COMPARATIVE STUDY BY NUMERICAL INVESTIGATION OF HEAT TRANSFER IN CIRCULAR TUBE BY USING HYBRID NANOFLUIDS

K. V. NARASIMHA RAO^{1*}, GOLLA VANNAPPA GARI RADHA²,
TALASILA VAMSIDHAR³ & G. MURALI⁴

¹Professor and Corresponding Author, Department of Mechanical Engineering, Koneru Lakshmaiah Educational Foundation, Green Fields, Vaddeswaram, Andhra Pradesh, India

²Student, Department of Mechanical Engineering, Koneru Lakshmaiah Educational Foundation, Green Fields, Vaddeswaram, Andhra Pradesh, India

³Assistant Professor, Department of Mechanical Engineering, Koneru Lakshmaiah Educational Foundation, Green Fields, Vaddeswaram, Andhra Pradesh, India

⁴Professor, Department of Mechanical Engineering, Koneru Lakshmaiah Educational Foundation, Green Fields, Vaddeswaram, Andhra Pradesh, India

ABSTRACT

Heat exchangers have bagged a noteworthy role in industrial and commercial applications with the passage of time. Heat transfer augmentation of the heat exchanger by using hybrid nanofluid has picked up lot of recognition due to its desirable thermal properties. In the current numerical investigation, thermal performance of tubular heat exchanger for turbulent flow owing to the use of Al_2O_3 - SiO_2 /water and AlN - Al_2O_3 /water at different volume concentrations was analyzed. Uniform heat flux of 7000 W/m^2 was given around the tube and simulated by varying Reynolds number from 5000 to 10000 with the use of ANSYS FLUENT. Computational results were validated with the available literature. The obtained results signified that Nusselt number in each case has been raised and friction factor got lowered with an increase in Reynolds number. Hybrid nanofluids have shown high grade thermal characteristics as compared to water which is used as base fluid in the present study. Observations revealed that 0.6% AlN -1.4% Al_2O_3 /water given high heat transfer rate among other AlN - Al_2O_3 /water volume concentrations. 0.2% Al_2O_3 -1.8% SiO_2 /water exhibited high thermal properties as compared with other Al_2O_3 - SiO_2 /water volume concentrations. Final outcome revealed that Al_2O_3 - SiO_2 /Water has given better heat transfer augmentation compared to AlN - Al_2O_3 /water and base fluid at each Reynolds number. Superior heat transfer characteristics were achieved at 0.2% Al_2O_3 -1.8% SiO_2 /water loading among all computations.

KEYWORDS: Hybrid nanofluid, Aluminum oxide, Silicon dioxide, Aluminum nitride, Volume concentration, Nusselt number, Friction factor and Heat transfer

Received: Apr 27, 2020; Accepted: May 18, 2020; Published: Jun 06, 2020; Paper Id.: IJMPERDJUN202085

NOMENCLATURE

C_p	Specific heat [J/Kg-K]		
d	Inner diameter of tube [mm]	Greek symbols	
f	Friction factor	μ	Dynamic viscosity [kg/m-s]
k	Thermal conductivity [W/m-K]	ΔP	Pressure drop [Pa]
L	Length of tube [mm]	ρ	Fluid density [Kg/m ³]
Nu	Nusselt number	ϕ	Volume concentration [%]

Pr	Prandtl number		
q_w	Heat flux	<i>Subscripts</i>	
Re	Reynolds number	<i>bf</i>	Base fluid
t	Thickness of tube [mm]	<i>hnf</i>	Hybrid nanofluid
T	Temperature [°C]	<i>np</i>	Nano particle
v	Velocity [m/s]	<i>t</i>	Total

1. INTRODUCTION

The rapid development of industries, viz. power generation, refrigeration and air conditioning, food processing, chemical, automobile, waste heat recovery, nuclear and electronic applications craves for ultra-cooling heat exchanger equipment. To achieve this goal, heat transfer augmentation techniques are introduced to enhance the thermo-hydraulic performance of heat exchanger [1]. Insertion of different geometrical fins, heat exchanger geometry optimization, various fluid flow patterns and utilization of different conventional fluids in the heat exchanger are different methods to enhance heat transfer device efficiency. Water is the most utilized working fluid in industries among all other conventional fluids like ethylene glycol, engine oil, etc. due to its abundant availability in the nature and hence results in low supply cost. But the thermal conductivity of water is low and this effect reduces the heat transfer rate. Nanofluids have been introduced to enhance the thermal conductivity of water [2]. Colloidal suspension of solid nanoparticles dispersed into the base fluid is considered as an efficient working fluid due to its desirable features like high thermal conductivity, large surface area and solubility. Augmentation in thermal conductivity was achieved due to aggregation and Brownian motion of dispersed nanoparticles. Nanofluids ruled the industries because of their better thermal properties, in comparison of conventional fluids [3-5].

Abbasian et al. [6] used TiO_2 /water nanofluid and conducted experiment analysis in counter flow double tube heat exchanger by varying volume fraction from 0.002 to 0.2. The thermal characteristics were observed by varying Reynolds number from 8000 to 51000. The results depicted that utilizing nanofluid enhances Nusselt number but more pumping power requires at higher Reynolds numbers.

Sharma et al. [7] performed experiments by using Al_2O_3 /water as nanofluid to investigate friction factor and heat transfer for the fluid flow. It was observed that at 0.1% volume fraction, there was 23.7% increase in heat transfer coefficient when compared with water for Reynolds number 9000. Rao et al. [8] conducted experimental investigation on Al_2O_3 / water nanofluid which was used in forced convection, by varying volume fraction 0.1% to 0.4%. From the investigation, it was clear that by using nanofluids, thermal properties like thermal conductivity, specific heat, heat transfer coefficient, density, viscosity have raised significantly.

In the recent scenario of mixing of two or more nano particles in to the working fluid (hybrid nanofluids) has grabbed the attention of many researchers due to its enticing features like attaining specific thermal properties which is required for the particular applications [9]. Sundar et al. [10] conducted experiment to investigate the heat transfer of MWCNT/ Fe_2O_3 hybrid nanofluid with water as base fluid. At 22,000 Reynolds number, results indicated that the Nusselt number of the hybrid nanofluid was enhanced by 31.1% with 1.8 times increase in pumping power when compared with base fluid at 0.3% volume concentration.

Ahmed et al. [11] performed experimentation to investigate MWCNTs-GNPs/water performance in circular tube at Reynolds number in between 200-500. Final outcomes depicted that highest heat transfer increment was achieved for

0.25 MWCNTs-0.035 GNPs/water hybrid nanofluids. Kaska et al. [12] enhanced the heat transfer of water by using alumina and aluminum nitride as hybrid nanofluid by CFD simulation. The results showed that heat transfer is enhanced significantly by adopting hybrid nanofluid. Numerical research of fluid flow behavior in elliptical tube with the suspension of MgO–MWCNT hybrid nanoparticles into Ethylene glycol was performed by Gabriela Huminic and Angel Huminic [13] at Reynolds numbers ranging 50 and 1000 and volume concentrations ranging from 0 to 0.4%. Results concluded that enhancement of heat transfer coefficient is high at 0.4%, in comparison with other particle loadings.

Tubular heat exchanger is selected for this study because it is relatively modular in design and requires low maintenance. Effect of various volume concentrations of two nanofluids dispersed in water under turbulent flow condition in a tube heat exchanger was analyzed in this work. Investigation of friction factor and convective heat transfer characteristics of hybrid nanofluid was computed by CFD commercial software. Mixture of Aluminum oxide and Silicon dioxide, Aluminum nitride and Aluminum oxide nanoparticles suspended in pure water was considered with different volume fractions.

2. METHODOLOGY

A circular copper (Cu) tube having inner diameter (d) as 20 mm with thickness (t) of 1 mm and length (L) of 1000 mm were modeled in Solid works software [14]. The geometry which was modeled in 'solidworks' has been imported and simulated in Ansys fluent software. Schematic diagram of tube is shown in Fig. 1.

Figure 1: Schematic Diagram of Tube.

Fluid flow starts at one side and exits at other side of the tube. Constant heat flux (q_w) of 7000W/m^2 was supplied throughout the length of the tube. Water is considered as base fluid in the present research. Two different nanoparticles were dispersed simultaneously in the base fluid and then forced to flow inside of the tube. Further, thermal characteristics of fluid flow behavior were investigated. Aluminum oxide (Al_2O_3), Silicon dioxide (SiO_2) and Aluminum nitride (AlN) nanoparticles were chosen for current study. Diameters of Al_2O_3 , SiO_2 and AlN nanoparticles are 33 nm, 22 nm and 30 nm respectively.

Thermophysical properties of Al_2O_3 , SiO_2 , AlN and pure water are enumerated in Table 1 at constant temperature (T) of 25°C .

Table 1: Thermophysical Properties of Nanoparticles and Base Fluid [15-17]

Properties	Water	Al_2O_3	SiO_2	AlN
Density (ρ) [Kg/m^3]	997.1	3970	2200	3260
Specific heat (C_p) [J/Kg-K]	4179	765	740	735
Thermal conductivity (k) [W/m-K]	0.613	40	1.38	180
Viscosity (μ) [kg/m-s]	9.0945×10^{-4}	-	-	-

Different volume concentrations of Al_2O_3 - SiO_2 and AlN - Al_2O_3 was incorporated in water such as 0.2% Al_2O_3 & 0.8% SiO_2 , 0.5% Al_2O_3 & 0.5% SiO_2 , 0.2% Al_2O_3 & 1.8% SiO_2 , 0.4% Al_2O_3 & 1.6% SiO_2 , 0.6% Al_2O_3 & 1.4% SiO_2 , 0.2% AlN & 0.8% Al_2O_3 , 0.5% AlN & 0.5% Al_2O_3 , 0.2% AlN & 1.8% Al_2O_3 , 0.4% AlN & 1.6% Al_2O_3 , 0.6% AlN & 1.4% Al_2O_3 . The hybrid nanofluid flow was supposed to be Newtonian, steady, incompressible and turbulent. Fluid flow examination was done at different Reynolds numbers ranging from 5000 to 10000.

2.1. Hybrid Nanofluid Thermophysical Properties

Hybrid nanofluid density can be estimated by J. Sarkar et al. [18],

$$\rho_{hmf} = \varphi_{np1} \rho_{np1} + \varphi_{np2} \rho_{np2} + [1-\varphi_t] \rho_{bf} \quad (1)$$

where, φ is the total volume concentration of two various kinds of nanoparticles [np1 and np2] suspended in the base fluid which can be determined as,

$$\varphi_t = \varphi_{np1} + \varphi_{np2} \quad (2)$$

Heat capacity of the hybrid nanofluid has been resolved as ensues [21],

$$(C_p)_{hmf} = \frac{\varphi_{np1} \rho_{np1} (C_p)_{np1} + \varphi_{np2} \rho_{np2} (C_p)_{np2} + [1-\varphi_t] \rho_{bf} (C_p)_{bf}}{\rho_{hmf}} \quad (3)$$

Thermal conductivity of the hybrid nanofluid is calculated as follows [21],

$$\frac{k_{hmf}}{k_{bf}} = \frac{[(\varphi_{np1} k_{np1} + \varphi_{np2} k_{np2}) / \varphi_t] + 2 k_{bf} + 2 (\varphi_{np1} k_{np1} + \varphi_{np2} k_{np2}) - 2 \varphi_t k_{bf}}{[(\varphi_{np1} k_{np1} + \varphi_{np2} k_{np2}) / \varphi_t] + 2 k_{bf} - (\varphi_{np1} k_{np1} + \varphi_{np2} k_{np2}) + \varphi_t k_{bf}} \quad (4)$$

Viscosity of the hybrid nanofluid is estimated as follows [21],

$$\mu_{hmf} = \mu_{bf} [1 + (32.795)(\varphi_t) - (7214)(\varphi_t^2) + (714600)(\varphi_t^3) - (0.1941)(10^8)(\varphi_t^4)] \quad (5)$$

2.2. Boundary Conditions

Respective volume concentrations of Al_2O_3 - SiO_2 and AlN - Al_2O_3 nano particles dispersed in water was given as input condition for computation. The inlet temperature of the working fluid was taken as 25°C. Uniform velocity (v) was given at the inlet condition of the working fluid and pressure-outlet condition was given at the exit of the fluid flow.

Uniform heat flux (q_w) was given through surface of the tube. Computational analysis was conducted for considered working fluids at different Reynolds numbers in the range 5000 to 10000.

2.3. CFD Analysis

Grid selection test was carried out by utilizing ANSYS FLUENT software. Simulations were carried out for base fluid by considering 9×10^4 , 1×10^5 , 10×10^5 , 11×10^5 , 12×10^5 , 14×10^5 , 15×10^5 , 16×10^5 , 18×10^5 and 20×10^5 meshing elements. Optimized mesh was found at 15×10^5 elements among the considered meshing elements for the preferred geometry due to fine accuracy. Simulation was carried out for base fluid and hybrid nanofluids for selected mesh. Turbulent viscous k- ϵ model was considered and fluid properties along with boundary conditions given as input in the setup. Convergence criteria considered at residuals lower than 10^{-6} . Data which was given to the solver has been evaluated and reached convergence criteria. Heat transfer calculations for the tube were done by taking numerical results in post processing stage.

3. RESULTS AND DISCUSSIONS

Hybrid nanofluids have been the leading edge for heat transfer improvement in current years. Superior thermal characteristics could be achieved with the usage of mixing of two different types of nanoparticles in base fluid instead of using mono nanoparticles. Two different hybrid nanofluids, $\text{Al}_2\text{O}_3\text{-SiO}_2$ and $\text{AlN-Al}_2\text{O}_3$ with various volume concentrations are chosen for current study.

Initially simulations were carried out for base fluid, i. e. water at different Reynolds number ranging 5000 to 10000 under turbulent condition. The Nusselt numbers from numerical results were calculated by means of Eq. (6). The current outcomes for water have been validated with standard available correlations [Eq. (7), (8) and (9)] to inspect the accuracy. It has been found that there is good fit with simulation and available correlations data.

Observations revealed that there is utmost $\pm 4\%$ deviation present between simulation data and available correlation data for Nusselt number, as represented in Fig. 2. Nusselt number for the fluid has been calculated from below equation,

$$\text{Nu}_{\text{hnf}} = \frac{h_{\text{hnf}} d}{k_{\text{hnf}}} \quad (6)$$

Available Nusselt number correlations for water under turbulent condition are mentioned below as follows:

(1) Gnielinski correlation [10],

$$\text{Nu} = \frac{(f/2) (Re-1000) (Pr)}{1.07 + 12.7 (f/2)^{0.5} (Pr^{2/3}-1)} \quad (7)$$

$$f = [1.58 \ln(Re) - 3.82]^{-2}, 0.5 < Pr < 2000, 2300 < Re < 10^6$$

(2) Notter-Rouse correlation[10],

$$\text{Nu} = 5 + 0.015 (Re)^{0.856} (Pr)^{0.347} \quad (8)$$

(3) Dittus and Boelter correlation [19],

$$\text{Nu} = 0.023 (Re)^{0.8} (Pr)^{0.4} \quad (9)$$

Figure 2: Validation of Nusselt Number for Base Fluid (Water)

Furthermore, Nusselt number values for $\text{Al}_2\text{O}_3\text{-SiO}_2/\text{water}$ and $\text{AlN-Al}_2\text{O}_3/\text{water}$ hybrid nanofluids were evaluated

by Eq. (6) and validated with available Duangthongsuk and Wongwises equation. Corresponding Nusselt numbers at each Reynolds number for both hybrid nanofluids reported a good agreement with Eq. (10) as represented in Fig. 3 and Fig. 4. Nusselt number correlation for nanofluid under turbulent condition is given below:

Duangthongsuk and Wongwises equation [20] is given by:

$$Nu = 0.074 (Re)^{0.707} (Pr)^{0.385} (\phi)^{0.074}, 3000 < Re < 18000 \quad (10)$$

Figure 3: Validation of Nusselt number for Al₂O₃-SiO₂/Water Hybrid nanofluid.

Figure 4: Validation of Nusselt Number for AlN-Al₂O₃/water Hybrid Nanofluid

Similar verification for friction factor has been performed. Friction factor for the base fluid which comprises pressure drop values has been evaluated by Eq. (11) and validated with well-known equations such as Blasius (12), Petukhov (13) and Filonenko (14).

Figure 5 illustrates the comparison of base fluid friction factor values and it could be noted that there is good fit between numerical results and correlations data. Friction factor of the fluid has been calculated from below mentioned equation,

$$f = \frac{\Delta P}{(L/d) [(pv^2)/2]} \quad (11)$$

Available Friction factor (f) correlations for water under turbulent condition are mentioned below [20] :

(1) Blasius correlation,

$$f = 0.3164 (\text{Re})^{-0.25}, 3000 < \text{Re} < 10^5 \quad (12)$$

(2) Petukhov correlation,

$$f = [0.79 \ln(\text{Re}) - 1.64]^{-2}, 2300 < \text{Re} < 5 \times 10^6 \quad (13)$$

(3) Filonenko correlation,

$$f = [1.82 \log(\text{Re}) - 1.64]^{-2} \quad (14)$$

Figure 5: Validation of Friction Factor for Base Fluid (Water).

Similarly, Friction factor values for hybrid nanofluids $\text{Al}_2\text{O}_3\text{-SiO}_2$ and $\text{AlN-Al}_2\text{O}_3$ are estimated by Eq. (11) and checked with equation (15) as reported by Sundar et al. The computational friction factor values are well matched with available prediction as charted in Figure 6 and Figure 7. Available Friction factor correlation for nanofluid under turbulent condition is mentioned below:

Sundar et al. equation [20],

$$f = 0.3491 (\text{Re})^{-0.25} (1 + \phi)^{0.1517} \quad (15)$$

Figure 6: Friction Factor Validation for Al₂O₃-SiO₂/water Hybrid Nanofluid.

Figure 7: Friction Factor Validation for AlN-Al₂O₃/water Hybrid Nanofluid.

Nusselt numbers for both hybrid nanofluids with selected volume concentrations along with the base fluid which were estimated from the simulation work are represented in Figures 8 and 9. Results depicted that both hybrid nanofluids showed better heat transfer characteristics when compared to water and this enhancement has been achieved due to Brownian motion and high specific surface area of the suspended nanoparticles. Brownian motion results in enhanced thermal conductivity of fluid.

It was observed that there is an enhancement of heat transfer of fluid as Reynolds number increases for both the hybrid nanofluids along with water. From Figure 8, it could be noted that Nusselt number increased with total particle volume concentration of Al₂O₃-SiO₂/water. At particular total volume concentration, more weightage of SiO₂ was given at slightly high Nusselt number. Hence, addition of more volume fraction of SiO₂ nanoparticles to the base fluid along with the small volume concentration of Al₂O₃ nanoparticles results in more heat transfer rate. Particle volume fraction of 0.2% Al₂O₃ -1.8% SiO₂/water exhibited better heat transfer augmentation among remaining volume fractions of Al₂O₃-SiO₂/water.

Figure 8: Nusselt Numbers for Al_2O_3 - SiO_2 /water Hybrid Nanofluid at Different Volume Concentrations along with Base Fluid.

Figure 9: Nusselt Numbers for AlN- Al_2O_3 /water Hybrid Nanofluid at different Volume Concentrations along with Base Fluid.

Nusselt number rose with increment in particle total volume concentration of AlN- Al_2O_3 /water, as shown in Fig. 9. Heat transfer enhancement was achieved at 0.6% AlN-1.4% Al_2O_3 /water volume concentration. So, addition of more weightage of Al_2O_3 nanoparticles along with small volume fraction of AlN enhances the heat transfer rate in this case. Final outcomes stated that 0.2% Al_2O_3 -1.8% SiO_2 /water showed superior heat transfer rate when compared with AlN- Al_2O_3 /water at each volume concentration and Reynolds number. Nusselt number at 0.2% Al_2O_3 -1.8% SiO_2 /water volume fraction exhibited 11.4% times the base fluid.

Velocity contour of 0.2% Al_2O_3 -1.8% SiO_2 /water hybrid nanofluid at outlet for Reynolds number 10000 is shown in Fig.10. Velocity variation along the diameter of the tube could be observed. Velocity is zero at the wall and gradually increased from the wall to the centre axis of the tube because of the viscosity effect.

Figure 10: Velocity Contour.

Friction factor for each Reynolds number obtained from present work for both hybrid nanofluids along with water is shown in Figures 11 and 12. Friction factor reduced as the Reynolds number rises. But there is a small increment in friction factor for two hybrid nanofluids as compared to water. This little increment in friction factor occurred due to the suspension of nanoparticles into the base fluid and this friction effect is very less as compared to heat transfer enhancement, thus it could be negligible. Hence, $\text{Al}_2\text{O}_3\text{-SiO}_2/\text{water}$ hybrid nanofluid has given better heat transfer characteristics as compared with $\text{AlN-Al}_2\text{O}_3/\text{water}$ hybrid nanofluid and base fluid.

Figure 11: Friction factors for $\text{Al}_2\text{O}_3\text{-SiO}_2/\text{water}$ hybrid nanofluid at different volume concentrations along with base fluid

Figure 12: Nusselt Numbers for AlN-Al₂O₃/water Hybrid Nanofluid at different Volume Concentrations along with Base Fluid.

4. CONCLUSIONS

Numerical simulation results of base fluid, Al₂O₃-SiO₂/water and AlN-Al₂O₃/water are well matched with the available literature correlations of Nusselt number and Friction factor values. Nusselt number increased and friction factor decreased as the Reynolds number increased for base fluid and also for Al₂O₃-SiO₂/water and AlN-Al₂O₃/water hybrid nanofluids. Nusselt number increased with total volume concentration of hybrid nanofluid. Al₂O₃-SiO₂/water revealed better heat transfer characteristics as compared with AlN-Al₂O₃/water hybrid nanofluid. 0.2% Al₂O₃-1.8%SiO₂/water loading exhibited highest heat transfer characteristics among all volume concentrations and base fluid.

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AUTHOR'S PROFILE

Dr K V Narasimha Rao is a senior Professor with 27 years experience in Academic, Consultancy and Industry and has been working with KLEF (Deemed to be University) Vaddeswaram since 2nd September 2016. Dr Narasimha Rao was graduated in Mechanical Engineering from Regional Engineering College, Warangal in 1986 and went on to obtain Master's and Doctoral degrees from the Indian Institute of Science, Bangalore during 1990 and 1995 respectively in the field of Thermal Engineering. He worked for seven years (1995-2002) as Research Associate and Fellow, Industrial Energy Group at Tata Energy Research Institute (TERI), Southern Regional Centre, Bangalore before moving into Academics in 2002. Prior to joining KLEF, he worked at few Engineering Colleges as Principal/Director/Dean. Dr Narasimha Rao has published 38 scientific papers (three in SCI Listed Journals, 30 Scopus indexed Journals and Chapter 10 in Recent Advances in Material Sciences, Lecture Notes on Multidisciplinary Industrial Engineering) and numerous technical reports for various National/International Agencies. He has filed 14 patents (six published so far).

Golla Vannappa Gari Radha is currently pursuing M. Tech. in Thermal Engineering at Department of Mechanical Engineering at Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur and graduated in Mechanical Engineering from Rajiv Gandhi University of Knowledge Technologies, RK valley, Andhra Pradesh in the year 2017. Her research interests are Thermal engineering, Heat transfer augmentation using nanofluids, etc.

Talasila Vamsidhar is working as Assistant Professor in department of CSE in Koneru Lakshmaiah Education Foundation. His research area is Machine Learning. He has published several papers in area of Machine Learning. He has around 7 years of experience in teaching Area. His interest area in subjects include Machine Learning, Artificial Intelligence, Image processing, Data mining and Data Warehousing, Data Structures, Python programming, OOPS through Java etc. Talasila Vamsidhar has published 4 Scopus indexed Journals and Lecture Notes on Multidisciplinary Mechanical Engineering) and numerous technical reports for various National/International Agencies.

Dr. G. Murali is a **Professor with 19 years** experience in Academic and has been working with KLEF (Deemed to be University) Vaddeswaram since 9th October 2017. Dr. Murali was graduated in Mechanical Engineering from Bharathiar University, Coimbatore in 1998 and went on to obtain Master's from at National Institute of Technology (NIT), Tiruchirapalli in the specialization of Thermal engineering in 2005. He received his Ph.D. from Anna University, Chennai in 2017 in the area of Thermal energy storage. Prior to joining KLEF, he worked at few Engineering Colleges as lecturer/Assistant professor/Associate professor/professor. Dr. Murali has published 35 papers in reputed international journals (Six in SCI Listed Journals, 29 Scopus indexed Journals and has filed 2 patents. He has presented various papers in many international conferences. He is member of Editorial Board/ Reviewer Board for International Journal of Bio Sciences & Engineering (IJBSE) and Thermal Science and Engineering. He is a certified reviewer in Elsevier publication, Also reviewer for various SCI journals. He has conducted various programs such as FDP, Workshop and Symposium in various institutions. He is a Recognized Supervisor for guiding Ph. D. in Anna University (Ref No: **3020040**) and Koneru Lakshmaiah Education Foundation (Deemed to be University). He received **Quality researcher** award in 2018 at KLEF. He was an Expert panel for International Conference ICSM - 2K19 conducted By KSR college of Engineering Tiruchengode. He was among Technical Committees member KGC-2019: Kalasalingam Global Conference 2019 - International Conference on Sustainable Development which was held in Kalasalingam Academy of Research and Education, Anand Nagar, Krishnankoil, Tamil Nadu.