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Experimental and Computational Analysis of Damage Due to Al_2O_3 Nanocoolant on Cooling System

P.A. Ingole[1], S.M. Shinde[2], P.A. Patil[3]

PG Student[1],Mechanical Engineering Department, Jayawantrao Sawant College of Engineering, Savitribai Phule Pune University, Pune, Maharashtra, India.
Research Guide[2], Mechanical Engineering Department, Jayawantrao Sawant College of Engineering, Savitribai Phule Pune University, Pune, Maharashtra, India.
Research Guide[3], Mechanical Engineering Department, Jayawantrao Sawant College of Engineering, Savitribai Phule Pune University, Pune, Maharashtra, India.

Abstract

Presence of Suspended metallic nanoparticles into the base fluid improves the thermal performance of cooling system by increasing rate of heat transfer. Along with the maximum possible heat transfer enhancement nanoparticle presence causes severe damage to the system components, depending on concentration, flow velocity and size of nanoparticles. This paper addresses the experimentation on determining the possible damage to cooling system component material due to presence of Al_2O_3 nanomaterial based on concentration. Experimental set-up consisting 4 identical loops is developed and experiment is conducted with four different working fluids of 4 different nano concentrations (i.e. water, Al_2O_3 2.5%, 5% and 7.5%) with a velocity of 1.2 m/s. Moreover addition of nanoparticles causes the viscosity to increase which directly reflects in the pumping power consumption. Hence to study the influence of nanoparticles on pumping power as well as component damage the experimental work is carried out. All the four working fluid are allowed to flow simultaneously for same time period of 200 hours. Component surface roughness testing before and after experiment is carried out. To cover the wide range of flow rate effect on erosion rate, we have done the CFD analysis for aluminum tube.

Keywords— *Aluminum oxide nanoparticles, Discrete phase model, Erosion rate, Pumping power, Surface roughness.*

1. Introduction

During the past few decades researchers are paying more attention toward the improvement in the advanced cooling system. Lots of new cooling techniques are come into existence. Nanofluid cooling system is one of them. [1] Nanofluid cooling system increases the rate of heat transfer as well as reduces the size and weight of cooling system. Thus these cooling systems are potential replacement of general cooling system. But as they look toward the applicability of nanofluid in cooling system they found that there is lack of proper evidence which prove that there is no influence of nanoparticles on components of cooling system. In actual case the flow of solid particles through the cooling system causes mechanical damage to the components of cooling system. In order to make nanofluid cooling system globalize there is need for an adequate understanding of effect of selected nanofluid on material of cooling system component. [2] Heat transfer efficiency is greatly influenced by nanoparticles concentration. Higher the concentration of nanoparticles, higher will be the heat transfer coefficient. [3] Investigated the damaging effect caused due to presence of Al_2O_3 nanoparticles. There results shows that presence of nanoparticles into the flowing system leads to considerable damage to flowing system. [4] Conducted experiment on two different sizes of radiator with two different nanofluids. The result showed that heat transfer rate and temperature difference for smaller car radiator with nanofluid is similar or higher than those with standard size radiator without nanofluid. [5] Experimentally studied the effect of flow of nanofluid containing TiO_2, Al_2O_3, ZrO_2, and SiC nanomaterials. Their result shows that 9 wt. % Al_2O_3 is a worst damaging nanomaterial. Aluminium material is most sensitive to Al_2O_3 nanoparticles than that of copper and stainless steel. [6] Investigated the effect of friction and wear characteristics of water based ZnO and Al_2O_3 nanomaterials. They found that the wear volume is higher for Al_2O_3 nanoparticles than that of ZnO nanoparticles. This is because the hardness of Al_2O_3 is more as compared to ZnO. [7] Studied erosion caused by micro and nano sized particles in a 90 degree bend pipe. Their result shows that erosion rate increases with increase in velocity, concentration, and diameter of injected particles. [8] Experimentally investigated the effect of Al_2O_3 and CuO nanoparticles on the efficiency of the pump. Their result shows that the efficiency of pump has a direct relation to nanoparticle concentration. Maximum percentage of efficiency reduction is found to 25% to 26% for Al_2O_3 and CuO nanoparticles respectively.This study adopts the nanocoolant to examine the amount of damage caused when they are replaced by general coolant. Effect ofdifferent concentration of nanocoolants in terms of pumping power and damage is studied over here.

2. Experimental Procedure and Design

2.1 Layout

To determine the negative effect caused by presence of nanofluid of different concentration, on pumping power and erosion rate we considered the closed loop system as shown in fig.1

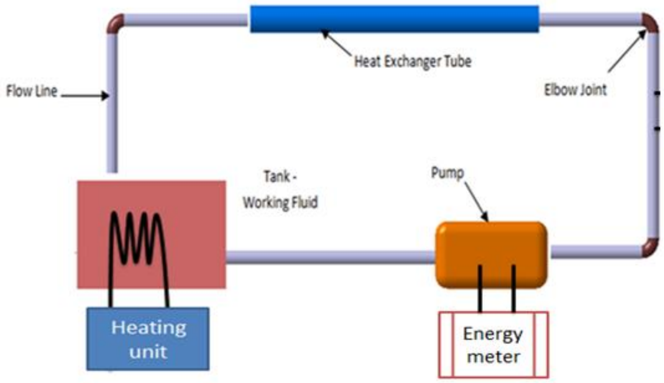

Fig. 1 proposed layout of experimental setup

Based on this proposed layout, experimental setup consisting four identical loops is developed to carry out the experimentation of 4 different fluids simultaneously under the same operating conditions. The designed setup is as shown in fig 2. The main components of setup is described below: Reservoir tanks of 12 liters capacity to store the fluid [1], Electric heater of 1kw capacity to heat the fluid [2], fluid pump of 550 lph with plastic impeller and 0.5 hp motor [3], Aluminium tube of length 500 mm and 12.7 mm diameter fitted in between hoses using clamps [4], Hose pipe made up of rubber commonly used in car cooling system [5], 4 Energy meter to measure power consumption of each loop separately[6], K-type thermocouples with temperature controller specifically at a temperature of 55 degree Celsius[7].

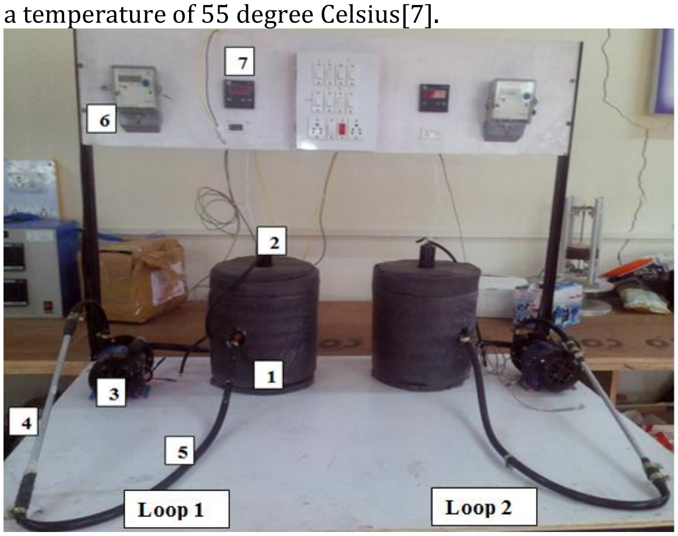

Fig. 2 Experimental arrangement of system component damage test rig. 1 Reservoir tank; 2 electric heater; 3 pump; 4 aluminium tube; 5 hose pipe; 6 energy meter; 7 temperature controller.

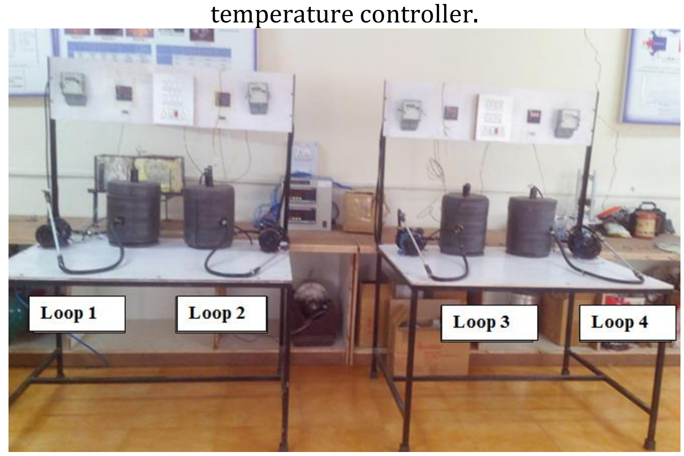

Fig.3 Test rig for damage and pumping power measurement

2.2 Material

Experimentation is conducted by using 4 different working fluids in each loop of setup. Commercially available water and water with concentration of 2.5%, 5% and 7.5% Al_2O_3 nanomaterial are obtained from maruti industries, Pune. Loop 1, loop 2, loop 3, loop 4, are filled with water, 2.5%, 5% and 7.5% W+Al_2O_3 nanofluid respectively.

2.3 Method

Initially before starting the experiment surface roughness test is carried out for 4 aluminium tubes, tabulated in table 1. System is started in such a way that all the 4 loops must start simultaneously and operates for a similar period of time. Temperature controller is used to maintain the temperature of fluid at 60 ^{0}C. Initially when the system is started we observe the energy meter readings for all loops to determine the initial power consumption of each pump incorporate in each loop. Surface roughness values for tubes before the start of experiment is required to determine the damage due to nanoparticle. System is allowed to run for 200 hours. Due to the time and cost limitations we restrict our experimental investigation for 550 lph only.

Table: 1 Operating parameters

Parameters	Contents
Working fluid	Water, Al_2O_3
Nano particle concentration	0 to 7.5 %
Flow Rate	550 lph
Working Fluid quantity	8 Liter
Operating temperature	55-60 ^{0}C

3. Experimental Results

Comparing the initial and final reading of pumping power consumption of 4 loops we can say that there is increase in pumping power requirement as the nanomaterial concentration increases. After 200 hours of operation we notice that power consumption for 2.5%, 5% and 7.5% Al_2O_3 concentration increased by 4.14%, 6.21% and 10.13 % respectively as compared to water .The power consumption values before and after the test are tabulated in the table 2. Rate of increase of pumping power is higher for higher concentration fluid and lower for lower concentration fluid. This phenomenon is due to additional rise in viscosity of fluid caused by nanoparticles. Damage caused due to presence of abrasive nanoparticles into the flowing fluid is detected experimentally in terms of surface roughness measured before and after experiment. This surface roughness value measurement is done in ideal instruments lab. Surface roughness caused by water, 2.5%, 5% and 7.5% Al_2O_3 concentration increased by 4%, 13.98 %, 17.47% and 25.55 % respectively.

Table 2: Pumping power consumption

Pumping Power consumption (kWh)			
Working fluid	Before operation	After 200 hours operation	Power Consumption
Water	0.68	14.2	13.52
2.5% Al_2O_3	0.58	14.66	14.08
5% Al_2O_3	0.58	14.94	14.36
7.5 % Al_2O_3	0.57	15.46	14.89

Table 3: Surface roughness of aluminum pipe

Surface roughness values (µm)		
Working fluid	Before operation	After 200 hours operation
Water	0.325	0.338
2.5% Al_2O_3	0.329	0.375
5% Al_2O_3	0.332	0.390
7.5 % Al_2O_3	0.321	0.403

4. CFD Model Creation

Due to time and cost restriction we have done CFD analysis for erosion rate prediction on different flow rates from 550 to 1000 lph. In this work CFD model is developed to study the rate of erosion depending on size and quantity of solid particles. Fig. 3 illustrates the domain of problem which is considered for erosion rate analysis. This section is of 500 mm length and 0.5 inches diameter representing the domain for aluminium tube on which erosion test is carried out.

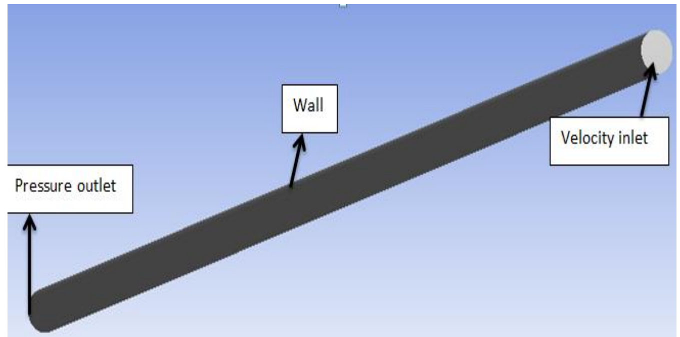

Fig. 4 Schematic representation of pipe domain considered for analysis

Particle volume loading <10% and we used DPM model. In DPM model we have injected the particles from surface of inlet zone using face normal direction. Particle diameter, particles velocity and flow rate are defined as shown in fig 4. In order to activate erosion model we enable interaction with continuous flow. Boundary conditions are applied with velocity inlet and pressure outlet. Hybrid initialization is done and after calculating the solution we come up with different results which are plotted in CFD results section.

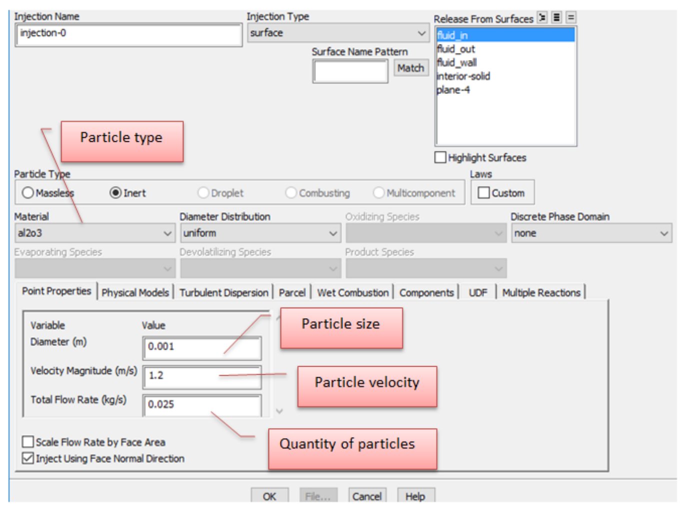

Fig. 5 Setting particle injection in DPM model

5. CFD Results

Damage due to presence of nanoparticle as well as micro sized particles in terms of erosion rate is predicted using CFD ANSYS 15.0 tool. Different contours for erosion rate along with maximum and minimum value for erosion rate caused by nano and micro particle in the flowing fluid with 550 to 1000 lph flow rate are investigated. Contours of erosion rate at 550 lph with nano and micro sized particles are as shown below:In fig. 6 and fig. 9 although the flowing particles are having same velocity and same concentration of 2.5%, smaller particle diameter shows higher rate of erosion than that of bigger diameter. This performance is similar for 5% and 7.5% concentration.

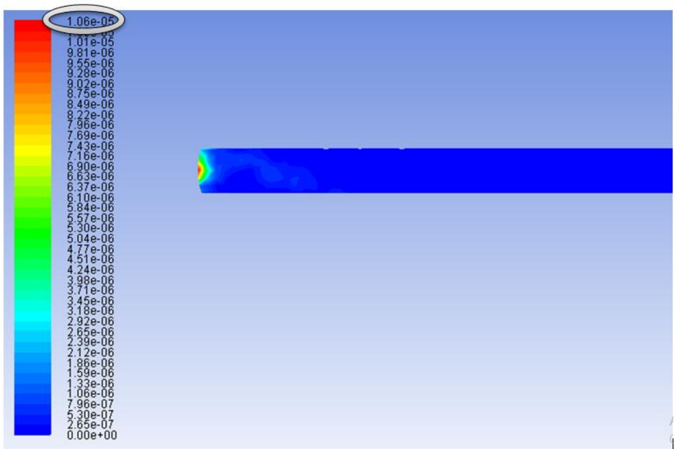

Fig. 6 Contour of erosion rate for 2.5% concentration and $1e^{-03}$ – particle diameter

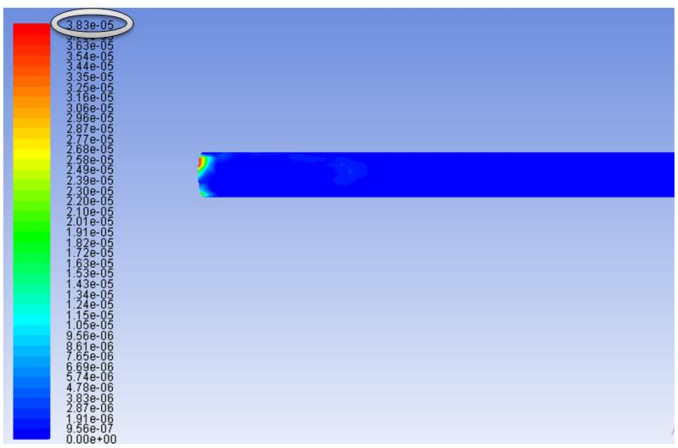

Fig. 7 Contour Erosion rate for 5% concentration and $1e^{-03}$– particle diameter

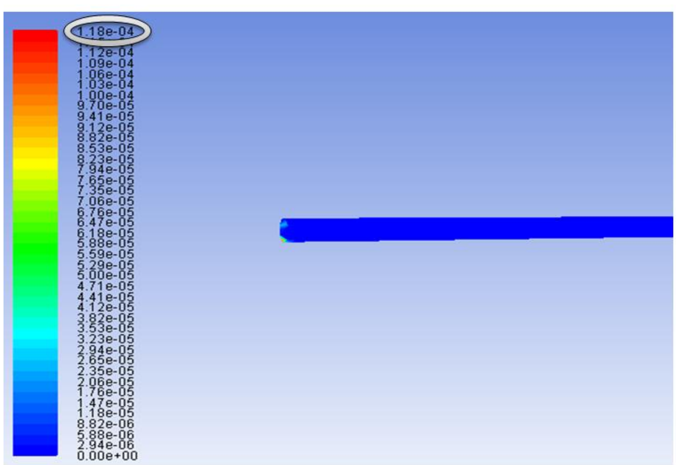

Fig. 8 Contour erosion rate for 7.5% concentration and $1e^{-03}$ – particle diameter

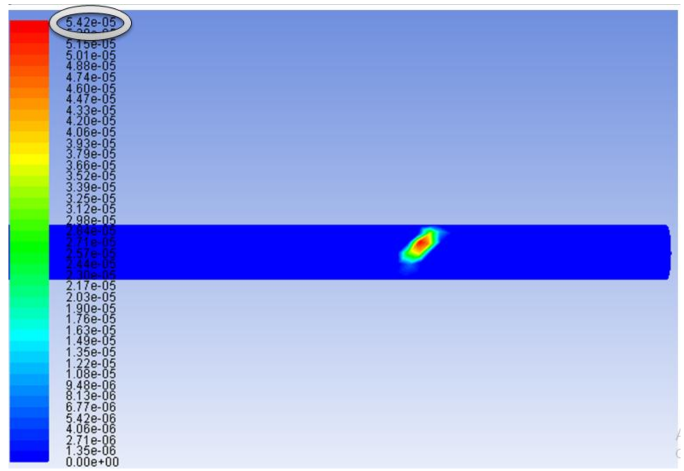

Fig. 9 Contour erosion rate for 2. 5% concentration and $1e^{-09}$ – particle diameter

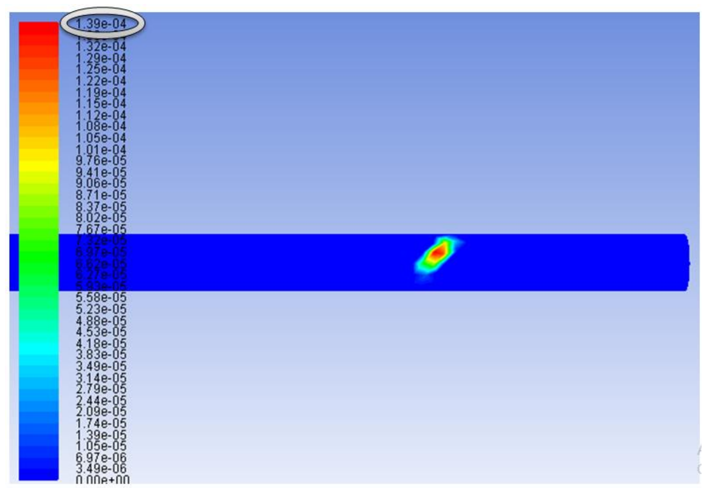

Fig. 10 Contour Erosion rate for 5% concentration and $1e^{-09}$– particle diameter

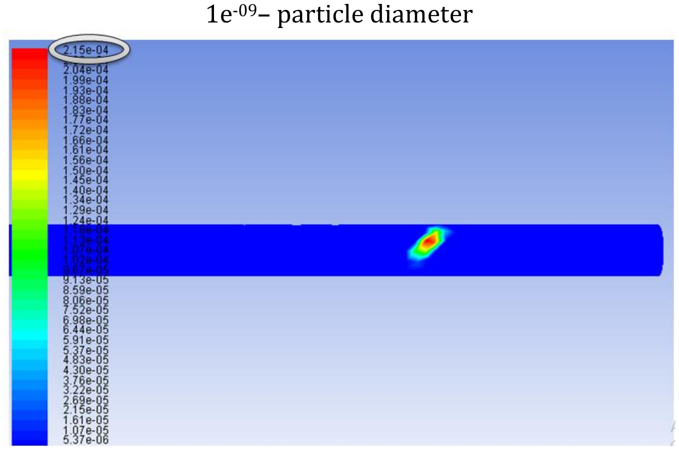

Fig. 11 Contour erosion rate for 7.5% concentration and $1e^{-09}$ – particle diameter

Fig. 12 shows the changes in erosion rate for different flow rates at different concentrations of nanoparticles. The result demonstrates that the erosion rate increases with the increase in flow rate and concentration. The erosion rate for 7.5 % Al_2O_3 nano concentration is higher than 2.5 %. This phenomenon is primarily due to the impact of injected particles on pipe surface. As the particle quantity increases, no of particles contributing the erosion also increases. Hence rate of erosion is higher for higher concentration and lower for lower concentration.

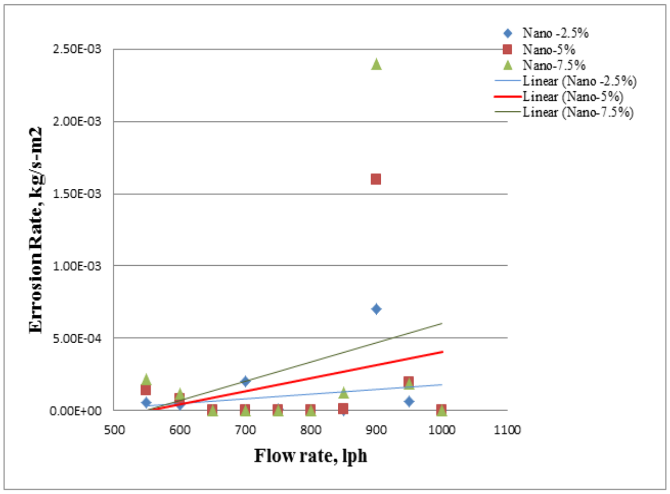

Fig. 12 Erosion rate as a function of flow rate for different nanoparticles concentration

Fig. 13 shows the changes in erosion rate for different flow rates at different concentrations of microparticles. The result shows that erosion rate by micro particles increases with increase in flow rate and increase in concentration.

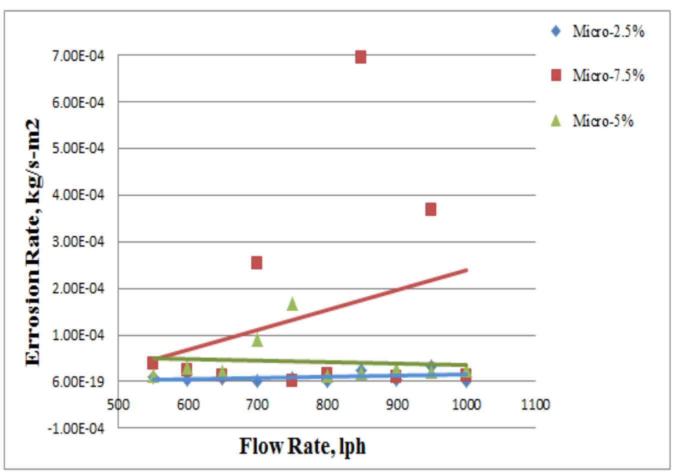

Fig. 13 Erosion rate as a function of flow rate for different micro particles concentration

Fig.14 shows the effect of micro and nano particles on erosion rate with respect to flow rate. The result indicates that erosion rate for nano particles are higher as compare to erosion rate by micro particles.

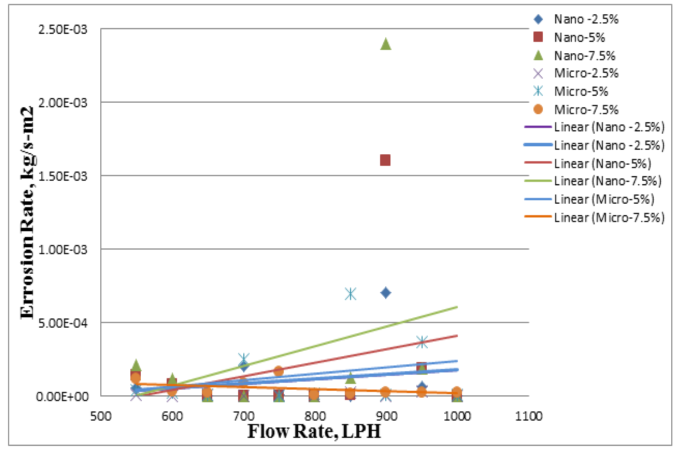

Fig. 14 Nano and Micro particles at different % Concentration

Conclusion

In this work experimental and computational analysis is done to study the negative behavior of nano and microfluids when they are used in cooling system as a heat transfer medium. Pumping power requirement and erosion rate with three different concentrations and flow rate are studied here.

1. Experimentally obtained pumping power value indicates that Power consumption by higher concentration fluid is on higher side where as for lower concentration fluid power consumption is lower. In our case Power consumption for 2.5%, 5% and 7.5% Al_2O_3 concentration increased by 4.14%, 6.21% and 10.13 % respectively as compared to water. Also the surface roughness value of pipe through which higher concentration of nanomaterial is flowing shows higher values as compared to normal water. Surface roughness values of pipe by water, 2.5%, 5% and 7.5% Al_2O_3 nano concentration increases by 4%, 13.98%, 17.47%, 25.55 % respectively.

2. CFD results shown similar results for nano and micro particles. Higher concentration of nano and microparticles damage the system more rapidly than that of lower one.

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