International Journal of Emerging Technology in Computer Science & Electronics (IJETCSE)
ISSN: 0976-1353 Volume 19 Issue 2 – JANUARY 2016.

FORCED CONVECTIVE HEAT TRANSFER ANALYSIS OF AL_2O_3 (NANO FLUID) AND WATER (BASE FLUID) IN HEAT EXCHANGER WITH TWISTED TAPE INSERT

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***Abstract*--Heat transfer is one of the most important processes in many industrial and consumer products. Nanofluids have been demonstrated to be promising for heat transfer enhancement in forced convection. The addition of carbon, copper, and other high thermal conductivity material nanoparticles to water, oil, ethylene glycol, and other fluids has been determined to increase the thermal conductivities of these fluids. The increased effective thermal conductivities of these fluids enhance their abilities to dissipate heat in such applications. The use of nanofluids for heat transfer medium in cross flow heat exchanger with twist plate inserted in the total length of the tube is an extension of the application of nanofluids for enhancement of heat dissipation. In this investigation, experiments were performed to determine the level of heat transfer enhancement with the addition of aluminum oxide nanoparticles to the fluid. Using Volume percentages of Upto 0.1% aluminum oxide nanoparticles suspended in water, heat fluxes and surface temperatures were measured and compared. This project considered the problem of forced convection flow of fluid inside a uniformly heated tube at the wall. The heat transfer co-efficient is analyzed at the same Reynolds number for both base fluids and Nano fluids. In this work, a comparative study of heat transfer co-efficient of base fluids (water) and Nano fluid (Al_2O_3) in cross tube heat exchanger with twist tape insert were carried out.**

I. INTRODUCTION

1.1 Brief Histroy Of Nanofluids

Conventional fluids such as water, ethylene glycol are normally used as heat transfer fluids. They play an important role in many industry sectors including power generation, chemical production, air-conditioning transportation and micro-electronics. Various techniques are applied to enhance the heat transfer; the low heat transfer performance of these conventional fluids obstructs the effective functionality and the compactness of heat exchangers. The use of nano particles as an additive suspended in the base fluid is a technique for heat transfer enhancement. Improving of the thermal conductivity is a key idea to improve the heat transfer characteristics of conventional fluids. Since a solid metal have more thermal conductivity than a base fluid, suspending metallic solid fine particles into the base fluid is expected to improve the thermal conductivity of that fluid. The enhancement of thermal conductivity of conventional fluids by the suspension of solid particles, such a millimeter or micrometer-sized particles has been well known for more than 100 years. However they have not been used for the practical difficulties such as sedimentation, erosion, and fouling and increased pressure drop of the flow channel. The recent advance in materials technology has made it possible to produce nanometer sizes particles that can overcome these problems.

1.2 Nanofluids

Heat transfer fluids (HTFs) have many industrial and civil applications, including in transport, energy supply, air-conditioning and electronic cooling, etc. Traditional HTFs, such as water, oils, glycols and fluorocarbons, however, have inherently poor heat transfer performance due to their low thermal conductivities. Research and development activities are being carried out to improve the heat transport properties of fluids. Solid metallic materials, such as silver, copper and iron, and non-metallic materials, such as alumina, CuO, SiC and carbon nanotubes, have much higher thermal conductivities than HTFs. It is thus an innovative idea trying to enhance the thermal conductivity by adding solid particles into HTFs since Maxwell initiated it in 1881 (Maxwell 1873). At the very beginning, solid particles of micrometer, even millimeter magnitudes were blended into the base fluids to make suspensions or slurries. However, large solid particles cause troublesome problems, such as abrasion of the surface, clogging the micro channels, eroding the pipeline and increasing the pressure drop, which substantially limits the practical applications.

Actually, liquid suspension was primarily a theoretical treatment only of some theoretical interest, and subsequent studies by other researchers achieved minor success. The large size of the particles and the difficulty in production of small particles were limiting factors.

The situation changed when S.U.S. Choi and J. Eastman in Argonne National Laboratory revisited this field with their nanoscale metallic particle and carbon nanotubes suspensions (Choi and Eastman 1995; Eastman et al. 1996). Choi and Eastman have tried to suspend various metal and metal oxides nanoparticles in several different fluids (Choi 1998; Choi et al. 2001; Chon et al. 2005; Chon et al. 2006; Eastman et al. 2001; Eastman et al. 1999; Eastman et al. 2004), and the results are promising, however, many things remain elusive about these suspensions of nano-structured materials, which have been termed “nanofluids” by Choi and Eastman. Generally, nanofluids are formed by dispersing nanometer-sized particles (1-100 nm) or droplets into HTFs. Nanoparticles have unique properties, such as large surface area to volume ratio, dimension-dependent physical properties, and lower kinetic energy, which can be exploited by the nanofluids. At the same time, the large surface area make nanoparticles better and more stably dispersed in base fluids. Compared with micro-fluids or milli-fluids, nanofluids stay more stable, so nanofluids are promising for practical applications without causing problems mentioned above. Nanofluids well keep the fluidic properties of the base fluids, behave like pure liquids and incur little penalty in pressure drop due to the fact that the dispersed phase (nanoparticles) are extremely tiny, which can be very stably suspended in fluids with or even without the help of surfactants (Xuan and Li 2003). A most attractive characteristic of nanofluids is that even by the addition of small amount of nanoparticles, they show anomalous enhancement in thermal conductivity over 10 times more than the theoretically predicted. Eastman et al (Eastman et al. 2001) reported a 40% thermal conductivity increase in ethylene glycol by adding only 0.3 vol. % of copper nanoparticles with a diameter smaller than 10 nm. Experiments on convection heat transfer of nanofluids were conducted by several research groups (Buongiorno 2006; Chein and Huang 2005; Etemad et al. 2006; Kim et al. 2004a; Said and Agarwal 2005; Xuan and Li 2003). The experimental results showed significant improvements in heat transfer rates of nanofluids. Meanwhile, the thermal conductivity enhancement of nanofluids show a temperature-dependent characteristic – increase of enhancement with rising temperature, which makes the nano fluids more suitable for applications at elevated temperatures (Das et al. 2003c; Yang and Han 2006a).

Another interesting phenomenon of nanofluids is that even extremely low concentration of small nano particle will increase the critical heat flux (CHF) in a pool boiling system (Das et al. 2003a;

Wen and Ding 2005b; You et al. 2003). The improved thermal transport properties of nanofluids would improve the efficiency of heat exchanging, reduce the size of the systems, save pump power, reduce operational cost and provide much greater safety margins. Better properties of nanofluids maybe obtained if higher-quality and more monodispersed nanoparticles can be synthesized. Meanwhile, nanofluids with the low volume fraction of the suspended nanoparticles incur almost no extra penalty of pump power (i.e., the viscosity increase is small.). However, the research work on nanofluids is only at its infant stage. More work is necessary for an in-depth understanding of the anomalous thermal conductivity jump and the enhancement in the convective heat transfer coefficient in nanofluids. Some of the current theoretical models attribute the increasing thermal conductivity to the high conductivity of solids. But Chen (Chen 1996; Chen et al. 2004) argued that when the particle size is smaller than the mean free path of heat-carriers (electrons, phonons, or molecules), the heat carrier transport is ballistic or non-local and Fourier’s law is not applicable. In fact, thermal conductivity decreases rapidly with decreasing particle size. Very limited data have indicated an inverse dependency of nanofluids’ thermal conductivity on the particle size -- with decreasing particle size, the effective thermal conductivity of nanofluids tends to increase, which apparently contradicts the phenomenological size-dependent thermal conductivity of nanoparticles, and thus an investigation of the effects of particle’s thermal conductivity on the thermal behavior of nanofluids is imperative. At the same time, with decreasing particle size, the interfacial area between particles and the base fluid increases dramatically so that the interfacial resistance (Kapitza resistance) should be carefully taken into consideration. There has not been a systematic experimental investigation of size dependent conductivity reported. An investigation of the effects of different particle sizes on thermal conductivity enhancement is necessary before good-performance nanofluids can be synthesized. On the other hand, the large interface areas between the nanoparticles and the base fluids increase the heat transfer rate, so nanosheets, nanorods, and nanowires, which have large surface areas, perhaps are favorable to more significantly increase the thermal conductivity of nanofluids. Nanofluids are a new class of fluids engineered by dispersing nanometer-sized materials **(**nanoparticles, nanofibers, nanotubes, nanowires, nanorods, nanosheet, or droplets**)** in base fluids. Common base fluids include water, organic liquids (e.g. ethylene, tri-ethylene-glycols, refrigerants, etc.), oils and lubricants, bio-fluids, polymeric solutions and other common liquids. Materials commonly used as nanoparticles include chemically stable metals (e.g. gold, copper), metal oxides (e.g., alumina, silica, zirconia, titania), oxide ceramics (e.g. Al_2O_3, CuO), metal carbides (e.g. SiC), carbon in various forms (e.g., diamond, graphite, carbon nanotubes, fullerene) and functionalized nanoparticles. Much attention has been paid in the past decade to this new type of composite material because of its enhanced properties and behavior associated with heat transfer, mass transfer, wetting and spreading and antimicrobial activities and the number of publications related to nanofluids increases in an exponential manner. In this project, experimental studies are reviewed for nanofluid thermal conductivity and heat transfer enhancement. Specifically, comparisons between thermal measurement techniques and optical measurement techniques are discussed. Researchers have also tried to increase the thermal conductivity of base fluids by suspending micro or larger-sized solid particles in fluids since the thermal conductivity of solid is typically higher than that of liquids, seen from Table 1.

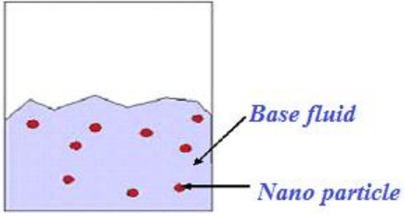


Fig 1 Principle of Nanofluids

Table: 1 Thermal conductivities of various solids and liquids

	Material	Thermal conductivity (W/mK)
Carbon	Nanotubes Diamond Graphite Fullerenes film	1800-6600 2300 110-190 0.4
Metallic solids (pure)	Copper Aluminum	401 237
Nonmetallic solids	Silicon Alumina (Al_2O_3)	148 40
Metallic liquids	Sodium (644 K)	72.3
Nonmetallic liquids	Water Ethylene glycol (EG) Engine oil (EO)	0.613 0.253 0.145

1.3 The Concept Of Nanofluids

In the development of energy-efficient heat transfer equipment, the thermal conductivity of the heat transfer fluid plays a vital role. However, traditional heat transfer fluids such as water, oil, and ethylene glycol mixtures are inherently poor heat transfer fluids. With increasing global competition industries have a strong need to develop advanced heat transfer fluids with significantly higher thermal conductivities than are presently available. Despite considerable previous research and development efforts on heat transfer enhancement major improvements in cooling capabilities have been constrained because of the low thermal conductivity of conventional heat transfer fluids. However, it is well known that at room temperature, metals in solid form have orders-of-magnitude higher thermal conductivities than those of fluids (Touloukian et al., 1970). For example, the thermal conductivity of copper at room temperature is about 700 times greater than that of water and about 3000 times greater than that of engine oil.

The thermal conductivity of metallic liquids is much greater than that of nonmetallic liquids. Therefore, the thermal conductivities of fluids that contain suspended solid metallic particles could be expected to be significantly higher than those of conventional heat transfer fluids. In fact, numerous theoretical and experimental studies of the effective thermal conductivity of dispersions that contain solid particles have been conducted since Maxwell’s theoretical work was published more than 100 years ago (Maxwell, 1873). However, all of the studies on thermal conductivity of suspensions have been confined to millimeter- or micrometer-sized particles. The major problem with suspensions containing millimeter- or micrometer-sized particles is the rapid settling of these particles. Furthermore, such particles are too large for micro systems. Modern nanotechnology provides great opportunities to process and produce materials with average crystallite sizes below 50 nm. Recognizing an opportunity to apply this emerging nanotechnology to established thermal energy engineering, the author proposed in 1993 that nanometer-sized metallic particles could be suspended in industrial heat transfer fluids such as water, ethylene glycol, or engine oil to produce a new class of engineered fluids with high thermal conductivity. Nanofluids are this new class of heat transfer fluids and are engineered by suspending nanometer-sized particles in conventional heat transfer fluids.

The average size of particles used in nanofluids is below 50 nm. The author coined the term nanofluids for this new class of heat transfer fluids (Choi, 1995). It should be noted that in today's science and technology, '`size does matter."` Maxwell’s concept of enhancing the thermal conductivity of fluids by dispersing solid particles is old. But what is new and innovative with the concept of nanofluids is the idea of using the nanometer-sized particles that have become available to investigators only recently.

1.4 Motivation Of Improving Thermal Conductivity Of Fluids

Recent years have eye-witnessed a blossom in the development of electronics, communications, and auto-computing industries, and this trend is indisputably continuing in this century. Cooling of mechanical, electrical and electronic components has become a problem in today’s fast growing technologies. The heat required to be rejected is continually increasing due to trends toward faster speeds and smaller volumes for microelectronic devices, more power output for engines, and brighter beams for optical devices. Though all three modes of heat transfer can be used for cooling, the utilization of fluids by taking the advantage of the large heat flux of convection and boiling is one of the most common and effective way.

Heat transfer fluids have found many industrial and civil applications, including in automotive, aerospace, energy supply, air-conditioning and electronic cooling, etc. However, the low thermal conductivity of the heat transfer fluids is a limiting factor in the design of the cooling systems. The increasing power but decreasing size of the equipments calls for innovative cooling technologies and now the thermal management has become one of the top technical challenges and a primary concern of component design. There are two ways to meet the cooling requirements: designing new cooling devices, such as increasing the surface by fins, micro channels, integrated spot cooling and miniaturized cry devices, and improving the heat transfer capability of the fluids (Duncan and Peterson 1994; Eastman et al. 2004).

The effectiveness of updating the design of cooling devices as a conventional method to increase the heat transfer rate, however, has reached a limit (Eastman et al. 2004). With the increasing demand for machines and devices to operate efficiently, the seeking for new heat transfer fluids with higher thermal conductivity and more effective cooling capacity is an emergency now. The research and development work are being carried out to improve the heat transport properties of conventional heat transfer fluids (Das et al. 2006).

Liquid metals are thermally conductive and their heat transfer characteristics have been attracting much interest. Liquid metals are used as heat transfer fluids in specialized branches of engineering involving very high heat fluxes (Miner and Ghoshal 2004).As an example, in nuclear engineering, there is the requirement to obtain high rates of heat extraction from reactors. Also liquid metal is used in gas turbine, where the need for effective blade-cooling systems remains as press in gas ever in order to achieve the greatest thermodynamic advantage. Liquid metals usually have very high thermal conductivity, which mark them off from other conventional HTFs, i.g., water, oils and glycols. Liquid mercury has been proposed as the working fluid in cooling devices like heat pipes for the heat rejection systems or the radiation panels of spacecraft. Moreover, liquid mercury is sometimes used as the coolant for nuclear reactors; however, because of its high density, a lot more energy is required to circulate liquid mercury as coolant (Fleitman and Weeks 1971).

1.5 Preparation Methods For Nanofluids

Preparation of nanofluids is the first key step in experimental studies with nanofluids. Nanofluids are not just dispersion of solid particles in a fluid. The essential requirements that a nanofluid must fulfill are even and stable suspension, negligible agglomeration of particles, no chemical change of the particles or fluid, etc.

Nanofluids are produced by dispersing Nano meter scale solid particles into base liquids such as water, ethylene glycol, oil, etc. In the synthesis of nanofluids, agglomeration is a major problem. There are mainly two techniques used to produce nanofluids: the single-step and the two-step techniques.

1.5.1 Two Step Technique

Two-step method is the most widely used method for preparing nanofluids. Nanoparticles, nanofibers, nanotubes, or other nanomaterials used in this method are first produced as dry powders by chemical or physical methods. Then, the nanosized powder will be dispersed into a fluid in the second processing step with the help of intensive magnetic force agitation, ultrasonic agitation, high-shear mixing, homogenizing, and ball milling. Two-step method is the most economic method to produce nanofluids in large scale, because nanopowder synthesis techniques have already been scaled up to industrial production levels. Due to the high surface area and surface activity, nanoparticles have the tendency to aggregate. The important technique to enhance the stability of nanoparticles in fluids is the use of surfactants. However, the functionality of the surfactants under high temperature is also a big concern, especially for high-temperature applications. Due to the difficulty in preparing stable nanofluids by two-step method, several advanced techniques are developed to produce nanofluids, including one-step method. In the following part, we will introduce one-step method in detail.

1.5.2 Single Step Technique

The single step simultaneously makes and disperses the nanoparticles directly into a base fluid; best for metallic nanofluids. Single-disperses. Various methods have been tried to produce different kinds of nanoparticles and Nano suspensions.

The initial materials tried for nanofluids were oxide particles, primarily because they were easy to produce and chemically stable in solution. Various investigators have produced Al2O3 and CuO nanopowder by an inert gas condensation process and found to be 2–200 nm-sized particles. The major problem with this method is its tendency to form agglomerates and its unsuitability to produce pure metallic Nano powders. The problem of agglomeration can be reduced to a good extent by using a direct evaporation condensation method.

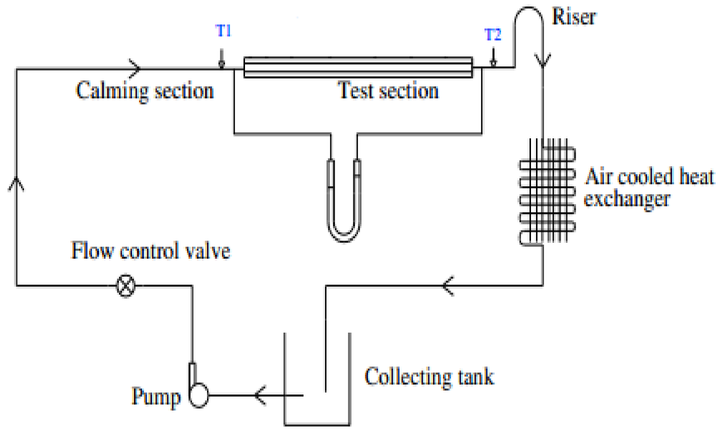
1.6 Heat Conduction Mechanisms In Nanofluids

The four possible mechanisms in Nano fluids which may contribute to thermal conduction.

(i) Brownian motion of Nano particles.
(ii) Liquid layering at the liquid/particle interface.
(iii) Ballistic nature of heat transport in nanoparticles.
(iv) Nano particle clustering in Nano fluids.

The Brownian motion of Nano particles is too slow to directly transfer heat through a nanofluid; however, it could have an indirect role to produce convection like micro environment around the Nano particles and particle clustering to increase the heat transfer. This mechanism works well only when the particle clustering has both the positive and negative effects of thermal conductivity. The presence of an ordered interfacial liquid molecule layer is responsible for the increase in thermal conductivity.

II. EXPERIMENTAL SETUP (HORIZONTAL FLOW HEAT EXCHANGER) AND WORKING



The schematic diagram of the experimental setup is shown in Figure .The fluid flows through a copper tube with twist tape insert, collecting tank, a storage tank with the aid of a pump. The working fluid is heated uniformly by a nichrome heater in the storage tank and subject entire test section to constant heat flux boundary condition. After the experimental setup is assembled, the storage tank is filled with the working fluid. Experiments are conducted for water at constant temperature with various flow rates to determine the heat transfer coefficients for flow in a tube. First the temperature of water is maintained at 35 °C by temperature controller.

After the steady state attains water is allowed to pass through the copper tube wounded with copper plate to measure the inlet and outlet temperatures of water. The fluid after passing through the copper tube is collected in the reservoir for recirculation. The volume flow rate of the working fluid, the inlet and outlet temperatures are noted down. The flow rate of the water is now varied (200 l/hr, 400 l/hr, 600 l/hr, 800 l/hr) and the readings are noted down. Now the heater is switched on and the temperature is set to 45°C. After the set temperature is attained the water is again circulated and readings are noted down.

III. THERMAL PROPERTIES OF NANOFLUIDS

Density of the fluid:

The thermo physical properties of Al2O3/water nanofluid are estimated by using the Eqns. at the average bulk temperature Where 'n' indicates solid particle, without suffix indicates base fluid. Density of Al_2O_3 /water nanofluid is determined by using the formula given by Pak, and Cho (1998).

$$\rho_{nf} = \varphi\, \rho_n + (1-\varphi)\, \rho_{bf}\ ,\mathrm{kg/m^3}$$

Specific heat capacity of the fluid:

The specific heat capacity of Al_2O_3/water nanofluid is estimated by using equation given by Yimin Xuan, and Wilfred Roetzel (2000)

$$C_{nf} = (1-\varphi)\, \rho_{bf}\ C_{bf} + \varphi\, \rho_p\, C_p / \rho_{nf}$$

Viscosity of the fluid :

The effective viscosity of nanofluid is found by using the formula proposed by Einstein,(1956).This model is suitable for spherical particles and 0.1% volume concentration. The thermal conductivity of Al_2O_3 / water nanofluid was measured with KD2 Pro thermal analyzer and the viscosity was measured with Brookfield cone plate viscometer.

$$\mu_{nf} = \mu_f\,(1+2.5\varphi)$$

Thermal conductivity:

The effective thermal conductivity is estimated by using the equation

$$K_{nf} / K_{bf} = 1 + 8.73 \times \varphi$$

Table 1 Flow of water inside the tube T =35^0 c

S.No	Flow rate (Q) ,LPH	T_{fluid} inlet (^{0}c)	T_{fluid} outlet(^{0}c)	Surface temperature of the tube (^{0}c)				
				T_1	T_2	T_3	T_4	T_5
1	120	36	35	35.2	35.7	36.9	36.2	52
2	180	37.6	36.3	37	36.3	38.2	37.9	53.8
3	240	39.5	37.9	41	40	41.4	41.5	55
4	300	40.7	39.3	42.2	41.2	42.4	42.2	58.4

Table 2 Flow of Nanofluid inside the tube T =35^0 c

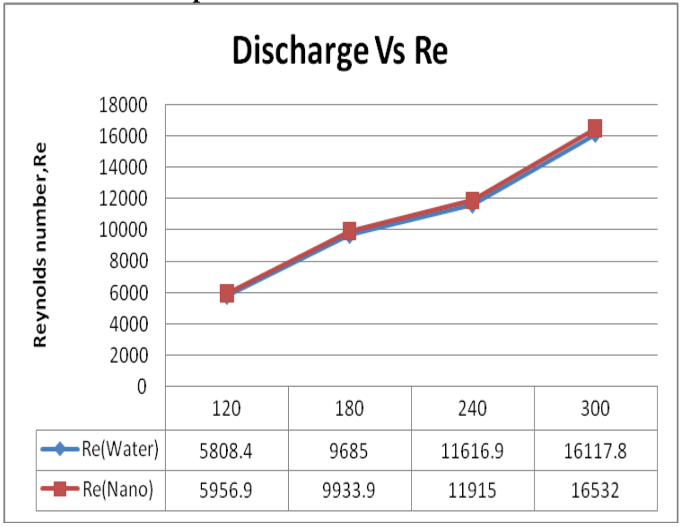
S.No	Flow rate (Q) ,LPH	$T_{nanofluid}$ inlet (^{0}c)	$T_{nanofluid}$ outlet(^{0}c)	Surface temperature of the tube (^{0}c)				
				T_1	T_2	T_3	T_4	T_5
1	120	43.6	41.1	43.4	43.4	44.6	44.1	60.1
2	180	45.3	42.4	45.5	45.2	46.4	46	62.4
3	240	46.7	43.8	47.1	46.6	47.7	47.4	63.8
4	300	48.3	45.2	48.5	47.9	48.9	48.9	65.1

IV. RESULTS AND DISCUSSION

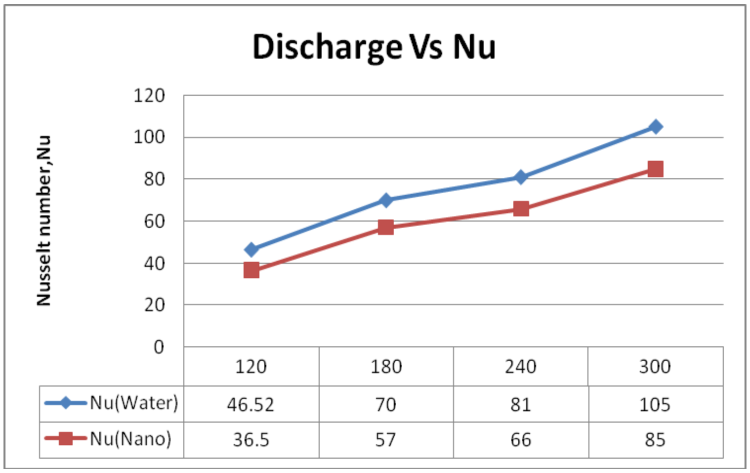
4.1 Heat Transfer Coefficient for horizontal flow heat exchanger

The following graph shows that the effect of increasing the particle volume concentration on experimental tube side or inner Nusselt number in turbulent flow. It is clear that the tube side Reynold's number increases over the particle volume concentration. The enhancement of tube side experimental Reynold's number, heat transfer coefficient and heat transfer were found to be 120,180,240,300 LPH flow rate at 0.1% particle volume concentration respectively. This is due to the better fluid mixing and higher effective thermal conductivity of nanofluid. This secondary flow provides proper mixing to enhance heat transfer. Results enhanced heat transfer coefficient. It is observed the increasing trend of experimental Nusselt number for 0.1% particle volume concentration of nanofluid.

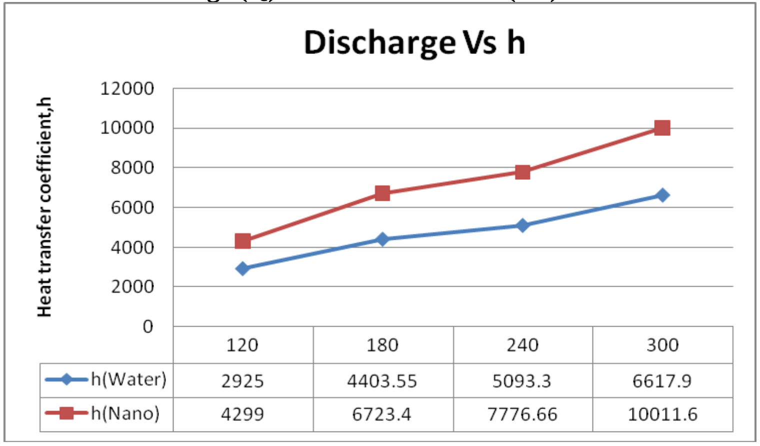
Temperature of Heater coil at 35^0c



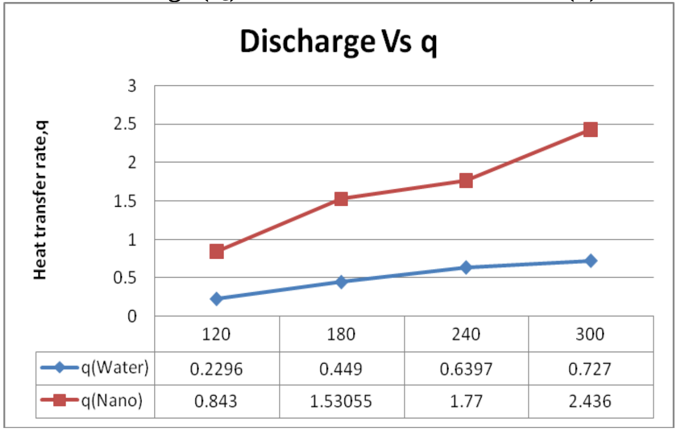
Discharge (Q) Vs Reynolds number (Re)



Discharge (Q) Vs Nusselt number (Nu)



Discharge (Q) Vs Heat transfer coefficient (h)



Discharge (Q) Vs Heat transfer rate (q)

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