iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** XI **Month of publication:** November 2025

DOI: https://doi.org/10.22214/ijraset.2025.75361

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue XI Nov 2025- Available at www.ijraset.com

Design Development and Experimental Investigation of Nano Fluid Car Radiator

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Abstract: Heat exchangers play an important part in the field of energy conservation, conversion and recovery. Numerous studies have focused on direct transfer type heat exchanger, where heat transfer between fluids occurs through a separating wall or into and out of a wall in a transient manner. There are two important phenomena happening in a heat exchanger: fluid flow in channels and heat transfer between fluids and channel walls. Thus, improvements to heat exchangers can be achieved by improving the processes occurring during those phenomena. Nanofluids, on the other hand, display much superior heat transfer characteristics compared to traditional heat transfer fluids. Nanofluids refer to engineered fluids that contain suspended nanoparticles with average size below 100nm in traditional heat transfer fluids such as water, oil and ethylene glycol. An experimental system will be designed and constructed to investigate heat transfer behavior of different type of nanofluid a car-radiator heat exchanger. Heat transfer characteristics will be measured under the turbulent flow condition. The experiments is planned to be conducted for wide ranges of Peclet numbers, and volume concentrations of suspended nanoparticles. The outcome expectation is to measure the significance of Peclet number on the heat transfer characteristics. The optimum volume concentrations in which the heat transfer characteristics become the maximum enhancement is also addressed. Finally, the structure of different nanofluid is compared.
Keywords: Nano fluid, PCM etc.

I. INTRODUCTION

Heat transfer is one of the most essential physical processes in nature and engineering. It governs the performance of thermal systems in power plants, refrigeration units, air conditioning systems, automotive engines, chemical process plants, electronic cooling devices, and renewable energy technologies. The efficiency of heat exchangers and thermal transport systems depends heavily on the thermophysical properties of the working fluid used. Conventional heat transfer fluids such as water, ethylene glycol, engine coolants, and mineral oils have been extensively employed due to their abundance, chemical stability, safety, and relatively low cost. However, their low thermal conductivity severely limits the heat transfer capability of systems that rely on them. For instance, water has a thermal conductivity of only ~0.6 W/m•K, ethylene glycol is ~0.25 W/m•K, and engine oils fall below 0.15 W/m•K. In contrast, solid metals such as copper (~400 W/m•K) or aluminum (~237 W/m•K) have thermal conductivities that are hundreds to thousands of times higher. Page Layout.

This disparity inspired researchers to develop methods to enhance fluid thermal properties. Initially, the idea of adding micrometer-sized solid particles to a base fluid was explored. While such suspensions exhibited higher conductivity, they suffered from several critical problems including sedimentation of particles, erosion of pipelines, clogging of micro channels, and dramatic increases in pumping power requirements. These drawbacks limited their practical adoption. The concept of nano fluids, pioneered by Choi and Eastman in 1995 at Argonne National Laboratory, revolutionized the field [1]. Nano fluids are stable colloidal suspensions of nanoparticles (1–100 nm in size) dispersed in conventional fluids. At such a small scale, nanoparticles remain well-dispersed for extended periods, and they interact with the base fluid in unique ways that enhance energy transport. Compared to micrometer particles, nanoparticles have a vastly larger surface-to-volume ratio, which increases surface energy exchange and Brownian motion effects, thereby improving heat conduction and convection.

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II. LITERATURE REVIEW

The continuous demand for high-performance heat transfer systems has driven the search for advanced thermal fluids. Conventional coolants such as water, ethylene glycol, and oil are widely used due to their availability, low cost, and ease of handling.

However, their thermal conductivities are inherently low — often less than 1 W/m·K — which significantly limits their capacity to dissipate heat. For comparison, solid metals such as copper and aluminum have thermal conductivities two to three orders of magnitude higher. This disparity created early scientific curiosity about whether introducing solid particles into fluids could bridge the gap. The theoretical groundwork was laid by James Clerk Maxwell in the late 19th century, who provided models for the effective thermal conductivity of two-phase mixtures. Later, Hamilton and Crosser (1962) refined these models by including particle shape factors. These works suggested that suspensions of solid particles in liquids could indeed improve thermal conductivity. However, experiments with micrometer- and millimeter-scale particles often led to severe practical challenges. Large particles sediment quickly under gravity, erode surfaces, and cause clogging in narrow passages. Moreover, suspensions exhibited non-Newtonian behaviour and large pressure drops, making them unsuitable for industrial adoption . The emergence of nanotechnology in the late 20th century fundamentally changed the landscape. Nanoparticles — with dimensions typically between 1 and 100 nm — offer a large surface-to-volume ratio, high surface energy, and unique thermo physical properties. Unlike larger particles, they can remain suspended for long periods, especially with stabilizers or ultra sonication. Choi and Eastman (1995) coined the term ―nanofluids‖ to describe these engineered suspensions. Their pioneering experiments demonstrated substantial thermal conductivity enhancement with minimal stability problems. Since then, nanofluids have become a central topic in thermal sciences, with thousands of studies exploring different particle types, base fluids, preparation methods, and applications. Today, nanofluids encompass a wide range of systems: metallic nanoparticles (Cu, Ag, Au), metal oxides (Al_2O_3, TiO_2, ZnO), carbons (CNTs, graphene, diamond), and hybrid nanofluids that combine multiple particle types. They have been studied in fundamental settings (tubes, annuli, microchannels), and practical devices (radiators, solar collectors, condensers, desalination plants). Despite promising laboratory results, full-scale industrial application remains limited due to concerns over cost, stability, long-term performance, and environmental impact.

III. SYSTEM DESIGN

Since our project is mainly about setting up an experiment to investigate a theory that concluded, ―heat transfer rate can be enhanced with using nanoparticles flowing through the fluid layers‖, our concern is about how to setup an experiment in a way that gives reliable results. In other words, we will consider the possible sources of errors and how to be prevented or limited. One of main problems is controlling the flow of the nanoparticles that we have to overcome as illustrated in the next chapter. In addition, the relationship between the amount of nanoparticles in the water flow and heat transfer efficiency is directly proportional, however, its behavior reverse at a specific point ―breaking point‖, and the pressure drop is inversely proportional with the heat transfer efficiency, [1]. Accordingly optimization between these parameters should be conducted, meaning to reach the highest possible efficiency with the least possible pressure drop. Moreover, as engineers we consider engineering standards, environmental, economic, manufacturing, and safety issues. As a result, we have taken into consideration the engineering standards for parts and equipment selection. The main equipment in our prototype are a fan, car radiator, electric water pump, heater, and a water container, in addition to the tubes, valves, pressure gage, and temperature sensors. Most of the parts and some of the equipment are locally made following the SASO standards. The car radiator, the fan, and the water pump we have used are South Korean made, which follows the national standard KATS (The Korean Agency for Technology and Standards), [2]. Environmentally speaking, the prototype design has no serious issues. There are no harm exhausts or plenty of water used since we planned to use the least possible water to reach our goals. In addition, we opened an additional outlet in the water container for water discharge and we used a container for the waste discharged water that including nanoparticles to keep the area dry and clean.

A. *Design Methodology and Theoretical Calculations*

Figure illustrates the project architecture. It shows the function of the system with the devices and the way the whole system operate. The approach of the system design started with finding a heat exchanger and we chose a car radiator with a fan. However, the water pump used in cars are mechanical (it connects to the engine) which cannot be properly worked in the experiment. This caused us to try an electrical pump with features that illustrated in section 3.3. In addition, we planned to use woody frames for the fan and heat exchanger to fix them on the table. We need to find the best quality places with the minimum prices (to control our budget) to do the frames and the table. After choosing the proper parts and devices, we used Solid Works software in order to simulate the assembly of the system. Last but not the least, we must assemble the components of the experiment in the way we instructed by the advisor with the consideration of previous works. Finally, we will do several experiment with and without using nanoparticles and publish our results and recommendations we observed.

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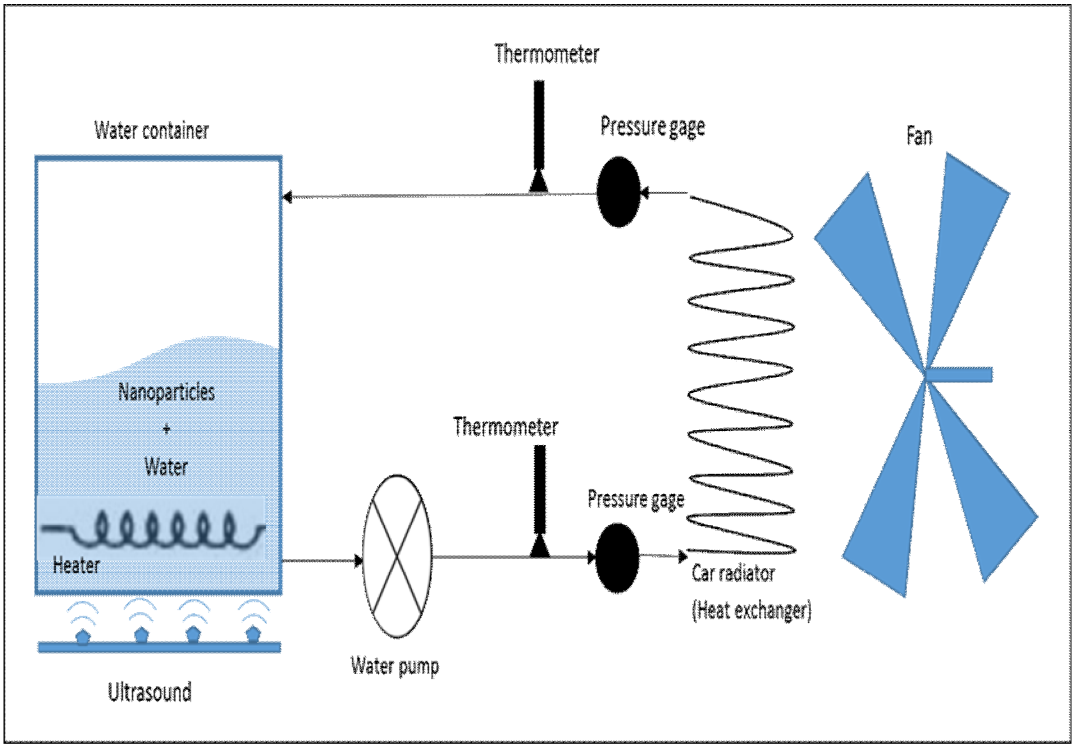


IV. EXPERIMENTATION

A. Objective:

Objective: to investigate heat transfer behavior of different type of nanofluid in a car-radiator heat exchanger. Heat transfer characteristics will be measured under the turbulent flow conditions. In addition, the optimum volume concentrations in which the heat transfer characteristics become the maximum enhancement is addressed and also the performance of the two nanoparticles is compared.

B. Experimental Setup:

Heat transfer is a critical phenomenon in numerous industrial and engineering systems such as power plants, refrigeration, automotive cooling, and electronic device management. Conventional heat transfer fluids such as water and ethylene glycol have limitations in terms of thermal conductivity, which restricts their efficiency. To overcome these drawbacks, nanofluids—colloidal suspensions of nanoparticles in base fluids—have been extensively researched for their enhanced thermophysical properties. In the present experimental study, a closed-loop test rig was designed and fabricated to investigate the heat transfer performance of water-based nanofluids under controlled laboratory conditions. The detailed description of the experimental setup is provided in this section.

1) General Layout of the System

The experimental system consists of a closed circulation loop in which the working fluid (nanofluid) is stored, heated, circulated, cooled, and measured. The major components of the system include:

- Reservoir with heater for storing and preheating the nanofluid.
- Pump to circulate the fluid throughout the loop.
- Radiator-type heat exchanger serving as the test section.
- Cooling fan for providing forced convection cooling to the radiator.
- Measuring instruments including thermocouples
- Piping and connections for fluid circulation.

Fig 4.1 : Actual Setup

The layout ensures that the nanofluid can be subjected to repeatable heating and cooling cycles while key parameters such as temperature difference, flow rate, and heat input are monitored.

2) Reservoir with Heater

The reservoir is a stainless-steel tank used to store the nanofluid before it enters the circulation loop. The volume of the tank is sufficiently large to accommodate the required test fluid and minimize the risk of thermal stratification.

At the base of the reservoir, an electric immersion heater is installed. The heater is responsible for raising the temperature of the nanofluid to the desired inlet condition. The power rating of the heater is chosen such that heating is neither too rapid (to avoid thermal shock) nor too slow (to ensure efficient experimentation). The heater input is controlled via a variable power supply, and the electrical input is measured using a voltmeter and ammeter to calculate the power delivered.

In order to ensure homogeneous suspension of nanoparticles, the tank is mounted on an ultrasonic vibrator platform. Ultrasonic agitation helps to break down any nanoparticle agglomerates and prevents sedimentation during the experiment. In some trials, a magnetic stirrer may also be used for continuous mixing. Maintaining nanoparticle dispersion is critical for obtaining reliable and reproducible results, as clustering of particles can alter the thermophysical properties of the fluid.

3) Pumping System

The circulation of nanofluid in the loop is achieved by means of a centrifugal pump. The pump is selected based on the required flow rate and head loss in the system. The pump ensures steady, uniform, and continuous flow of fluid through the heat exchanger. The flow rate is a crucial parameter, since it directly affects the Reynolds number, heat transfer coefficient, and overall thermal performance.

To monitor the volumetric flow rate, a flow meter is installed in the pipeline. Depending on the accuracy requirements, either a rotameter or a digital turbine flow meter may be used. Flow regulation is carried out with the help of control valves, allowing the operator to perform experiments at different flow rates and flow regimes (laminar or turbulent).

4) Heat Exchanger (Test Section)

The heart of the experimental system is the heat exchanger, which acts as the test section for evaluating nanofluid heat transfer performance. In this setup, a radiator-type heat exchanger is used, similar to those employed in automotive cooling systems. The radiator consists of a series of parallel tubes through which the hot nanofluid flows. These tubes are connected to thin metallic fins that increase the surface area available for heat dissipation.

C. Working Principle

The operation of the experimental setup can be described as follows:

1) The prepared nanofluid is filled into the reservoir.
2) The heater is switched on to raise the fluid temperature to the desired level.
3) The pump circulates the hot nanofluid through the loop and into the radiator.
4) The fan blows air across the radiator, causing the nanofluid to lose heat.
5) The cooled fluid exits the radiator and returns to the reservoir, completing the cycle.
6) Temperatures at the inlet and outlet of the radiator are recorded, along with the flow rate and heater input.
7) Heat transfer parameters such as heat transfer rate, overall heat transfer coefficient, and effectiveness are calculated.
8) The process is repeated for different concentrations of nanoparticles and for pure water to enable comparison.

D. Experimental Procedure

The experiment begins with the preparation of nanofluid by dispersing the required concentration of nanoparticles into distilled water. The prepared nanofluid is filled into the reservoir, and the heater is switched on to bring the fluid to the desired temperature. The pump is then started to circulate the nanofluid through the loop, while the fan provides cooling air over the radiator. The inlet and outlet temperatures of the fluid are measured using thermocouples, and the flow rate is kept constant during each test run. From the obtained data, the heat transfer coefficient, heat transfer rate, and effectiveness of the nanofluid can be determined. For comparison, similar experiments are conducted using pure water as the base fluid.

E. Observations

1) Observation for pure water with no nano particle put

Table 4.1 : Observation for pure water with no nano particle put

Sr no.	Mass flow rate (Water) Kg/s	Ch W/K	Air flow rate Kg/s	Cc W/K	Air Tin °C	Air $Tout$ °C	Water Tin °C	Water $Tout$ °C
a1	0.667	2786	0.5	503	30.2	31.7	44	42
a2	0.667	2786	1	1005	30.2	31.9	44	42.2
a3	0.333	1391	0.5	503	30.2	31.4	44	41.5
a4	0.333	1391	1	1005	30.2	31.5	44	41.7

The observed data for pure water without nanoparticles is summarized in Table 4.1. Four experimental cases were conducted with two different water mass flow rates (0.667 kg/s and 0.333 kg/s) and two different air mass flow rates (0.5 kg/s and 1.0 kg/s). The table records inlet and outlet temperatures of air and water, as well as the calculated heat capacity rates of both fluids.

Key highlights from the table:

Case a1 (High water flow, low air flow)

- Water mass flow rate: 0.667 kg/s
- Air flow rate: 0.5 kg/s
- Water temperature drops from 44°C to 42°C ($\Delta T = 2°C$).
- Air temperature increases from 30.2°C to 31.7°C ($\Delta T = 1.5°C$).
- Heat exchanger effectiveness (ε): 10.86%.

Calculation For a1

For water:

- $c_{p,h} \approx 4180$ J/kg.K
- Mass flow rate: 0.667 kg/s

$C_h = \dot{m}_h \times c_{ph} = 0.667 \times 4180 \approx 2786$ W/K

For air:

- $c_{p,c} \approx 1005$ J/kg.K
- Typical radiator fans give ~ 0.5 kg/s airflow

$C_c = \dot{m}_c \times c_{pc} = 0.5 \times 1005 \approx 503$ W/K

Here,

c_{min} = 503 W/K (air)

c_{max} = 2786 W/K (water)

From water side:

$Q_h = C_h \cdot (T_{h,in} - T_{h,out}) = 2786 \times (44 - 42) = 5572$ W

From air side:

$Q_c = C_c \cdot (T_{c,out} - T_{c,in}) = 503 \times (31.6 - 30.1) = 754.5$ W

Maximum heat transfer

$Q_{max} = C_{min} \cdot (T_{h,in} - T_{c,in}) = 503 \times (13.8) \approx 6941.4$W

Effectiveness

Using air-side heat transfer (since it's Cmin):

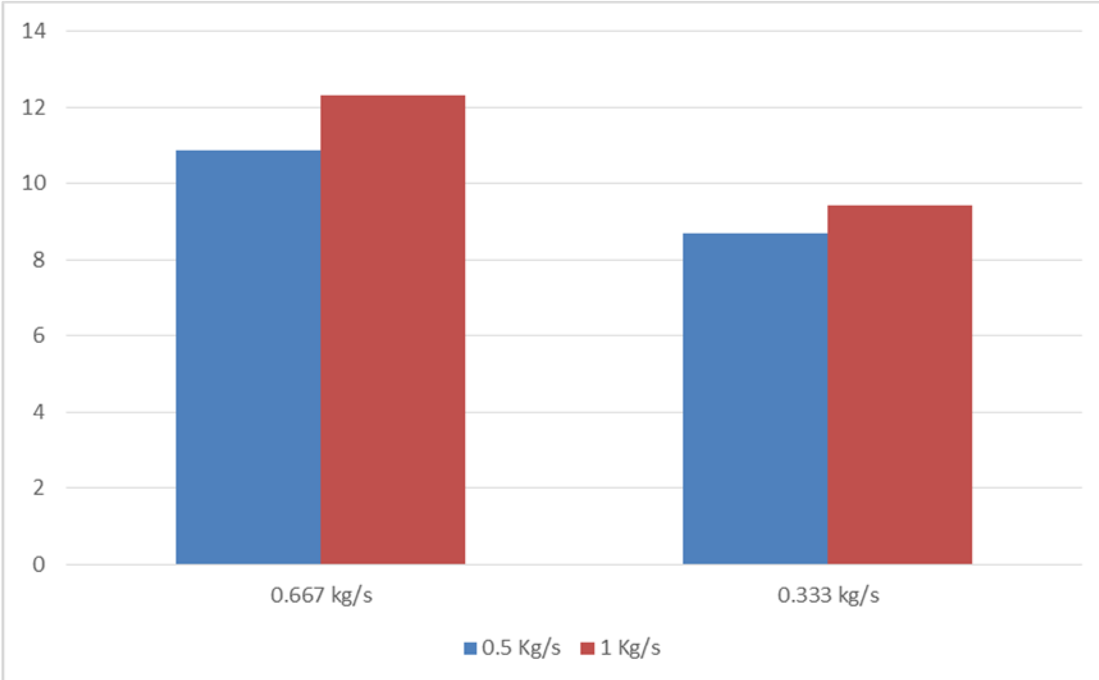
$\varepsilon = Q_{actual}/Q_{max} = 754.5 / 6941.4 = 10.86$ %

V. RESULTS, ANALYSIS AND DISCUSSION

A. Result for pure water with no nano particle

Table 5.1 : Result for pure water with no nano particle

Obs no.	Mass flow rate (Water) Kg/s	C_h W/K	Air flow rate Kg/s	C_c W/K	ϵ
a1	0.667	2786	0.5	503	10.86
a2	0.667	2786	1	1005	12.31
a3	0.333	1391	0.5	503	8.69
a4	0.333	1391	1	1005	9.42



Graph 5.1 : efficiency vs waterflow

B. *Result for water with aluminum nano particle*

Table 5.2 : Result for water with aluminum nano particle

Mass flow rate (Water) Kg/s	C_h W/K	Air flow rate Kg/s	C_c W/K	V_{water} L	V_{nano} % of V_{water}	ϵ %
0.667	2786	0.5	503	20	0.1%	14.5
0.667	2786	1	1005			16.23
0.333	1391	0.5	503			13.67
0.333	1391	1	1005			14.52
0.667	2786	0.5	503	20	0.5%	10.25
0.667	2786	1	1005			14.52
0.333	1391	0.5	503			11.96
0.333	1391	1	1005			13.67
0.667	2786	0.5	503	20	0.9%	15.38
0.667	2786	1	1005			18.8
0.333	1391	0.5	503			14.5
0.333	1391	1	1005			17.09

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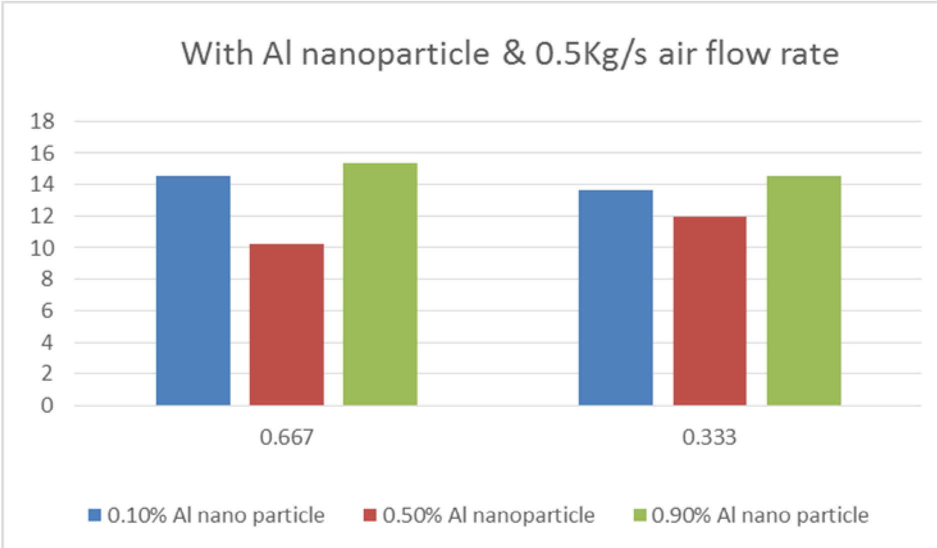
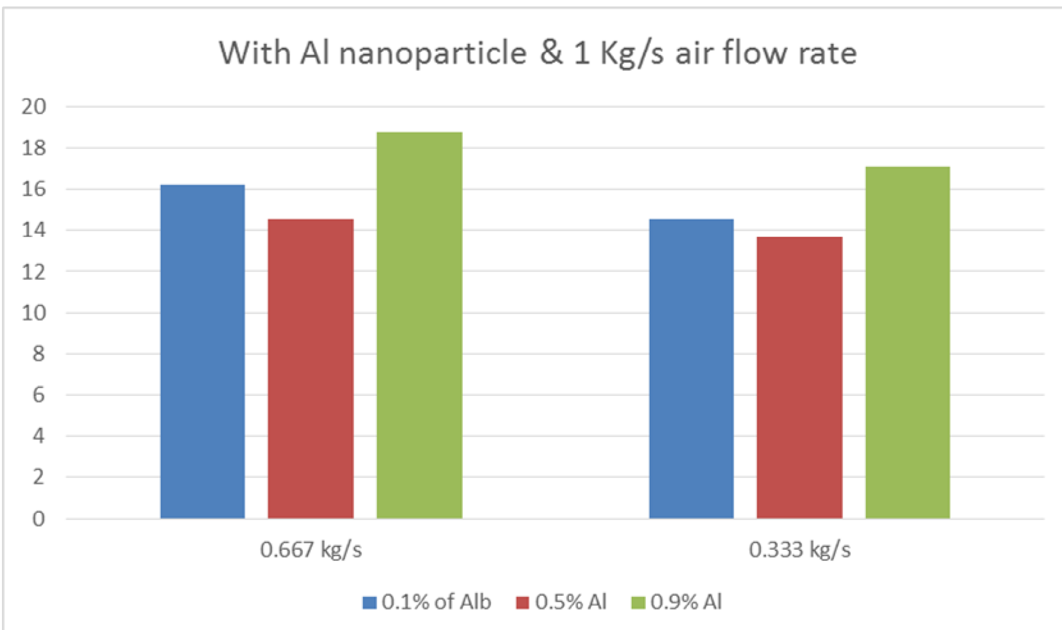


Graph 5.2 : Efficiency vs water flow rate @ 0.5 kg/s air flow rate



Graph 5.3 : Efficiency vs water flow rate @ 1 kg/s air flow rate

Comparative Summary (Water vs. Al vs. Cu Nanofluids)

- Pure Water (baseline): Max effectiveness ≈ 12.31%.
- Aluminium Nanofluids: Max effectiveness ≈ 18.8% (≈ 52% improvement).
- Copper Nanofluids: Max effectiveness ≈ 22.72% (≈ 90% improvement).

Thus, copper nanoparticles clearly outperform both water and aluminium in enhancing thermal performance.

VI. CONCLUSION

The experiments with copper nanofluids establish several key findings:

1) Significant Enhancement: Copper nanoparticles nearly double the effectiveness of the heat exchanger compared to pure water.
2) Concentration Dependence: Performance consistently increases with nanoparticle concentration, peaking at 0.9%.

3) Air Flow Sensitivity: Higher air flow rates yield substantial improvements since the air side is the limiting factor.
4) Water Flow Influence: Higher water flow aids convection but has less impact than air flow or nanoparticle concentration.
5) Superiority Over Aluminium: Copper nanofluids deliver higher effectiveness than aluminium nanofluids at similar concentrations.

Overall, copper nanofluids show great promise as advanced heat transfer fluids for demanding thermal management applications.

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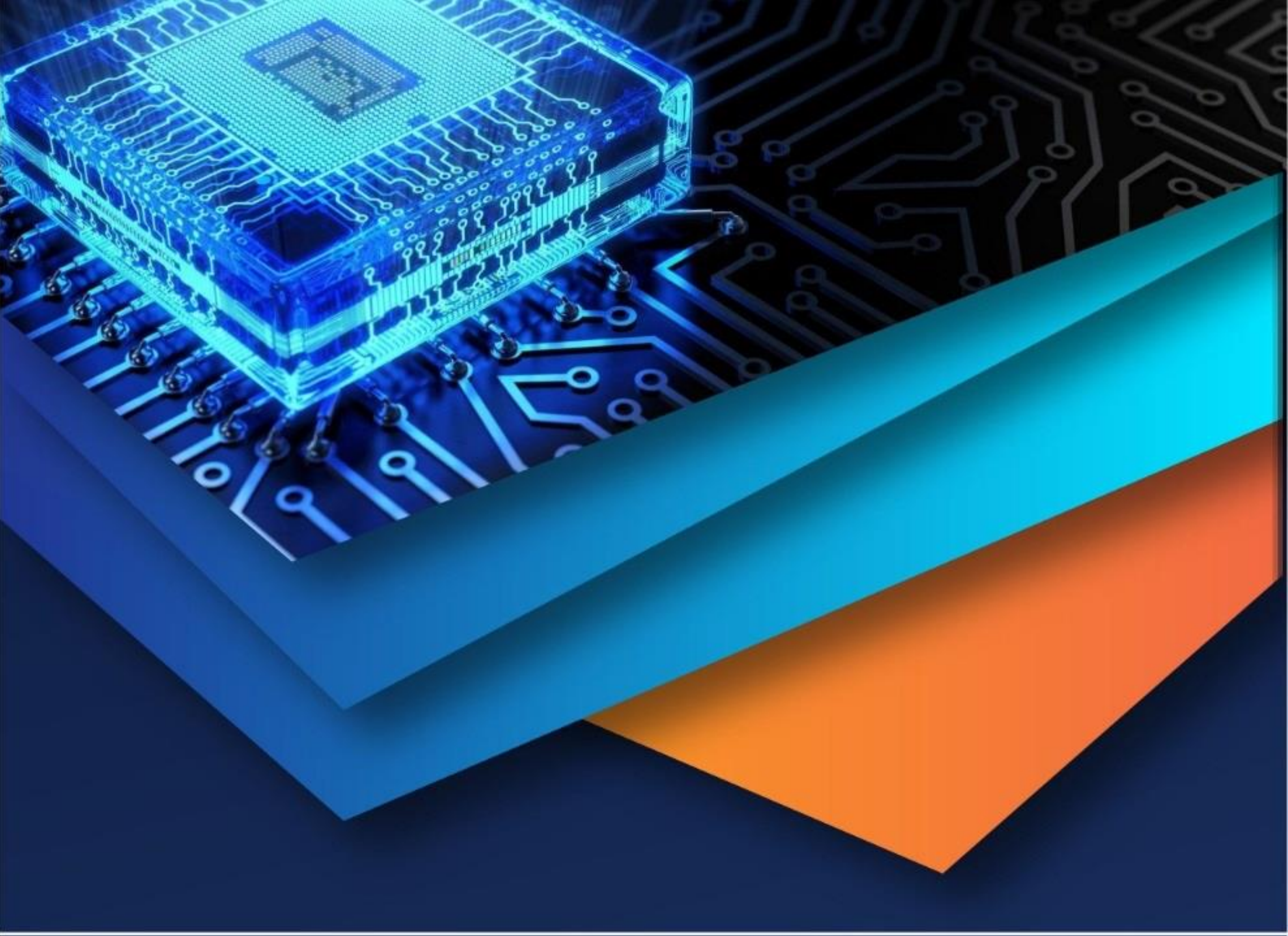

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