, it is discovered that the output temperature of the working fluid increases with the pulsing flowrate. Due to the pulsing flow rate, the collector's flow will be more turbulent than it would be with a constant inlet velocity and this issue leads to higher DASC efficiency.

Moreover, the main obstacle for commercializing the nanofluid-based solar collectors is the sedimentation of nanoparticles in the long-term period which can be prevented by using pulsating flowrate. Thus, not only does applying pulsating flowrate in DASC improve its thermal efficiency but also the sedimentation and aggregation of nanoparticles can be controlled. This issue can pave the way of using nanofluid-based DASC in HVAC systems.

5 Conclusion

In this research, to overcome a noticeable demerit of nanofluid based direct absorption solar collector, a new design of this collector with pulsating flowrate was simulated with COMSOL software and the following conclusions resulted:

- PVP-coated silver nanoparticles can be used to enhance the thermal characteristics of deionized water. At 55 ºC, 1000 ppm PVP-coated silver nanofluid has a thermal conductivity two times higher than water.
- Thermal efficiency of the DASC rises from 43% to 79.8% by using PVP coated silver nanofluid instead of water as the working fluid.
- Applying pulsating flowrate in DASC, improves the thermal efficiency from 43% to 46.6% and 79.8% to 84.2% for water and nanofluid, respectively.
- The increment efficiency caused by pulsing flowrate is greater for nanofluid than for base fluid. Furthermore, pulsating flowrate eliminate the sedimentation of nanoparticles in DASC which improves its performance in long term.

6 References

[1] M. Karami, M. Bozorgi, and S. Delfani, “Effect of design and operating parameters on thermal performance of low-temperature direct absorption solar collectors: a review,” *J. Therm. Anal. Calorim.*, vol. 146, no. 3, pp. 993–1013, 2021, doi: 10.1007/s10973-020-10043-z.

[2] T. P. Otanicar, P. E. Phelan, R. S. Prasher, G. Rosengarten, and R. A. Taylor, “Nanofluid-based direct absorption solar collector,” *J. Renew. Sustain. Energy*, vol. 2, no. 3, 2010, doi: 10.1063/1.3429737.

[3] H. Tyagi, P. Phelan, and R. Prasher, “Predicted efficiency of a Low-temperature Nanofluid-based direct absorption solar collector,” *J. Sol. Energy Eng. Trans. ASME*, vol. 131, no. 4, pp. 0410041–0410047, 2009, doi: 10.1115/1.3197562.

[4] S. M. Ladjevardi, A. Asnaghi, P. S. Izadkhast, and A. H. Kashani, “Applicability of graphite nanofluids in direct solar energy absorption,” *Sol. Energy*, vol. 94, pp. 327–334, 2013, doi: 10.1016/j.solener.2013.05.012.

[5] M. Karami, M. Raisee, and S. Delfani, “Numerical investigation of nanofluid-based solar collectors,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 64, no. 1, 2014, doi: 10.1088/1757-899X/64/1/012044.

[6] M. Karami, M. A. Akhavan-Bahabadi, S. Delfani, and M. Raisee, “Experimental investigation of CuO nanofluid-based Direct Absorption Solar Collector for residential applications,” *Renew. Sustain. Energy Rev.*, vol. 52, pp. 793–801, 2015, doi: 10.1016/j.rser.2015.07.131.

[7] S. Delfani, M. Karami, and M. A. Akhavan-Behabadi, “Performance characteristics of a residential-type direct absorption solar collector using MWCNT nanofluid,” *Renew. Energy*, vol. 87, pp. 754–764, 2016, doi: 10.1016/j.renene.2015.11.004.

[8] M. Karami, M. Bozorgi, S. Delfani, and M. A. Akhavan-Behabadi, “Empirical correlations for heat transfer in a silver nanofluid-based direct absorption solar collector,” *Sustain. Energy Technol. Assessments*, vol. 28, no. November 2017, pp. 14–21, 2018, doi: 10.1016/j.seta.2018.05.001.

[9] M. Karami and M. A. A.-B. B. Asghari, S. Delfanic, “Journal of Solar Energy Research (JSER) Potential of Nanodiamond / Water Nanofluid as Working Fluid of Volumetric Click here , type the title of your,” vol. 23, pp. 71–78, 2017.

[10] M. Karami, “Experimental investigation of first and second laws in a direct absorption solar collector using hybrid Fe 3 O 4 /SiO 2 nanofluid,” *J. Therm. Anal. Calorim.*, vol. 136, no. 2, pp. 661–671, 2019, doi: 10.1007/s10973-018-7624-x.
[11] M. Siavashi, K. Ghasemi, R. Yousofvand, and S. Derakhshan, “Computational analysis of SWCNH nanofluid-based direct absorption solar collector with a metal sheet,” *Sol. Energy*, vol. 170, no. January, pp. 252–262, 2018, doi: 10.1016/j.solener.2018.05.020.
[12] M. Turkyilmazoglu, “Performance of direct absorption solar collector with nanofluid mixture,” *Energy Convers. Manag.*, vol. 114, pp. 1–10, 2016, doi: 10.1016/j.enconman.2016.02.003.
[13] L. Jyani, M. Singh, and S. Bohra, “Effect of Volume Concentration on Direct Absorption Solar Collector in Laminar and Turbulent Flow Using,” vol. 5, no. 4, pp. 268–272, 2017.
[14] J. Guo *et al.*, “Enhanced optical properties and light-to-heat conversion performance of Ti3C2/[BMIM]BF4 nanofluids based direct absorption solar collector,” *Sol. Energy Mater. Sol. Cells*, vol. 237, no. June 2021, p. 111558, 2022, doi: 10.1016/j.solmat.2021.111558.
[15] S. Alqaed, J. Mustafa, M. Sharifpur, and G. Cheraghian, “Using nanoparticles in solar collector to enhance solar-assisted hot process stream usefulness,” *Sustain. Energy Technol. Assessments*, vol. 52, no. PA, p. 101992, 2022, doi: 10.1016/j.seta.2022.101992.
[16] M. Vakili, M. Yahyaei, J. Ramsay, P. Aghajannezhad, and B. Paknezhad, “Adaptive neuro-fuzzy inference system modeling to predict the performance of graphene nanoplatelets nanofluid-based direct absorption solar collector based on experimental study,” *Renew. Energy*, vol. 163, pp. 807–824, 2021, doi: 10.1016/j.renene.2020.08.134.