Journal of Mines, Metals and Fuels, *73(6): 1699-1706; 2025. DOI: 10.18311/jmmf/2025/49028*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.co.in/index.php/jmmf*

Enhancing Heat Transfer in Tubular Heat Exchanger Using Minijet Technology

Shital Yashwant Waware[1,5,6]*, Pallavi Pankaj Ahire[2], Priti Ravishankar Ghutepatil[3], Ramdas Biradar[2], Arjun Arun Kadam[4], Sandeep Sadashiv Kore[5], Anant Sidhappa Kurhade[1,6] and Komal Baban Ghunake[7]

[1]Department of Mechanical Engineering, Dr. D. Y. Patil Institute of Technology Pimpri, Pune - 411018, Maharashtra, India; sywdit@gmail.com

[2]School of Engineering and Technology, PCET's Pimpri Chinchwad University, Sate, Pune - 412106, Maharashtra, India

[3]Department of Applied Science, PCET's Pimpri Chinchwad College of Engineering and Research, Ravet - 412101, Pune, Maharashtra, India

[4]Department of Mechanical Engineering, Arvind Gavali College of Engineering, Satara - 415015, Maharashtra, India

[5]Department of Mechanical Engineering, Vishwakarma Institute of Information Technology, Pune - 411048, Maharashtra, India

[6]School of Technology and Research, Dr. D. Y. Patil Dnyan Prasad University, Pune - 411018, Maharashtra, India

[7]Department of Physics, Dr. D. Y. Patil Art, Commerce and Science College, Akurdi, Pune - 411044, Maharashtra, India

Abstract

This study introduces a patented cylindrical heat exchanger design enhanced by minijet technology to improve heat transfer performance. A series of systematic experiments was conducted, focusing on single-phase convection heat transfer. The experimental results were used to validate various relationships for the Nusselt number as described in existing literature. The thermal-hydraulic performance of this innovative Minijet Heat Exchanger (MJHE) was compared with that of a conventional shell-and-tube heat exchanger (RHE). Both exchangers were tested under identical thermal conditions, with the same working fluid flow rates and temperatures at the inlets. The results demonstrated a significant increase in heat transfer coefficients for the MJHE, while the hydraulic resistance also saw an increase due to the jet impingement. The minijet heat exchanger's performance was especially advantageous for waste heat recovery applications, particularly when utilizing low-temperature gaseous waste sources. The experimental findings highlight the increased effectiveness of the MJHE, with a notable improvement in air-side heat transfer, which makes this technology a promising solution for micro-CHP systems and other industrial applications requiring efficient heat transfer.

Major Findings: *The Mini-Jet Heat Exchanger (MJHE) enhanced heat transfer coefficients by up to 45 % using jet impingement technology compared to the reference model. Despite increased hydraulic resistance, its compact design proved efficient for low-temperature waste heat recovery. This makes MJHE highly suitable for industrial and micro-CHP applications requiring high thermal performance.*

Keywords: *Energy, Heat Transfer Enhancement, Microjet Technology, Patented Design of Shell-and-Tube Heat Exchanger, Thermal-Hydraulic Characteristics*

**Author for correspondence*

1.0 Introduction

In heat exchanger design, maximizing heat transfer is crucial. This process focuses on improving heating efficiency, measured by increased heat flux, while maintaining manageable hydraulic resistance. Two primary techniques for enhancing heat transfer are commonly used: active and passive methods. Often, a combination of both approaches, referred to as mixed techniques, is employed in engineering practice to achieve more efficient results.

Active techniques require an external energy source. For instance, mechanical disruption of the laminar boundary layer, such as rotating scrapers against the heat transfer surface, can boost heat transfer[1]. Additionally, ultrasound vibrations applied to the heat transfer surface or the fluid passing over it have been shown to increase heat transfer coefficients significantly in laminar flow, which is the predominant flow regime in heat exchangers.

In contrast, passive methods do not require external energy. Instead, they involve modifications to the heat exchanger design or the heat transfer surface, as well as changes to the physical and thermal properties of the heat-carrying fluids[2-4]. Common passive techniques include:

1. Increasing surface roughness,
2. Adding fins to expand the heat transfer area,
3. Twisting the heat transfer surface,
4. Adding solid particles to fluids to create nanofluids,
5. Reducing the hydraulic diameter of flow channels, and
6. Using impinging jets.

Research indicates that surface roughness plays a significant role in thermal performance, though the type of working fluid and operating conditions influence its effectiveness. For example, while increased roughness decreased heat transfer in water, it enhanced heat transfer in alcohol. Flow rate also impacts performance, with increased roughness benefiting heat transfer in boiling operations, as evidenced in both pool and flow boiling studies.

Vortex generators have also been explored for improving heat transfer. These devices create swirling flow patterns that enhance heat exchange. For example, perforations used to generate vortex flows at the heat exchanger entrance improve performance. Additionally, nanofluids, created by adding metallic particles to base fluids like water, can significantly improve heat conductivity[5-7].

The development of micro- and mini channels in heat exchangers is gaining attention due to their ability to reduce hydraulic diameter and intensify heat transfer. These small-scale heat exchangers, such as those used in micro-CHP systems or high-temperature applications like nuclear reactors, demonstrate enhanced heat transfer capabilities.

Impinging jets, a technique that directs high-velocity jets onto a surface, is another promising method for improving heat transfer. For instance, in solar collector applications, impinging jets increase Nusselt numbers, indicating better heat transfer performance. This study focuses on a cylindrical heat exchanger design incorporating minijet technology, an innovative approach still uncommon in the field.

The proposed Minijet Heat Exchanger (MJHE) utilizes radial fluid impingement on a cylindrical heat transfer surface, effectively reducing thermal resistance. Simulations and experiments have validated the role of jet impingement in disrupting the boundary layer and enhancing heat transfer[8-12]. The interaction between jets and crossflow creates vortical patterns that further improve heat exchange efficiency.

Current research is aimed at optimizing the MJHE design to minimize hydraulic resistance while enhancing thermal performance[13]. Initial experiments comparing the MJHE with conventional designs under identical flow and temperature conditions demonstrate the promising potential of minijet technology, especially in improving heat transfer at low flow rates or with small temperature differences.

2.0 Object to Study

2.1 Minijets Heat Exchanger (MJHE)

The following labels: 1 and 3 represent the perforated tubes through which the heating and heated mediums flow, 2 refers to the heat-conducting wall, 4 denotes the shell, and 5 and 6 correspond to the inlet and outlet for the heating medium, while 7 and 8 represent the inlet and outlet for the heated medium. The perforated tubes are separated by a solid heat transfer wall. Perforated partitions are strategically placed to generate jets of

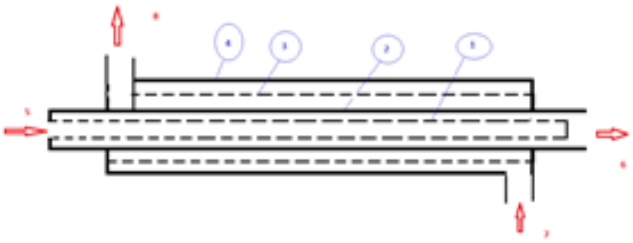


Figure 1. Minjet heat exchanger schematic diagram.

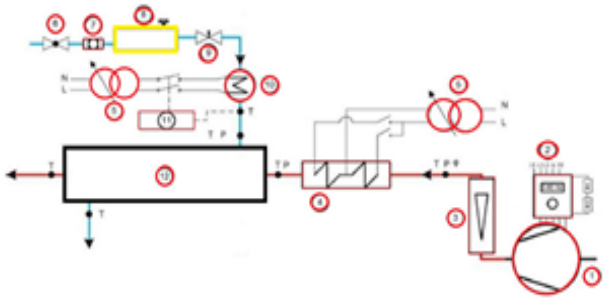


Figure 2. Diagram of the system; 1- radial fan, 2- inverter, 3- rotameter, 4- air heater, 5- autotransformer, 6- main water valve, 7- filter, 8- mass flowmeter, 9- throttling vavle, 10- heater, 11- relay regulator, 12- heat exchanger.

heated fluid from the intake (5) and (1). These jets then impinge upon the cylindrical heat transfer wall (2) as the coolant moves towards the outlet (1) and (6).

The heated medium enters the shell (4) through the intake (7), flowing through the perforated partitions (3). As the heated jets advance towards the outlet, the perforated wall directs them radially, causing them to impinge on the cylindrical heat transfer wall (2), exiting through (8).

2.2 Reference Heat Exchanger

The Reference Heat Exchanger (RHE) was designed without jet impingement technology to match the Minijet Heat Exchanger (MJHE) for comparative analysis.

Thermal conductivity

Diameters of the inlet and outlet connections

Heat exchanger shell and cylindrical heat transfer wall

Overall thermal conductivity.

It is important to note that the two heat exchangers have different hydraulic diameters[14-18]. In the MJHE, a perforated barrier separates the fluid flow from the surrounding area, creating distinct zones of inflow and dispersed flow, especially in the region where the jets impinge upon the heat transfer surface. In contrast, the RHE features a single zone where the heating and heated fluids wash over the heat transfer surface[19,20]. The hydraulic resistance across each heat exchanger is influenced by the differences in flow regimes, such as laminar and turbulent flow.

3.0 Experimental System

Figure 2 shows the laboratory setup at Gdansk University of Technology, designed for heat exchanger analysis and convective heat transfer experiments.

A frequency converter powered a radial fan to circulate air through the setup, passing through a rotameter before reaching the heat exchanger. The system had a 1.8 kW output with an autotransformer ensuring precise control, while a throttling valve regulated water flow, measured by a mass flowmeter[21,22]. T-type thermocouples monitored inlet and exit temperatures, with data stored via an acquisition system, achieving 0.1 K accuracy through sensor calibration[23-25]. For consistency, the temperature for heating air and water was maintained at 23°C, aligning with its use in heat recovery from low-temperature gaseous waste sources[26-31].

Kurhade *et al.*[31–33] explored the performance of solar collectors and investigated the effects of biodiesel and dimethyl carbonate blends on engine efficiency. Waware *et al.*[34] provided a comprehensive review of nanofluid applications in heat exchangers. Further work by Kurhade *et al.*,[35–40] focused on MQL grinding and thermal management in electronic components, emphasizing the role of substrate thermal conductivity and strategic placement of phase change materials in temperature control. Additional studies examined heat transfer in IC chips on SMPS boards and reviewed advanced electronic cooling technologies suited for harsh environments. Research on aerofoil optimization through CFD simulations, coupled with fuzzy logic-based predictions of heat transfer improvements using twisted tape inserts, contributed valuable insights into enhancing heat exchanger efficiency. Moreover, investigations have addressed the mechanical behavior of curved plates[41,42], thermal performance of electronic systems[43], heat transfer enhancement using twisted tape inserts[44,45],

advanced cooling strategies for electronics under extreme conditions[46], and CFD-driven optimization of heat exchanger designs[47–50].

4.0 Results

4.1 Thermal Characteristics

Thermal-hydraulic parameters were measured for heat exchangers operating in a countercurrent configuration, including air and water temperatures, air volume flow rate, water mass flow rate, and air inlet pressure. Both the Mini-Jet Heat Exchanger (MJHE) and the Reference Heat Exchanger (RHE) were tested under identical conditions, with air volume flow rates ranging from 3 to 11 m^3/h and water mass flow rates between 3 and 13 g/s. The Wilson plot method was used to calculate heat transfer coefficients, effectively determining thermal resistance and heat transfer mechanisms. Figure 3 compares the heat exchangers, showing heat transfer coefficients as a function of mass flux at different temperatures (70°C, 100°C, and 130°C). Results indicate that heat transfer coefficients increased with mass flux and ambient temperature, with the MJHE's jet impingement technique enhancing heat transfer by 25 % on the heating side and up to 45 % on the heated side under specific conditions.

Both heat exchangers were subjected to hydraulic resistance tests at temperatures ranging from 20°C to 40°C and 130°C, with the heated medium in each case. There was an increase in the studied flow rates compared to the thermal testing (up to 13 m^3/h for air and up to 35 g/s for water) during these tests. Hydraulic resistance was not influenced by the gravity component by putting the exchangers horizontally. As seen in Figure 4, the hydraulic properties are:

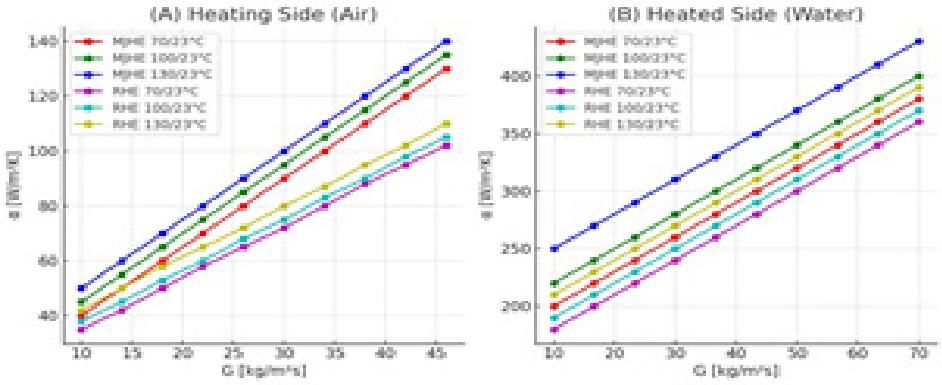


Figure 3. Heat transfer coefficients vs. mass flow density (A) heating side (Air) and (B) heated side (Water).

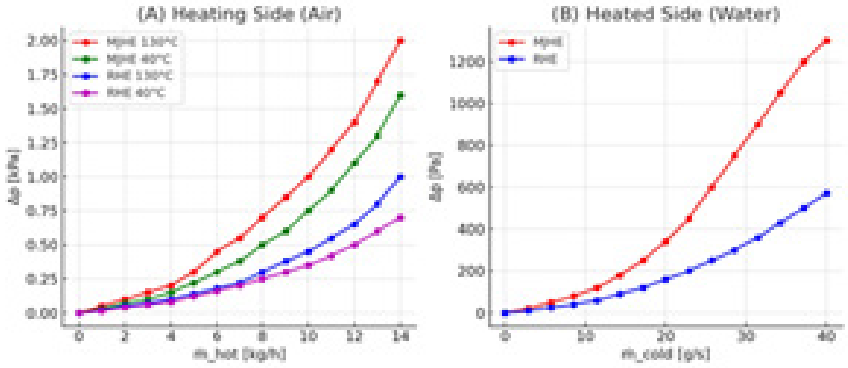


Figure 4. Flow characteristics of MJHE and RHE.

As temperature increases, hydraulic resistance also rises due to increased air viscosity and decreased air density, leading to higher airflow velocity within the heat exchanger. A comparative study showed that jet technology significantly increases hydraulic resistance, with the MJHE exhibiting approximately eight times higher resistance than the RHE on the water side at a mass flow rate of 13 g/s, and about four times higher on the air side. However, at lower air mass flow rates (2–3 kg/h), both units demonstrate similar resistance levels. While the RHE was designed to match the MJHE's heat transfer surface for thermal performance comparisons, variations in design assumptions led to differences in hydraulic diameters, thereby affecting hydraulic resistance. Measurement uncertainties in mass flow should also be taken into account.

4.2 Analysis of the Measurement Uncertainties

In all sorts of experiments, it is critical to analyse the measurement uncertainties. Because they are based on probability distributions, the statistical uncertainties (type A and type B) according to GUM were not taken into consideration in the studies described here. In addition, the findings were noted for their great reproducibility. As a result, the only analysis that could be performed took into account the extended uncertainties analysis, which is based on the uncertainty propagation principle, defined by the formula.

4.3 Future Works

First, the question of hydraulic diameter is brought up again in the presentation of data. Laminar/turbulent flow affects heat exchanger hydraulic resistance (which, in turn, affects heat transfer efficiency), as discussed in Section 2.2. The difference between MJHE and RHE's hydraulic diameters. We didn't investigate this because the focus of the current study was on maintaining the same overall unit size and thermo-flow conditions. While the writers are aware of the importance of this divergence, they do not go into detail. Therefore, the experiments are still ongoing to determine both hydraulic diameters, their difference, and to minimise the influence of the mass flow rate or the pressure on the hydraulic diameters. To further understand the impact of measurement errors on hydraulic resistance at low mass flow rates, more research will be done at even lower flow rates.

5.0 Conclusion

This study highlights the remarkable efficiency of the Mini-Jet Heat Exchanger (MJHE) in enhancing heat transfer through the innovative use of jet impingement technology. The findings confirm its potential for advanced industrial applications.

1. Heat transfer coefficients improved by up to 45% at minimal temperature differentials between heating and heated mediums.
2. The use of jet impingement technology resulted in higher hydraulic resistance, which is acceptable given the thermal performance gains.
3. MJHE is especially suitable for low-temperature waste heat recovery and micro-CHP systems due to its compact and efficient design.
4. The device demonstrates significant potential for energy recovery applications in industries requiring high thermal efficiency.
5. Future research should focus on optimizing hydraulic diameters and testing performance under lower mass flow rates to further enhance its usability.

6.0 References

1. Incropera FP, DeWitt DP. Fundamentals of heat and mass transfer. 6th ed. Hoboken, NJ: Wiley; 2007.
2. Patankar SV. Numerical heat transfer and fluid flow. New York, NY: McGraw-Hill; 1980.
3. Versteeg HK, Malalasekera W. An introduction to computational fluid dynamics: the finite volume method. 2nd ed. Harlow, England: Pearson; 2007.
4. Hasan MF, Danışmaz M, Majel BM. Thermal performance investigation of double pipe heat exchanger embedded with extended surfaces using nanofluid technique as enhancement. Case Stud Therm Eng. 2023; 43:102774. https://doi.org/10.1016/j.csite.2023.102774
5. Kamel HA, Kadhim ZK, Khalaf KA. CFD study of heat transfer enhancement in double pipe heat exchanger with twisted tape inserts. In: 2018 International Conference on Advance of Sustainable Engineering and Its Application (ICASEA); 2018; 14-15; Wasit, Iraq. Piscataway, NJ: IEEE; 2018; 227-32. https://doi.org/10.1109/ICASEA.2018.8370986

6. Kannadhasan V, Senthil Kumar A, Vairamuthu J, Nagarajan R. Experimental research and CFD analysis on double pipe heat exchanger with CuO nano particle suspended in cold water. J Therm Anal Calorim. 2022; 147(5):3831-8. https://doi.org/10.1007/s10973-021-10804-4
7. Seban RA, McLaughlin EF. Heat transfer in tube coils with laminar and turbulent flow. Int J Heat Mass Transf. 1963; 6(5):387-95. https://doi.org/10.1016/0017-9310(63)90100-5
8. Ham J, Shin Y, Cho H. Theoretical investigation of the influence of pipe diameter and exit channel width in welded plate heat exchanger on heat exchanger performance. Heat Mass Transf. 2019; 55:1-13. https://doi.org/10.1007/s00231-019-02733-8
9. Rehman UU. Heat transfer optimization of shell-and-tube heat exchanger through CFD studies; 2011.
10. Ghazikhani M, Noorifar E, Sharafi A. Experimental investigation of different kinds of vortex generator on a gas liquid finned-tube heat exchanger using exergy analysis. J Solid Fluid Mech. 2013; 2(4):61-75.
11. Baruah M, Dewan A, Mahanta P. Performance of elliptical pin fin heat exchanger with three elliptical perforations. CFD Lett. 2011; 3(2):65-73.
12. Heydari A, Shateri M, Sanjari S. Numerical analysis of a small size baffled shell-and-tube heat exchanger using different nano-fluids. Heat Transf Eng. 2018; 39(2):141-53. https://doi.org/10.1080/01457632.2017.1288052
13. Solanki AK, Kumar R. Condensation of R-134a inside dimpled helically coiled tube-in-shell type heat exchanger. Appl Therm Eng. 2018; 129:535-48. https://doi.org/10.1016/j.applthermaleng.2017.10.026
14. Solanki AK, Kumar R. Two-phase flow condensation heat transfer characteristic of R-600a inside the horizontal smooth and dimpled helical coiled tube in shell type heat exchanger. Int J Refrig. 2019; 107:155-64. https://doi.org/10.1016/j.ijrefrig.2019.07.017
15. Zuo JW, Wong KC, Ng HK. The thermal performance of three-layered microchannel heat sink with tapered channel profile. J Adv Res Fluid Mech Therm Sci. 2019; 56(1):147-56.
16. Majidi D, Alighardashi H, Farhadi F. Experimental studies of heat transfer of air in a double-pipe helical heat exchanger. Appl Therm Eng. 2018; 133:276-82. https://doi.org/10.1016/j.applthermaleng.2018.01.057
17. Kurhade AS, Sugumaran S, Kolhalkar NR, Karad MM, Mahajan RG, Shinde NM, Dalvi SA, Waware SY. Thermal Management of Mobile Devices via PCM. JMMF. 2025; 73(5):1313-20
18. Kurhade A, Talele V, Rao TV, Chandak A, Mathew VK. Computational study of PCM cooling for electronic circuit of smartphone. Mater Today Proc. 2021; 47:3171-6. https://doi.org/10.1016/j.matpr.2021.06.284
19. Kurhade AS, Murali G. Thermal control of IC chips using phase change material: a CFD investigation. Int J Mod Phys C. 2022; 33(12):2250159. https://doi.org/10.1142/S0129183122501595
20. Kurhade AS, Murali G, Rao TV. CFD approach for thermal management to enhance the reliability of IC chips. Int J Eng Trends Technol. 2022; 71(3):65-72. https://doi.org/10.14445/22315381/IJETT-V71I3P208
21. Kurhade AS, Biradar R, Yadav RS, Patil P, Kardekar NB, Waware SY, *et al*. Predictive placement of IC chips using ANN-GA approach for efficient thermal cooling. J Adv Res Fluid Mech Therm Sci. 2024; 118(2):137-47. https://doi.org/10.37934/arfmts.118.2.137147
22. Kurhade AS, Upadhe SN, Mhamane SC, Bapat PV, Dhavale DB, Kore LJ. Water saving and hygienic faucet for public places in developing countries. In: Pawar P, Ronge B, Balasubramaniam R, Vibhute A, Apte S, editors. Techno-Societal 2018. Cham: Springer; 2020. p. 659-68.
23. Waware SY, Patil SP, Kore SS. Characterization and machinability studies of aluminum-based hybrid metal matrix composites - A critical review. J Adv Res Fluid Mech Therm Sci. 2023; 101(2):137-63. https://doi.org/10.37934/arfmts.101.2.137163
24. Waware SY, Kore SS. Heat transfer enhancement in tubular heat exchanger with jet impingement: a review. J Adv Res Fluid Mech Therm Sci. 2023; 101(2):8-25. https://doi.org/10.37934/arfmts.101.2.825
25. Waware SY, Kore SS, Kurhade AS, Patil SP. Innovative heat transfer enhancement in tubular heat exchanger: an experimental investigation with minijet impingement. J Adv Res Fluid Mech Therm Sci. 2024; 116(2):51-58. https://doi.org/10.37934/arfmts.116.2.5158
26. Khot RS, Kadam PR. Structural behavior of fillet weld joint for bimetallic curved plate using Finite Element Analysis (FEA). In: 6th International Conference on Advanced Research in Arts, Science, Engineering and Technology (ICARASET); 2021.
27. Khot RS, Rao TV. Investigation of mechanical behavior of laser-welded butt joint of Transformed Induced Plasticity (TRIP) steel with effect of laser incident angle.

Int J Res Eng Technol. 2020; 13(11):3398-403. https://doi.org/10.37624/IJERT/13.11.2020.3398-3403
28. Khot RS, Rao TV, Natu H, Girish HN, Ishigaki T, Madhusudan P. An investigation on laser welding parameters on strength of TRIP steel. Strojniški Vestnik J Mech Eng. 2021; 67(1-2):45-52. https://doi.org/10.5545/sv-jme.2020.6912
29. Khot RS, Rao TV. Effect of quenching media on laser butt welded joint on Transformed-Induced Plasticity (TRIP) steel. Int J Emerg Trends Eng Res. 2020; 8(10):7686-91. https://doi.org/10.30534/ijeter/2020/1588102020
30. Khot RS, Rao TV, Keskar A, Girish HN, Madhusudan P. Investigation on the effect of power and velocity of laser beam welding on the butt weld joint on TRIP steel. J Laser Appl. 2020; 32(1):012016. https://doi.org/10.2351/1.5133158
31. Kurhade AS, Hande SS, Patil SB, Maske VR. Heat transfer enhancement by using twisted tape inserts with circular holes in forced convection. Int J Innov Res Sci Eng Technol. 2016;3(3):1-7.
32. Kurhade AS, Waware SY, Bhambare PS, Biradar R, Yadav RS, Patil VN. A comprehensive study on *Calophyllum inophyllum* biodiesel and dimethyl carbonate blends: performance optimization and emission control in diesel engines. J Mines Met Fuels. 2024; 72(5):499-507. https://doi.org/10.18311/jmmf/2024/45188
33. Kurhade AS, Waware SY, Munde KH, Biradar R, Yadav RS, Patil P, *et al*. Performance of solar collector using recycled aluminum cans for drying. J Mines Met Fuels. 2024; 72(5):455-61. https://doi.org/10.18311/jmmf/2024/44643
34. Waware SY, Chougule SM, Yadav RS, Biradar R, Patil P, Munde KH, *et al*. A comprehensive evaluation of recent studies investigating nanofluids utilization in heat exchangers. J Adv Res Fluid Mech Therm Sci. 2024; 119(2):160-72. https://doi.org/10.37934/arfmts.119.2.160172
35. Patil P, Kardekar NB, Yadav RS, Kurhade AS, Kamble D. Al_2O_3 nanofluids: an experimental study for MQL grinding. J Mines Met Fuels. 2023; 71(12):2751-6. https://doi.org/10.18311/jmmf/2023/41766
36. Kurhade AS, Siraskar GD, Bhambare PS, Dixit SM, Waware SY. Numerical investigation on the influence of substrate board thermal conductivity on electronic component temperature regulation. J Adv Res Numer Heat Transf. 2024; 23(1):28-37. https://doi.org/10.37934/arnht.23.1.2837
37. Kurhade AS, Kadam AA, Biradar R, Bhambare PS, Gadekar T, Patil P, Yadav RS, Waware SY. Experimental investigation of heat transfer from symmetric and asymmetric IC chips mounted on the SMPS board with and without PCM. J Adv Res Fluid Mech Therm Sci. 2024; 121(1):137-47. https://doi.org/10.37934/arfmts.121.1.137147
38. Kurhade AS, Kardekar NB, Bhambare PS, Waware SY, Yadav RS, Pawar P, Kirpekar S. A comprehensive review of electronic cooling technologies in harsh field environments: obstacles, progress, and prospects. J Mines Met Fuels. 2024; 72(2):557-79. https://doi.org/10.18311/jmmf/2024/452 in a shell and tube heat exchanger. Int J Adv Eng Technol. 2016; 7(1):859-61.
39. Kurhade AS, Siraskar GD, Kondhalkar GE, Darade MM, Yadav RS, Biradar R, Waware SY, Charwad GA. Optimizing aerofoil design: a comprehensive analysis of aerodynamic efficiency through CFD simulations and wind tunnel experiments. J Mines Met Fuels. 2024; 72(7):713-24. https://doi.org/10.18311/jmmf/2024/45361
40. Kurhade AS, Siraskar GD, Darade MM, Dhumal JR, Kardile CS, Biradar R, Patil SP, Waware SY. Predicting heat transfer enhancement with twisted tape inserts using fuzzy logic techniques in heat exchangers. J Mines Met Fuels. 2024; 72(7):743-50. https://doi.org/10.18311/jmmf/2024/45348
41. Yadav RS, Gandhi P, Veeranjaneyulu K, Gaji R, Kirpekar S, Pawar D, Khairnar YS, Patil S, Kurhade AS, Patil SP. Influence of plate thickness on the mechanical behaviour of mild steel curved plates: an experimental study. J Mines Met Fuels. 2024; 72(12):[In press]. https://doi.org/10.18311/jmmf/2024/46253
42. Yadav RS, Gadekar T, Gundage V, Patil P, Patil A, Patil P, Patil A, Sutar R, Kurhade AS. Numerical and experimental investigation of the effect of overlapping angle on strength and deformation of curved plate joined using arc welding process. J Mines Met Fuels. 2024; 72(10):1059-66. https://doi.org/10.18311/jmmf/2024/45697
43. Kurhade AS, Gadekar T, Siraskar GD, Jawalkar SS, Biradar R, Kadam AA, Yadav RS, Dalvi SA, Waware SY, Mali CN. Thermal performance analysis of electronic components on different substrate materials. J Mines Met Fuels. 2024; 72(10):1093-8. https://doi.org/10.18311/jmmf/2024/45569
44. Kurhade AS, Siraskar GD, Jawalkar SS, Gadekar T, Bhambare PS, Biradar R, Yadav RS, Waware SY, Mali CN. The impact of circular holes in twisted tape inserts on forced convection heat transfer. J Mines Met

Fuels. 2024; 72(10):1005-12. https://doi.org/10.18311/jmmf/2024/45505
45. Yadav RS, Nimbalkar A, Gadekar T, Patil P, Patil VN, Gholap AB, Kurhade AS, Dhumal JR, Waware SY. Comparison of experimental and numerical investigation of mono-composite and metal leaf spring. J Mines Met Fuels. 2024; 72(9):815-27. https://doi.org/10.18311/jmmf/2024/45325
46. Kurhade AS, Darade MM, Siraskar GD, Biradar R, Mahajan RG, Kardile CS, Waware SY, Yadav RS. State-of-the-art cooling solutions for electronic devices operating in harsh conditions. J Mines Met Fuels. 2024; 72(9):843-61. https://doi.org/10.18311/jmmf/2024/45374
47. Murali G, Vikram G. A study on performance enhancement of heat exchanger in thermoelectric generator using CFD. Int J Innov Res Sci Technol. 2016; 2(10):128-33.
48. Arunkumar M, Kannan M, Murali G. Numerical simulation to reduce the fouling numerical simulation to reduce the fouling in a shell and tube heat exchanger. Int J Adv Engg Tech. 2016; VII(1):859-861
49. Kurhade AS, Siraskar GD, Bhambare PS, Kaithari DK, Dixit SM, Waware SY. Enhancing smartphone circuit cooling: a computational study of PCM integration. J Adv Res Numer Heat Transf. 2024; 27(1):132-45. https://doi.org/10.37934/arnht.27.1.132145
50. Kurhade AS, Bhambare PS, Siraskar GD, Dixit SM, Purandare PS, Waware SY. Computational study on thermal management of IC chips with phase change materials. J Adv Res Numer Heat Transf. 2024; 26(1):34-43. https://doi.org/10.37934/arnht.26.1.3443