Journal of Advanced Research in Numerical Heat Transfer 25, Issue 1 (2024) 87-99

Journal of Advanced Research in
Numerical Heat Transfer

Journal homepage:
https://semarakilmu.com.my/journals/index.php/arnht/index
ISSN: 2735-0142

Optimizing Solar Dish Concentrator Efficiency with Nanofluids and Diverse Cavity Design

Muhammad Ilham Maulana[1], Mohd Fairusham Ghazali[2,3,*], Arman Abdullah[4], Nor Azwadi Che Sidik[5], Gholamhassan Najafi [1,6], Mohammadreza Hasandust Rostami[6], Ahmad Najafpour[7]

[1] Department of Mechanical Engineering, Faculty of Engineering, Syiah Kuala University, Indonesia
[2] Centre for Research in Advanced Fluid and Process, University Malaysia Pahang, Lebuhraya Tun Razak, Gambang, Kuantan 26300, Pahang, Malaysia
[3] Faculty of Mechanical Engineering, Industrial University of Ho Chi Minh City, 12 Nguyen Van Bao St, Go Vap, Ho Chi Minh City, Vietnam
[4] Faculty of electrical and electronics engineering, University of Malaysia Pahang Al-Sultan Abdullah, 26600 Pekan, Pahang, Malaysia
[5] Semarak Ilmu, Kuala Lampur, No. 7-G, Jalan Puteri 3A/7, Bandar Bukit Mahkota, 43000 Kajang, Selangor, Malaysia
[6] Department of Biosystems Engineering, Tarbiat Modares University, Tehran, Iran
[7] Department of Mechanical Engineering, Babol Noshirvani University of Technology, Babol, Iran

ARTICLE INFO

Article history:
Received 17 July 2024
Received in revised form 15 August 2024
Accepted 19 September 2024
Available online 30 October 2024

Keywords:
Solar Dish Concentrator; CFD Simulation; Nanofluids; Sustainable Energy Solution; Cubical cavity receiver

ABSTRACT

The quest for enhanced efficiency in solar energy systems has directed significant attention towards optimizing solar dish concentrators. This study investigates the performance enhancement of solar dish concentrators through the use of advanced nanofluid solutions and innovative cavity designs. The experimental setup includes various nanofluid concentrations and different cavity geometries to evaluate their impact on the overall efficiency of the system. Experimental and numerical results demonstrate a marked improvement in thermal performance, with nanofluid and cavity designs achieving up to 12% increase in efficiency compared to conventional systems. The results revealed that the hemispherical and the cubical cavities are the most effective designs, while the cylindrical cavity presents lower performance. The findings provide valuable insights into the potential of nanofluid-based solar dish concentrators and underline the importance of cavity design in optimizing solar energy harnessing. This study lays the groundwork for future research and development in high-efficiency solar energy systems, contributing to the advancement of suitable and renewable energy technologies.

1. Introduction

The increasing demand for renewable energy sources has intensified the focus on optimizing solar energy systems. Among various solar technologies, solar dish concentrators are highly efficient in converting solar energy into thermal energy. However, their performance can be significantly influenced by the type of working fluid and the design of the cavity receiver. In this context, the integration of nanofluids has emerged as a promising solution to enhance the thermal properties of

---

[*] *Corresponding author.*
E-mail address: fairusham@umpsa.edu.my (Mohd Fairusham Ghazali)

https://doi.org/10.37934/arnht.25.1.8799

the working fluid. Furthermore, innovative cavity designs can play a crucial minimizing heat loss and maximizing the absorption of solar radiation. Nanofluids offer superior thermal conductivity, higher heat transfer coefficients, and improved heat capacity compared to conventional fluids, making them ideal candidates for solar thermal applications. By dispersing nanoparticles, the heat transfer characteristics of the base fluid can be significantly improved. This enhancement leads to more efficient thermal energy absorption, storage, and transfer within the solar dish concentrator system. In parallel, the design of the cavity receiver, where the concentrated solar radiation is absorbed and converted into thermal energy, is critical for the overall efficiency of the system. Factors such as cavity shape, size, and material can influence the thermal performance and optical efficiency of the concentrator. Diverse cavity designs, including conical, cylindrical, and spherical shapes, offer varying degrees of thermal insulation and radiation trapping, impacting the efficiency of solar energy conversion. Some studies numerically have considered the nanofluid application in the solar collectors [1-3]. Edalatpour and Solano [4] numerically investigated a flat plate collector using Al2O3/water nanofluid as the solar working fluid. The results indicated that the working fluid outlet temperature decrease with increasing Reynolds number at fix nanoparticle volume fraction. Mahian *et al.,* [5] numerically evaluated the first and second thermodynamic laws on the different water-based nanofluids (Cu/water, Al2O3/water, TiO2/water, and SiO2/water) in a minichannel-based solar collector. The results show the Cu/water nanofluid is the appropriate nanofluid for application in the investigated solar collector due to the highest outlet temperature and the lowest entropy generation. Kaloudis *et al.,* [6] numerically investigated the application of the nanofluid as the solar working fluid in a parabolic trough collector. Bellos *et al.,* [7] theoretically considered a parabolic trough collector using a nanofluid as the solar working fluid. They concluded that the thermal performance of the investigated collector can be improved by 4.25% using the nanofluid as the solar heat transfer fluid. Dugaria *et al.,* [8] numerically investigated a volumetric absorber in a concentrating direct absorption solar collector using the nanofluid application as the solar working fluid. Their simulated results show a good agreement with the experimental results. Application of nanofluid in the solar collector was experimentally investigated by many researches as [9-17]. The thermal performance of a vacuum tube solar collector using two nanofluids including water/TiO2 and water/carbon nanotube, under sunny and cloudy weather conditions has been evaluated by [17]. They concluded that the water/carbon nanofluid shows higher performance compare to water/TiO2. Taylor *et al.,* [18] considered the influence of the nanofluid application in the concentrating solar thermal system. The results indicate the thermal efficiency of the based concentrating solar thermal system could be increased by 10% in the application of nanofluid as the working fluid. Mahian *et al.,* [5] studied the effect of the alumina/water-ethylene glycol nanofluid application as the solar working fluid in a flat plate minichannel-based solar collector. The influence of the different shape of nanoparticles on the energy and exergy analysis was evaluated. They concluded that the outlet temperature increased by application of the nanofluids independent of nanoparticle shape. Meibodi *et al.,* [19] experimentally considered a flat-plate solar collector using SiO2/ ethylene glycol–water nanofluids as the solar working fluid. The influence of the different parameters such as nanoparticle volume fractions, mass flow rate, and solar radiation was evaluated in their study. The results show the exergy efficiency is higher at higher nanoparticle volume fraction. Yousefi *et al.,* [14-16] experimentally evaluated the application of Al2O3/water nanofluid as the solar working fluid in a flat-plate solar collector. Mwesigye *et al.,* [20] numerically research the application of the Al2O3/synthetic oil nanofluid as a solar working fluid of a parabolic trough collector. The results reveal that the thermal efficiency of the investigated collector can be increased by up to 7.6% using nanofluids as the solar working fluid.

This paper explores the optimization of solar dish concentrator efficiency through both experimental and theoretical approaches, focusing on the combined impact of nanofluids and varied cavity configurations. This paper aims to explore the synergetic effect of using advanced nanofluid and optimizing cavity designs on the performance of solar dish concentrators. By conducting both experimental analyses and numerical simulations, the study seeks to identify the optimal combination of nanofluids and cavity configurations that maximize thermal efficiency and minimize energy losses. The findings are expected to contribute to the development of high-performance solar thermal systems, promoting sustainable and efficient renewable energy solutions.

2. Methodology

The experimental setup includes a solar dish concentrator, cavity receivers and a hydraulic close cycle. Figure 1 shows a view of the dish concentrator with an aperture diameter of 1.9 m, the focal distance equal to 1 m and the tracking error to be up to 1º. The volumetric flow rate was 10 ml/s in all the cases. The reflectance of the concentrator was about 84%. Three shapes of cavity receiver including cubical, cylindrical, and hemispherical were designed and built based on the optimum dimensions. As seen from Figure 1, all of the incoming solar radiation at the dish aperture area was concentrated at the focal point where the cavity receivers were located. The focused solar irradiation hit the cavity tubes and absorbed with the solar working fluid which flows through the cavity tubes. The solar working fluid enters from the bottom of the cavity and exits from the upper side of the cavity receivers as a recommended way for increasing solar radiation absorption. Generally, the working fluid is pumped from the inlet tank to the cavity receiver. The volume flow rate of the working fluid is measured between the pump and the inlet of the cavity receiver by a volume flow meter FLUIDWELL model: F016-P. The solar irradiation is absorbed by the receiver and it is given to the heat transfer fluid. The temperature of the working fluid is measured at the inlet and outlet of the cavity receiver by using K-type thermocouples (Chromel-Alumel). The heated working fluid was entered in a heat exchanger system for rejecting the absorbed heat. Finally, the cooled working fluid enters in the inlet tank for another cycle. It should be mentioned that the environmental parameters including wind speed, solar irradiation and ambient temperature were measured using anemometer CT model: AM-4220, Hukseflux Pyranometer, model SR12, and K-type thermocouple, during the experimental tests, respectively. Also, an Omron data logger model: ZR-RX-45 was used for monitoring and storing measured temperatures. In this work, the investigated nanofluid is the Al2O3/oil. The nanoparticles Al2O3 (gamma, 99%, 30-40 nm) were provided by the US Research Nanomaterial Company in the American. Figure 1 (left) illustrates the Al2O3 nanoparticles preparation process.

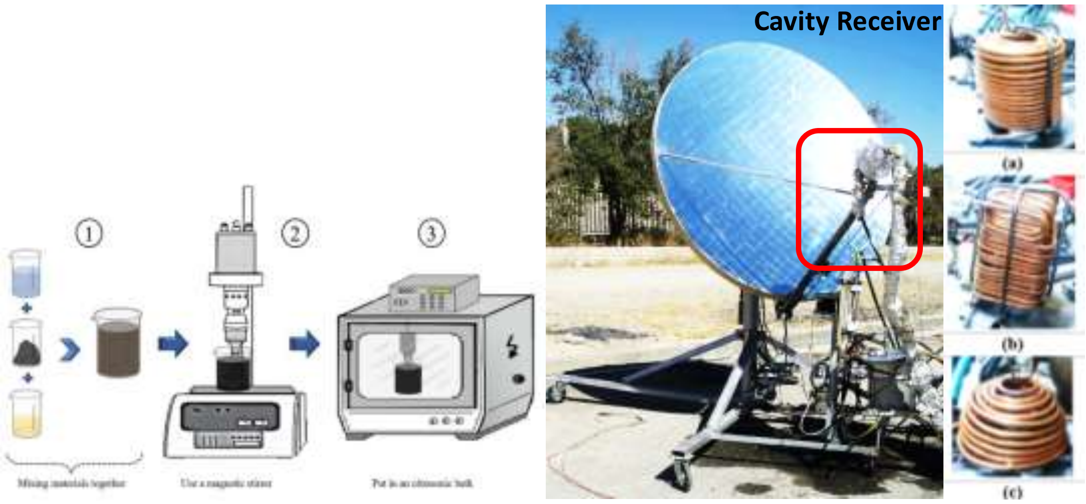
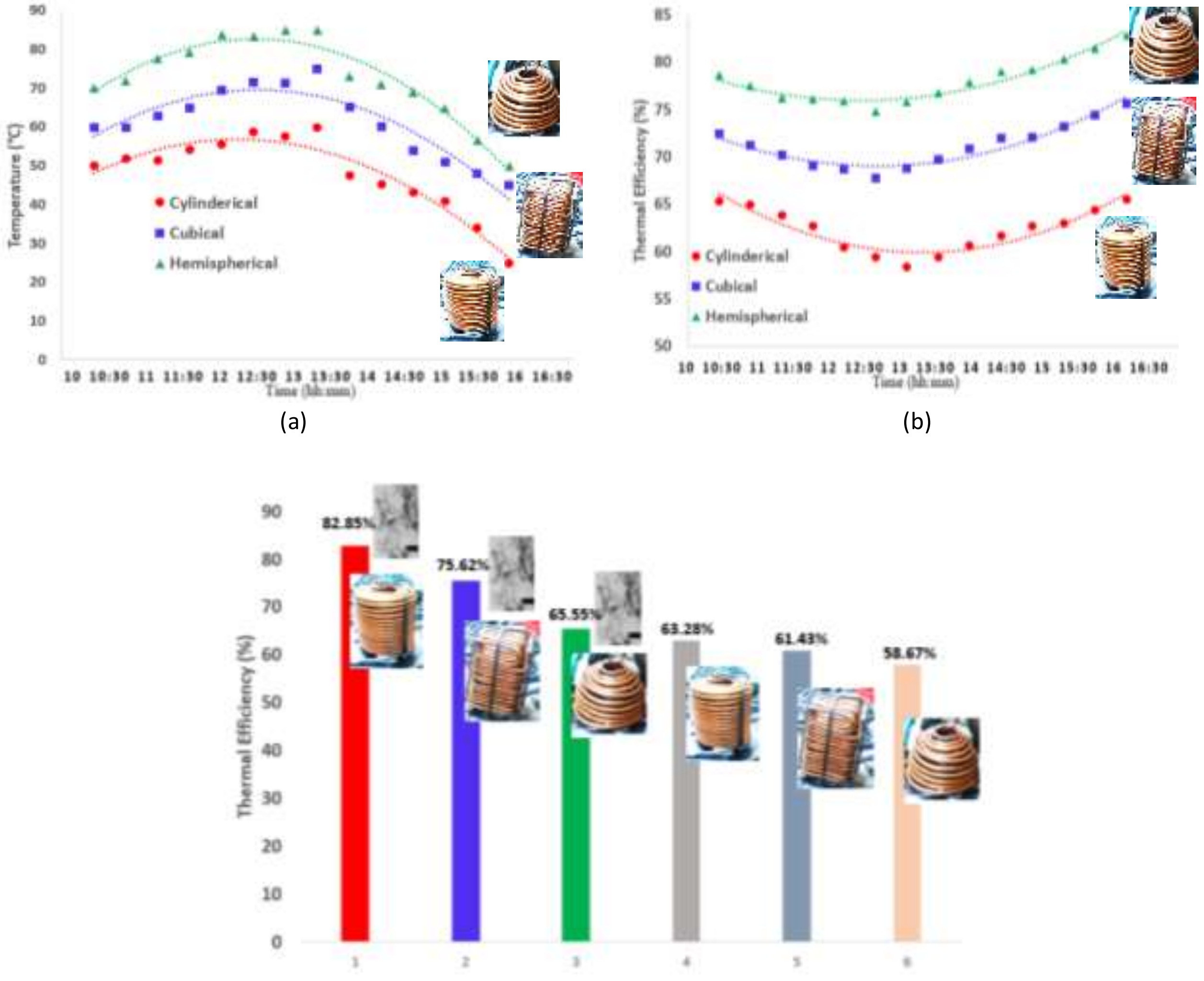


Fig. 1. (left) Process of the Al_2O_3 nanoparticles preparation, (right) A view of the solar dish concentrator and the wounded cavity receivers with copper tube including a) cylindrical, b) cubical, and c) hemispherical cavity receiver

3. Results

As it has been described at Figure 2(a), using nanofluid reduced the solar dish surface temperature. Experimental results approved that using nanofluids reduces the solar dish surface temperature due to their enhanced thermal conductivity and heat transfer properties, nanofluids have a higher thermal conductivity compared to conventional fluids, this allows them to absorb and transfer heat more efficiently, leading to improved cooling of the solar dish surface. The addition of nanoparticles increases the heat transfer coefficient of the fluid. This enhances the rate at which heat is removed from the solar dish surface, thus reducing its temperature [12-18]. Nanoparticles increase the effective surface area available for heat transfer. This helps in dissipating more heat from the solar dish surface into the fluid. The presence of nanoparticles in the fluid reduces the thermal resistance between the solar dish surface and the cooling fluid. This results in more effective heat removal and lower solar dish surface temperatures [19-24]. Nanofluids enhance convective heat transfer due to improved fluid dynamics and thermal properties, this leads to better heat dissipation from the solar dish surface to the fluid. Overall, it can be concluded that the use of nanofluids helps in maintaining a lower PV surface temperature, which can improve the efficiency and longevity of the solar dish system [25-28]. The output power of the solar dish system increased with the use of nanofluids due to higher thermal conductivity of nanofluids compared to conventional fluids. This allows them to absorb and dissipate heat more efficiently, resulting in better cooling of the solar dish (Figure 2b). Cooler solar dish operates more efficiently, producing more electrical power [29-31]. The addition of nanoparticles to the fluid increases the overall heat transfer coefficient, this enhances the convective heat transfer from the solar dish to the cooling fluid, keeping the cells at a lower, more stable temperature and improving their performance. The output power of the solar dish was increased by 32% by utilizing nanofluid. The overall efficiency of the solar dish is increased by using nanofluids, using Al2O3 increased the efficiency by 22%. It can be said that the temperature increase, which is obvious through the horizontal axis parameter, leads to a small reduction in the thermal efficiency. This result indicates that the solar dish collectors are ideal for high-temperature applications. The use of nanofluid leads to higher thermal efficiency compared to the pure oil, the fact proves that the nanofluid is beneficial for the collector performance. However, the useful heat production with the pure oil is higher because of the higher solar potential during the experiments with the pure thermal oil. The thermal efficiency is higher for the hemispherical case with the cubical and the cylindrical to follow respectively. During the solar noon, the hemispherical and the cubical present approximately the same performance, the fact that makes them both optimum designs. The solar heat gain is higher for the hemispherical design due to the higher solar potential the day of its experimental investigation. The use of nanofluid leads always to better performance than the pure thermal oil. Moreover, the hemispherical design is better than cubical and the cylindrical is the worst case. Generally, the performance has been found between 58% and 83%, high values which proves that the solar dish concentrator is an efficient solar technology. The hemispherical cavity not only has the highest performance but also it is enhanced more than the others with the nanofluid. The cubical case is enhanced about 5.84% which is a promising value. Moreover, it is useful to state that the thermal efficiency enhancement is higher in greater inlet temperatures (Figure 2c). This is a very important result because the high temperatures are very interesting for solar dishes.

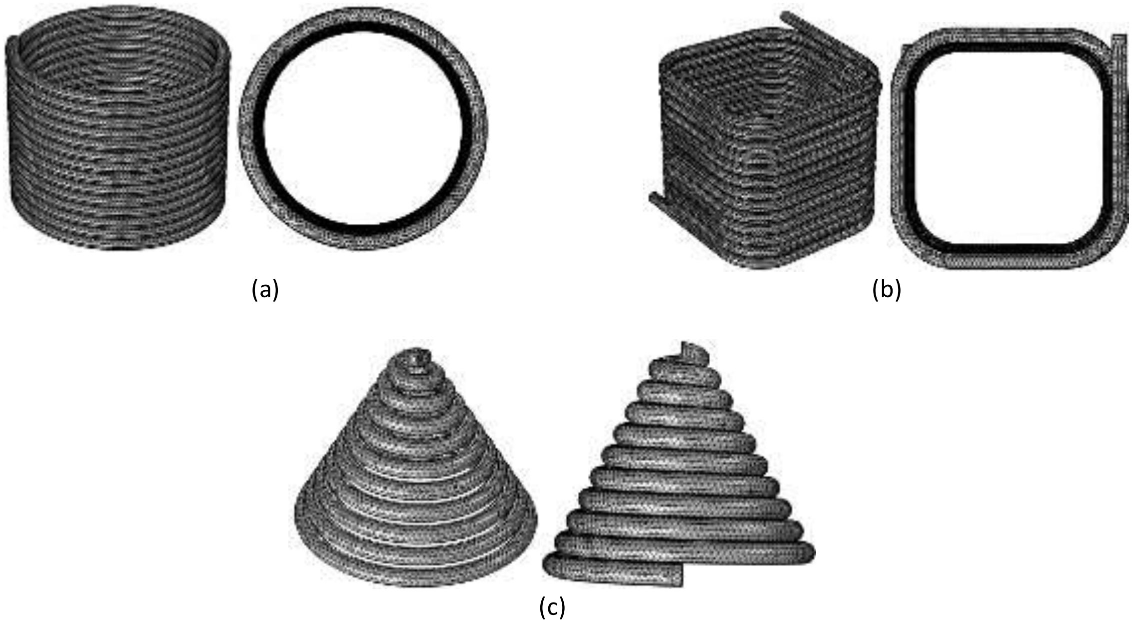


(a) (b)

(c)

Fig. 2. (a) Thermal efficiency curves for all the cavities with nanofluid as working fluid, (b) Thermal efficiency curves for all the cavities with nanofluid as working fluid, (c) Final comparison of the efficiency curves for cylindrical, cubical and hemispherical cavities with and without nanofluids

The temperature gradient in the solar dish concentrator system was analyzed using COMSOL Multiphysics software to visualize the temperature distribution contours. Figure 3 displays the detailed gridded model of the solar concentrator system, utilizing fine grids for enhanced calculation precision.

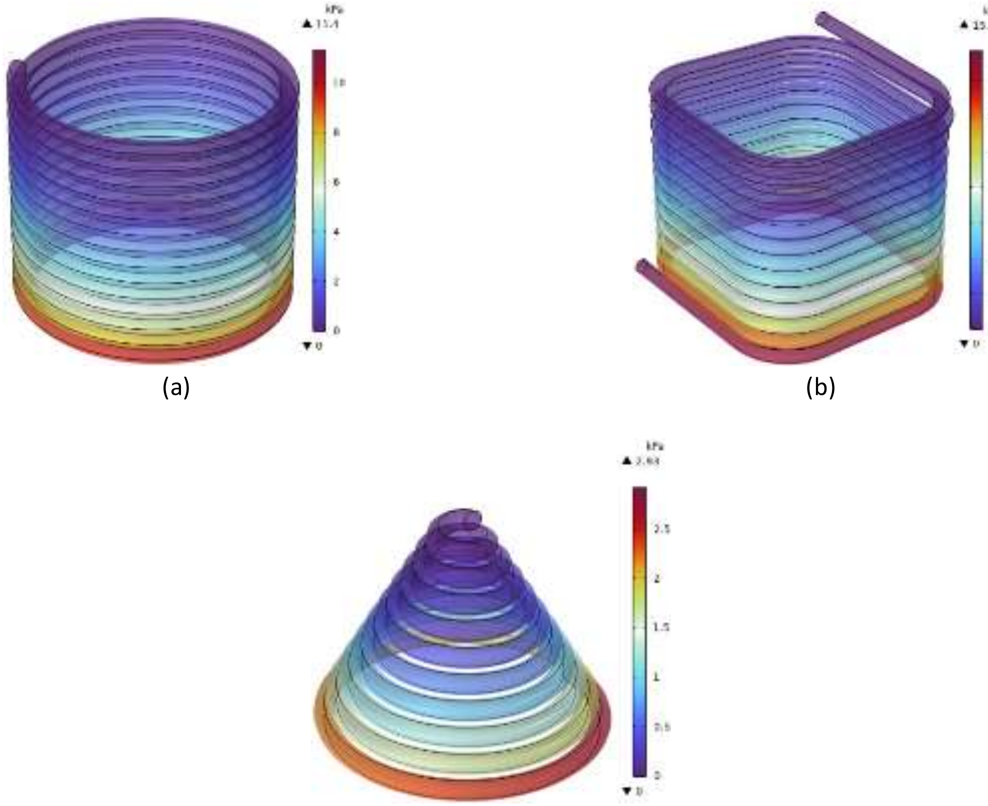


(a) (b)

(c)

Fig. 3. Different solar cavities, (a) Cylindrical, (b) Cubical and (c) Hemispherical

The number of elements has been selected in such a way that the grid independence operation has been carried out with high precision so that in addition to reducing the time and cost of computation, the results of the simulation are made with the least impact of the number and type of the grids. In this research, triangular grids have been used, which include a higher number of elements than other types. Figure 4 shows the pressure drop of the system in different types of cavities. The pressure contour at the entrance of different cases shows higher values, so that as the path increases and approaches the end of the fluid circulation path, the fluid pressure is lower and as a result the pressure drop increases. Because with the increase in the length of the thermal coil, the friction of the wall with the thermal fluid increases [32-40]. Also, the highest inlet pressure is related to the cubical case because it has more path curves, as a result, the pressure drop increases more. Also, in the cubical case, the inlet pressure increases more. While the hemispherical case shows the lowest pressure drop and the lowest input pressure, because the length of the heating coil is shorter and the desired path is smoother and softer.

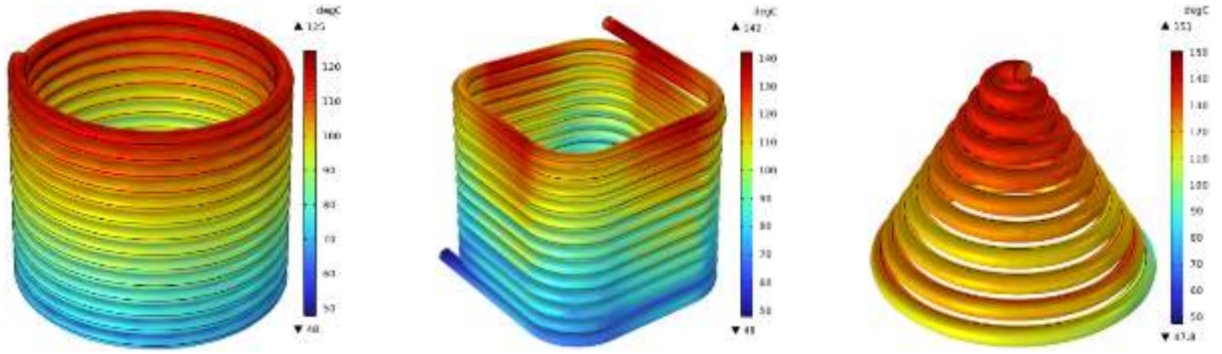


(a) (b)

(c)

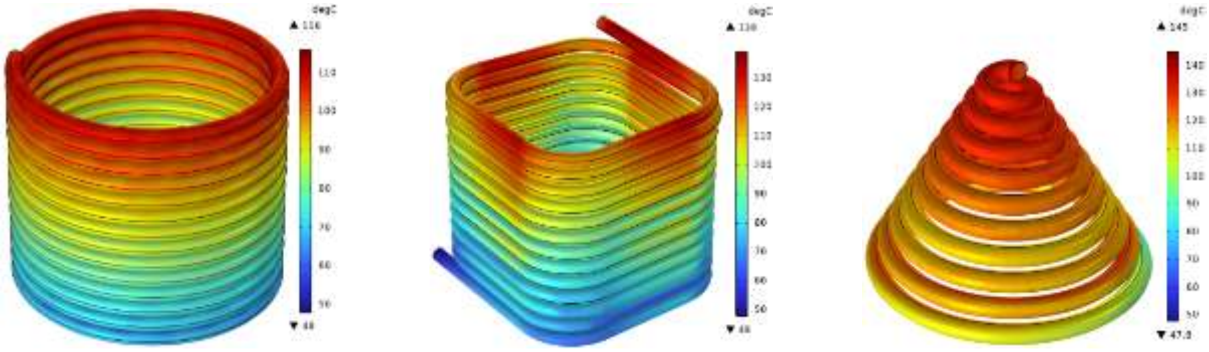
Fig. 4. Pressure drop of three cases of solar cavities at volume flow rate of 10 ml/s where a) Cylindrical, b) Cubical, c) Hemispherical

Figure 5 shows the temperature contour distributed on the surfaces of thermal cavities at 11:30 and 13:00. According to the desired shape, the hemispherical case shows the highest temperature gradient, and after that, the cubical and cylindrical cases performed better. Because in the hemispherical case, the end of the path and the conical head of the receiver can absorb more heat flux and the temperature is more concentrated at this point. On the other hand, the cubical case has a better performance than the cylindrical case because due to the increase in the corners of the fluid path, the amount of fluid retention time has increased



(a) (b) (c)

(i)

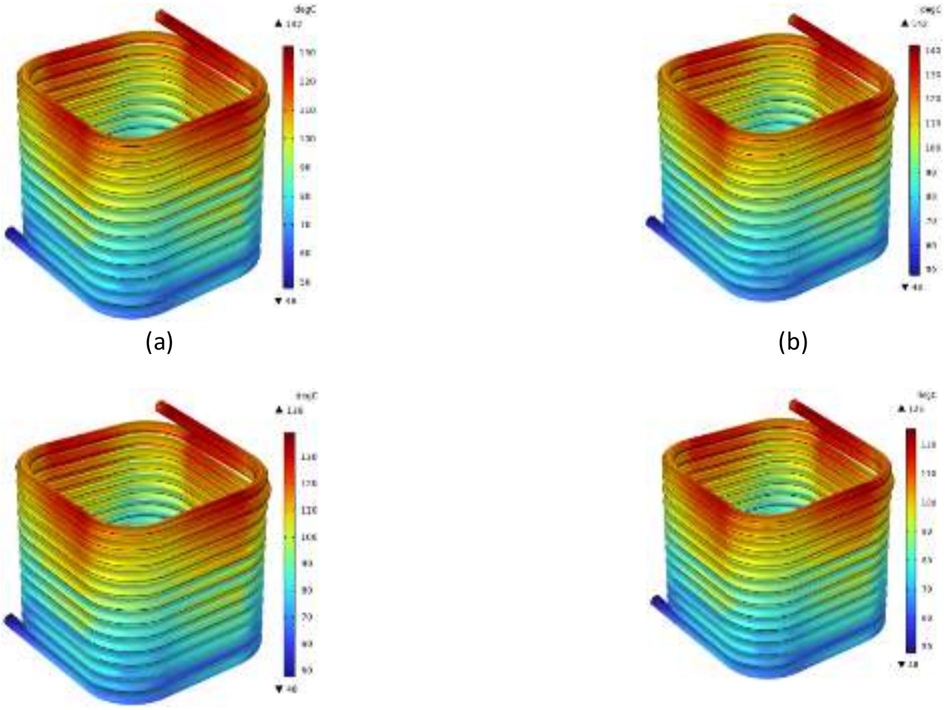


(a) (b) (c)

(ii)

Fig. 5. Temperature gradient of the cavities at volume flow rate of 10 ml/s at (i) 11:30 and (ii) 13:00, for a) Cylindrical, b) Cubical, c) Hemispherical

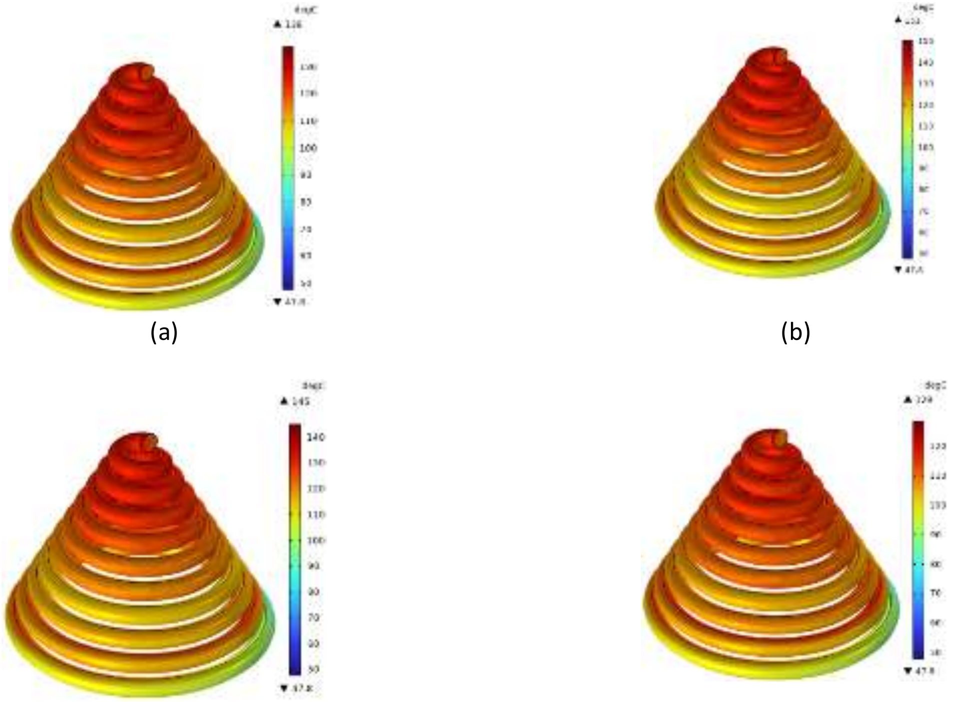
Figure 6 has evaluated two cubical and hemispherical thermal cavities at different hours of the day and at equal volumetric flow rates. Thermal contours have shown that at 11:30 and 13:00 hours the output temperature of the heating coils increased more because the solar radiation received by the coils increased [41-45]. Also, the comparison of the two cases shows that the hemispherical coil has a better performance than the other case at all times, which is due to the geometry of the coil and the conicalness of the coil. For this reason, the amount of heat flux and solar radiation in the head of the cone has increased, which has caused an increase in the output temperature. On the other hand, hemispherical coils deliver more heat to the working fluid due to the concentrated design along the flow path.



(a) (b)

(c) (d)

(i)



(a) (b)

(c) (d)

(ii)

Fig. 6. Working fluid temperature variation of (i) cubical temperature and (ii) hemispherical temperature at a) 10:00, b) 11:30, c) 13:00, d) 14:30

Figure 7 shows the evaluation and comparison of the results between the experimental and numerical mode for different cavities during the day. According to the diagram, it can be seen that the results in different cases are in good agreement with each other, so that the maximum percentage difference between the numerical and practical results in different cases is less than 7%. Also, the most consistent results are seen in the hemispherical coil and the biggest error is related to the cylindrical coil by 6.5% [46-51].

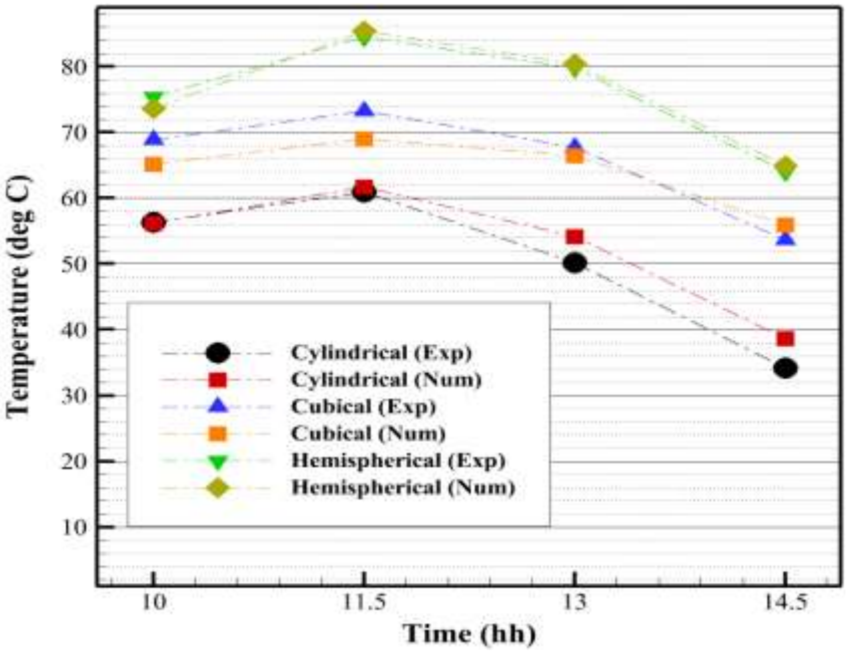


Fig. 7. Validation between numerical and experimental results

4. Conclusions

In this study, a dish concentrator with two shapes of cavity receiver including a cubical and cylindrical cavity receiver was analyzed numerically and experimentally. Thermal oil was used as the solar heat transfer fluid. The use of nanofluid in the cubical receiver leads to higher thermal performance compared to the operation with pure thermal oil. The cubical and the hemispherical cavities are the most efficient cavities, while the cylindrical cavity presents the less efficiency. For all the examined cavities, the use of nanofluids is found to be beneficial for the thermal performance. The comparison of experimental and numerical results in different cases proved that they are in good agreement with each other, so that the maximum percentage difference between the numerical and practical results in different cases is less than 7%. Also, the most consistent results are seen in the hemispherical coil and the biggest error is related to the cylindrical coil by 6.5%.

References

[1] Khullar, Vikrant, Himanshu Tyagi, Patrick E. Phelan, Todd P. Otanicar, Harjit Singh, and Robert A. Taylor. "Solar energy harvesting using nanofluids-based concentrating solar collector." *Journal of Nanotechnology in Engineering and Medicine* 3, no. 3 (2012): 031003. https://doi.org/10.1115/1.4007387

[2] Loni, R. al, E. Askari Asli-Ardeh, B. Ghobadian, A. B. Kasaeian, and Sh Gorjian. "Thermodynamic analysis of a solar dish receiver using different nanofluids." *Energy* 133 (2017): 749-760. https://doi.org/10.1016/j.energy.2017.05.016

[3] Tyagi, Himanshu, Patrick Phelan, and Ravi Prasher. "Predicted efficiency of a low-temperature nanofluid-based direct absorption solar collector." (2009): 041004. https://doi.org/10.1115/1.3197562

[4] Edalatpour, Mojtaba, and Juan P. Solano. "Thermal-hydraulic characteristics and exergy performance in tube-on-sheet flat plate solar collectors: Effects of nanofluids and mixed convection." *International Journal of Thermal Sciences* 118 (2017): 397-409. https://doi.org/10.1016/j.ijthermalsci.2017.05.004

[5] Mahian, Omid, Ali Kianifar, Ahmet Z. Sahin, and Somchai Wongwises. "Performance analysis of a minichannel-based solar collector using different nanofluids." *Energy conversion and management* 88 (2014): 129-138. https://doi.org/10.1016/j.enconman.2014.08.021

[6] Kaloudis, Efstathios, E. Papanicolaou, and V. J. R. E. Belessiotis. "Numerical simulations of a parabolic trough solar collector with nanofluid using a two-phase model." *Renewable Energy* 97 (2016): 218-229. https://doi.org/10.1016/j.renene.2016.05.046

[7] Bellos, E., C. Tzivanidis, K. A. Antonopoulos, and G. J. R. E. Gkinis. "Thermal enhancement of solar parabolic trough collectors by using nanofluids and converging-diverging absorber tube." *Renewable Energy* 94 (2016): 213-222. https://doi.org/10.1016/j.renene.2016.03.062

[8] Dugaria, Simone, Matteo Bortolato, and Davide Del Col. "Modelling of a direct absorption solar receiver using carbon based nanofluids under concentrated solar radiation." *Renewable Energy* 128 (2018): 495-508. https://doi.org/10.1016/j.renene.2017.06.029

[9] He, Qinbo, Shequan Zeng, and Shuangfeng Wang. "Experimental investigation on the efficiency of flat-plate solar collectors with nanofluids." *Applied Thermal Engineering* 88 (2015): 165-171. https://doi.org/10.1016/j.applthermaleng.2014.09.053

[10] Loni, Reyhaneh, E. Askari Asli-Ardeh, B. Ghobadian, M. H. Ahmadi, and Evangelos Bellos. "GMDH modeling and experimental investigation of thermal performance enhancement of hemispherical cavity receiver using MWCNT/oil nanofluid." *Solar Energy* 171 (2018): 790-803. https://doi.org/10.1016/j.solener.2018.07.003

[11] Loni, Reyhaneh, E. Askari Asli-Ardeh, B. Ghobadian, A. B. Kasaeian, and Evangelos Bellos. "Energy and exergy investigation of alumina/oil and silica/oil nanofluids in hemispherical cavity receiver: Experimental Study." *Energy* 164 (2018): 275-287. https://doi.org/10.1016/j.energy.2018.08.174

[12] Otanicar, Todd P., Patrick E. Phelan, Ravi S. Prasher, Gary Rosengarten, and Robert A. Taylor. "Nanofluid-based direct absorption solar collector." *Journal of renewable and sustainable energy* 2, no. 3 (2010). https://doi.org/10.1063/1.3429737

[13] Loni, R., E. Askari Asli-Ardeh, B. Ghobadian, A. B. Kasaeian, and Evangelos Bellos. "Thermal performance comparison between Al2O3/oil and SiO2/oil nanofluids in cylindrical cavity receiver based on experimental study." *Renewable energy* 129 (2018): 652-665. https://doi.org/10.1016/j.renene.2018.06.029

[14] Yousefi, Tooraj, E. Shojaeizadeh, F. Veysi, and S. Zinadini. "An experimental investigation on the effect of pH variation of MWCNT–H2O nanofluid on the efficiency of a flat-plate solar collector." *Solar Energy* 86, no. 2 (2012): 771-779. https://doi.org/10.1016/j.solener.2011.12.003

[15] Yousefi, Tooraj, Farzad Veisy, Ehsan Shojaeizadeh, and Sirus Zinadini. "An experimental investigation on the effect of MWCNT-H2O nanofluid on the efficiency of flat-plate solar collectors." *Experimental thermal and fluid science* 39 (2012): 207-212. https://doi.org/10.1016/j.expthermflusci.2012.01.025

[16] Yousefi, Tooraj, Farzad Veysi, Ehsan Shojaeizadeh, and Sirus Zinadini. "An experimental investigation on the effect of Al2O3–H2O nanofluid on the efficiency of flat-plate solar collectors." *Renewable Energy* 39, no. 1 (2012): 293-298. https://doi.org/10.1016/j.renene.2011.08.056

[17] He, Yurong, Shufu Wang, Junjun Ma, Fenglin Tian, and Yatao Ren. "Experimental study on the light-heat conversion characteristics of nanofluids." *Nanoscience and Nanotechnology Letters* 3, no. 4 (2011): 494-496. https://doi.org/10.1166/nnl.2011.1194

[18] Taylor, Robert A., Patrick E. Phelan, Todd P. Otanicar, Chad A. Walker, Monica Nguyen, Steven Trimble, and Ravi Prasher. "Applicability of nanofluids in high flux solar collectors." *Journal of Renewable and Sustainable Energy* 3, no. 2 (2011). https://doi.org/10.1063/1.3571565

[19] Meibodi, Saleh Salavati, Ali Kianifar, Omid Mahian, and Somchai Wongwises. "Second law analysis of a nanofluid-based solar collector using experimental data." *Journal of Thermal Analysis and Calorimetry* 126 (2016): 617-625. https://doi.org/10.1007/s10973-016-5522-7

[20] Mwesigye, Aggrey, Zhongjie Huan, and Josua P. Meyer. "Thermodynamic optimisation of the performance of a parabolic trough receiver using synthetic oil–Al2O3 nanofluid." *Applied Energy* 156 (2015): 398-412. https://doi.org/10.1016/j.apenergy.2015.07.035

[21] Ali, Obed M., Rizalman Mamat, Gholamhassan Najafi, Talal Yusaf, and Seyed Mohammad Safieddin Ardebili. "Optimization of biodiesel-diesel blended fuel properties and engine performance with ether additive using statistical analysis and response surface methods." *Energies* 8, no. 12 (2015): 14136-14150. https://doi.org/10.3390/en81212420. https://doi.org/10.3390/en81212420

[22] Hamid, K. Abdul, W. H. Azmi, Rizalman Mamat, N. A. Usri, and G. Najafi. "Effect of temperature on heat transfer coefficient of titanium dioxide in ethylene glycol-based nanofluid." *Journal of Mechanical Engineering and Sciences* 8 (2015): 1367-1375. https://doi.org/10.15282/jmes.8.2015.11.0133

[23] Darminesh, Sathuramalingam Pillay, Nor Azwadi Che Sidik, G. Najafi, Rizalman Mamat, Tan Lit Ken, and Yutaka Asako. "Recent development on biodegradable nanolubricant: A review." *International Communications in Heat and Mass Transfer* 86 (2017): 159-165. https://doi.org/10.1016/j.icheatmasstransfer.2017.05.022

[24] Najafi, Gholamhassan, Barat Ghobadian, Talal Yusaf, and Hadi Rahimi. "Combustion analysis of a CI engine performance using waste cooking biodiesel fuel with an artificial neural network aid." *American Journal of Applied Sciences* 4, no. 10 (2007): 756-764. https://doi.org/10.3844/ajassp.2007.759.767

[25] Yazid, Muhammad Noor Afiq Witri Muhammad, Nor Azwadi Che Sidik, Rizalman Mamat, and GJICiH Najafi. "A review of the impact of preparation on stability of carbon nanotube nanofluids." *International Communications in Heat and Mass Transfer* 78 (2016): 253-263. https://doi.org/10.1016/j.icheatmasstransfer.2016.09.021

[26] Najafi, Gholamhassan, and Barat Ghobadian. "LLK1694-wind energy resources and development in Iran." *Renewable and Sustainable Energy Reviews* 15, no. 6 (2011): 2719-2728. https://doi.org/10.1016/j.rser.2011.03.002

[27] Hoseini, S. S., G. Najafi, B. Ghobadian, R. Mamat, M. T. Ebadi, and Talal Yusaf. "Ailanthus altissima (tree of heaven) seed oil: Characterisation and optimisation of ultrasonication-assisted biodiesel production." *Fuel* 220 (2018): 621-630. https://doi.org/10.1016/j.fuel.2018.01.094

[28] Shayan, Mostafa Esmaeili, Gholamhassan Najafi, Barat Ghobadian, Shiva Gorjian, Rizalman Mamat, and Mohd Fairusham Ghazali. "Multi-microgrid optimization and energy management under boost voltage converter with Markov prediction chain and dynamic decision algorithm." *Renewable Energy* 201 (2022): 179-189. https://doi.org/10.1016/j.renene.2022.11.006

[29] Harun, M. H. S., M. F. Ghazali, and A. R. Yusoff. "Analysis of tri-axial force and vibration sensors for detection of failure criterion in deep twist drilling process." *The International Journal of Advanced Manufacturing Technology* 89 (2017): 3535-3545. https://doi.org/10.1007/s00170-016-9344-3

[30] Yusof, M. F. M., M. A. Kamaruzaman, M. Ishak, and M. F. Ghazali. "Porosity detection by analyzing arc sound signal acquired during the welding process of gas pipeline steel." *The International Journal of Advanced Manufacturing Technology* 89 (2017): 3661-3670. https://doi.org/10.1007/s00170-016-9343-4

[31] Zawawi, N. N. M., W. H. Azmi, and M. F. Ghazali. "Performance of Al2O3-SiO2/PAG composite nanolubricants in automotive air-conditioning system." *Applied Thermal Engineering* 204 (2022): 117998 https://doi.org/10.1016/j.applthermaleng.2021.117998.

[32] Yusof, M. F. M., M. Ishak, and M. F. Ghazali. "Weld depth estimation during pulse mode laser welding process by the analysis of the acquired sound using feature extraction analysis and artificial neural network." *Journal of manufacturing processes* 63 (2021): 163-178. https://doi.org/10.1016/j.jmapro.2020.04.004

[33] Zawawi, Nurul Nadia Mohd, Wan Hamzah Azmi, Mohd Fairusham Ghazali, and Hafiz Muhammad Ali. "Performance of air-conditioning system with different nanoparticle composition ratio of hybrid nanolubricant." *Micromachines* 13, no. 11 (2022): 1871. https://doi.org/10.3390/mi13111871

[34] Ahmadlou, Leila Abesh, Gholamhassan Najafi, Reyhaneh Loni, Alibakhsh Kasaeian, Rizalman Mamat, Mohd Fairusham Ghazali, A. Abdullah, A. S. Ei-Shafy, and Mohamed Mousa. "Experimental investigation of PV/T and thermoelectric systems using CNT/water nanofluids." *Applied Thermal Engineering* 227 (2023): 120350. https://doi.org/10.1016/j.applthermaleng.2023.120350

[35] Sharif, Mohd Zaki, Wan Hamzah Azmi, Mohd Fairusham Ghazali, Nurul Nadia Mohd Zawawi, and Hafiz Muhammad Ali. "Viscosity and friction reduction of double-end-capped polyalkylene glycol nanolubricants for eco-friendly refrigerant." *Lubricants* 11, no. 3 (2023): 129. https://doi.org/10.3390/lubricants11030129

[36] Sharif, M. Z., W. H. Azmi, M. F. Ghazali, N. N. M. Zawawi, and H. M. Ali. "Numerical and thermo-energy analysis of cycling in automotive air-conditioning operating with hybrid nanolubricants and R1234yf." *Numerical Heat Transfer, Part A: Applications* 83, no. 9 (2023): 935-957. https://doi.org/10.1080/10407782.2022.2155277

[37] Yusop, Hanafi M., M. F. Ghazali, M. F. M. Yusof, MA Pi Remli, and M. H. Kamarulzaman. "Pipe leak diagnostic using high frequency piezoelectric pressure sensor and automatic selection of intrinsic mode function." In *IOP Conference Series: Materials Science and Engineering*, vol. 257, no. 1, p. 012091. IOP Publishing, 2017. https://doi.org/10.1088/1757-899X/257/1/012091

[38] Yusof, M. F. M., M. Ishak, and M. F. Ghazali. "Feasibility of using acoustic method in monitoring the penetration status during the Pulse Mode Laser Welding process." In *IOP Conference Series: Materials Science and Engineering*, vol. 238, no. 1, p. 012006. IOP Publishing, 2017. https://doi.org/10.1088/1757-899X/238/1/012006

[39] M Yusop, Hanafi, M. F. Ghazali, M. F. M Yusof, and W. S. W Hamat. "Improvement of Cepstrum Analysis for the Purpose to Detect Leak, Feature and Its Location in Water Distribution System based on Pressure Transient Analysis/Hanafi. M. Yusop...[et al.]." *Journal of Mechanical Engineering (JMechE)* 4 (2019): 103-122.

[40] Yusof, M. F. M., M. M. Quazi, S. A. A. Aleem, M. Ishak, and M. F. Ghazali. "Identification of weld defect through the application of denoising method to the sound signal acquired during pulse mode laser welding." *Welding in the World* 67, no. 5 (2023): 1267-1281. https://doi.org/10.1007/s40194-023-01472-z

[41] Mopuri, Obulesu, Raghunath Kodi Madhu, Mohan Reddy Peram, Charankumar Ganteda, Giulio Lorenzini, and Nor Azwadi Sidik. "Unsteady MHD on convective flow of a Newtonian fluid past an inclined plate in presence of chemical reaction with radiation absorption and Dufour effects." *CFD Letters* 14, no. 7 (2022): 62-76. https://doi.org/10.37934/cfdl.14.7.6276

[42] Lounis, Selma, Redha Rebhi, Noureddine Hadidi, Giulio Lorenzini, Younes Menni, Houari Ameur, and Nor Azwadi Che Sidik. "Thermo-solutal convection of Carreau-Yasuda non-Newtonian fluids in inclined square cavities under Dufour and Soret impacts." *CFD Letters* 14, no. 3 (2022): 96-118. https://doi.org/10.37934/cfdl.14.3.96118

[43] Reddy, Thummala Sankar, P. Roja, S. Mohammed Ibrahim, Giulio Lorenzini, and Nor Azwadi Che Sidik. "Characteristic of Thermal Radiation on MHD Fluid Stream of Nano-Fluid over an Exponentially Elongating Sheet by Means of Warm and Mass Fluxes." *CFD Letters* 14, no. 4 (2022): 80-90. https://doi.org/10.37934/cfdl.14.4.8090

[44] Loni, Reyhaneh, Gholamhassan Najafi, Rizalman Mamat, Mohd Fairusham Ghazali, and Nor Azwadi Che Sidik. "Nusselt Number Prediction for Oil and Water in Solar Tubular Cavity Receivers." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 97, no. 2 (2022): 157-174. https://doi.org/10.37934/arfmts.97.2.157174

[45] Tan, Jian Hong, Toru Yamada, Yutaka Asako, Lit Ken Tan, and Nor Azwadi Che Sidik. "Study of self diffusion of nanoparticle using dissipative particle dynamics." *Journal of Advanced Research in Numerical Heat Transfer* 10, no. 1 (2022): 1-7.

[46] Lam, Boon Chun, Yutaka Asako, Chungpyo Hong, Lit Ken Tan, and Nor Azwadi Che Sidik. "Validity of Performance Factors used in Recent Studies on Heat Transfer Enhancement by Surface Modification or Insert Devices: Constant Heat Flux Case." *Journal of Advanced Research in Numerical Heat Transfer* 11, no. 1 (2022): 1-4.

[47] Rostami, Mohammadreza Hasandust, Gholamhassan Najafi, Ali Motevalli, Nor Azwadi Che Sidik, and Muhammad Arif Harun. "Evaluation and improvement of thermal energy of heat exchangers with SWCNT, GQD nanoparticles and PCM (RT82)." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 79, no. 1 (2021): 153-168. https://doi.org/10.37934/arfmts.79.1.153168

[48] Harun, Muhammad Arif, and Nor Azwadi Che Sidik. "Thermal Conductivity-Based Optimisation of Surfactant on Hybrid Nanofluid." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 98, no. 1 (2022): 73-81. https://doi.org/10.37934/arfmts.98.1.7381

[49] Xian, Hong Wei, Nor Azwadi Che Sidik, Siti Rahmah Aid, Tan Lit Ken, and Yutaka Asako. "Review on Preparation Techniques, Properties and Performance of Hybrid Nanofluid in Recent Engineering Application." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 45, no. 1 (2018): 1-13.

[50] Harun, Muhammad Arif, Nor Azwadi Che Sidik, Yutaka Asako, and Tan Lit Ken. "Recent review on preparation method, mixing ratio, and heat transfer application using hybrid nanofluid." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 95, no. 1 (2022): 44-53. https://doi.org/10.37934/arfmts.95.1.4453

[51] Selamat, Muhammad Syafiq Ridhwan, Muhammad Thalhah Zainal, Mohd Fairus Mohd Yasin, and Norikhwan Hamzah. "Modelling of the Flame Synthesis of Single-walled Carbon Nanotubes in Non-premixed Flames with Aerosol Catalyst." *Journal of Advanced Research in Numerical Heat Transfer* 13, no. 1 (2023): 39-51. https://doi.org/10.37934/arnht.13.1.3951