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A Comprehensive Review on Cooling of Hot Surfaces using Nano-Fluids

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Abstract - *Nanofluid, a simple product of nanotechnology has become a topic of attraction due to its extraordinary heat transfer performance in various areas including cooling, power generation, defense, nuclear, space, microelectronics, and biomedical appliances. However, the preparation and stabilization of such fluids are indeed a matter of concern for better understanding. For the last decade, numerous research and development works have been done in the synthesis and stability of such materials. In this contribution, a brief review has been presented to provide an update about the preparation and stabilization methods of Nanofluids.*

Key words:

Nanofluid, heat transfer, power generation, defense, nuclear, biomedical

1. Introduction:

Impinging jets have been widely used in various industrial and scientific applications because of their ability to achieve higher heat transfer rates from the smaller surface areas. These can be classified into two categories: submerged jet and free surface jet. In the case of the submerged jet, the fluid jet is issued in a medium that contains the same fluid, while in the case of free jets the fluid issues into a medium with less dense fluid. Free surface impinging jets are usually used to remove higher localized heat fluxes from the hot surfaces. Because of its inherent advantages, impinging jets find applications in various areas, such as drying of food products, textiles, metallurgical treatments, cooling of gas turbine blades, and cooling of fuel pins in reactor core following the loss of coolant accident [1].

Different heat transfer regions are observed during impinging jets with water as a coolant, namely film boiling, transition boiling, nucleate boiling, and forced convection [2–6]. Recent advances in technology demand higher heat removal rates in various industrial applications. However, conventional coolants usually have poor thermal transport properties. Therefore, one needs to find out new economical technologies to improve the thermophysical properties of conventional fluids. The heat removal rate of the conventional fluid can be enhanced by several additives, namely salts, nano-particles, alcohols, and surfactants in base fluids.

Nanofluids are suspensions of nanoparticles in fluids that show a significant enhancement of their properties at modest nanoparticle concentrations, their behavior can be utilized where straight heat transfer enhancement is paramount as in many industrial applications. Low thermal conductivity is a primary limitation in the development of energy-efficient heat transfer fluids that are required in many industrial applications. Nanofluids are prepared by suspending different nanofluids in base fluids such as water which increases heat transfer as compared to base fluids.

The application of nanoparticles provides an effective way of improving heat transfer characteristics of fluids (Eastman et al., 1997). Particles <100 nm in diameter exhibit properties different from those of conventional solids. Compared with micron-sized particles, nanophase powders have much larger relative surface areas and a great potential for heat transfer enhancement. Some researchers tried to suspend nanoparticles into fluids to form highly effective heat transfer fluids. Choi (1995) is the first who used the term nanofluids to refer to the fluids with suspended nanoparticles. Some preliminary experimental results (Eastman et al., 1997) showed that an increase in thermal conductivity of approximately 60% can be obtained for the nanofluid consisting of water and 5 vol% CuO nanoparticles.

By suspending nanophase particles in heating or cooling fluids, the heat transfer performance of the fluid can be significantly improved. The main reasons can be listed as follows-

1. The prepared nanoparticles increase the surface area and the heat capacity of the fluid.

2. The suspended nanoparticles increase the effective thermal conductivity of the fluid.

3. The interaction and collision among particles, fluid, and the flow passage surface are intensified.

4. The mixing fluctuation and turbulence of the fluid are intensified.

5. The dispersion of nanoparticles flattens the transverse temperature gradient of the fluid.

2. LITERATURE REVIEW-

Various researchers have performed various experiments at various concentrations of nanoparticles immersed in different base fluids with or without dispersant /surfactant and observed various readings of increase in heat dissipation % of heat transfer by jet impingement at various flow rates and Reynolds number.

C.T Nguyen[1] performed an Experimental Investigation of Impinging Jet Heat Transfer and Erosion Effect Using Al2O3-Water Nanofluid and Results have shown that the surface heat transfer coefficient increases considerably when the mass flow rate is increased, at 5% of Al2O3(36nm) Volume Fraction between 1700-20000Re.

T.Yousefi et al. [2] performed an experimental investigation on the impingement of a number jet of Al2O3-Water nanofluid on a V-shaped plate between Reynolds number, 1732-2719 results concluded that Water nanofluid at low volume fractions of 0.02%and 0.05% yield enhancements on both local and average heat transfer coefficients, and these positive effects increase with increasing Reynolds number. Zeitoun et al. [3] used 10nm size Al2O3 particles dispersed in water for Nanofluid impingement jet heat transfer for2000-2000 Reynolds numbers and 0, 6.6, and 10% nanoparticles concentration. The experimental results indicate that using nanofluid as a heat transfer carrier can enhance the heat transfer process. For the same Reynolds number, the experimental data show an increase in the Nusselt numbers as the nanoparticle concentration increases. The size of heating disk diameters shows a reverse effect on heat transfer. It is also found that presenting the data in terms of Reynolds number at impingement jet diameter can take into account both effects of jet heights and nozzle diameter.

Gherasim et al. [4] conducted an experimental investigation of nanofluids in confined laminar radial flows for Al2O3 dispersed in water for1 to 5% particle volume fractions. Results show that heat transfer enhancements are possible in radial flow cooling systems with the use of nanofluids. In general, it was noticed that the Nusselt number increases with particle volume fraction and Reynolds number and decreases with an increase in disk spacing.

Yang et al [5] used 47nm Al2O3 particles dispersed in water for Numerical investigation of cooling performance with the use of Al2O3/water nanofluids in a radial flow system for vol%= 0 to 10%, and Reynolds number Re-300 to 1000 Yang observed Considerable improvements in the average Nusselt number and significant reductions in the thermal resistance under a given pumping power are revealed compared to that of pure water at some supplied heat fluxes.

B.Jaberi et al[6] conducted an Experimental investigation on heat transfer enhancement due to Al2O3 water nanofluid using impingement of round jet on circular disk using Al2O3 water nanofluid + Sodium Dodecyl Benzene Sulfonate (SDBS) was added to the fluid as a dispersant. At 0.0198 to 0.0757 weight% and 4200-8200 Reynolds number. The results showed that, although the nanofluids increased HTCs, the maximum enhancement would correspond to the nanofluid with nanoparticle concentration of 0.0597 wt%, and adding more nanoparticles did not prove to be beneficial. In factthenano, particle concentration of 0.0757 wt% demonstrated the lowest enhancement in HTC. The maximum enhancement of the average nanofluid HTC in comparison with water is about 50% for Reynolds number 4200. The average HTC of nanofluids also remained constant with the increase of Reynolds number due to nano convection

Mayank Modak et al[7] conducted An experimental investigation on heat transfer enhancement in circular jet impingement on hot surfaces by using Al2O3/water nano-fluids and aqueous high-alcohol surfactant solution (HAS, i.e., 2-ethyl-hexanol,100–400 ppm) for 0.15%,0.6% vol%, and 5,000–12,000 Reynolds number The enhancement in the heat transfer rates for Al2O3-water nano-fluids with $\phi = 0.15\%$, $\phi = 0.60\%$, and aqueous surfactant solution(150ppm) is found to be 140%, 207%, and 117% higher compared to pure water results, respectively.

R. Reji Kumar et al [8] performed Inline Array Jet Impingement Cooling Using Al2O3 / Water Nanofluid In A Plate Finned Electronic Heat Sink using Al2O3/water nanofluid, 50nm for 0.1% mass concentration and volume flow rate of the fluid was in the range of 1.315 to 2.778. Results concluded that the convective heat transfer coefficient h gradually increases with increasing volume flow rate and it is high for Al2O3 /water nanofluid compared to deionized water.

Qiang Li et al [9] conducted an Experimental investigation of submerged single jet impingement using Cu–water nanofluid using Cu–water nanofluids (Cu particles with 25 nm diameter of 100 nm) for the volume fraction of 3.0% and 2000-16000 Reynolds number results indicated that. The convective heat transfer coefficient of Cu–water nanofluid with the volume fraction of 3.0% has 52% higher than the pure water.

P.Selvakumar et al [10] performed the Convective performance of CuO/water nanofluid in an electronic heat sink using CuO/water nanofluids and deionized water. At volume fractions 0.1% and 0.2% and 2985–9360 Reynolds number. Results specified that It can be understood from the values of interface temperature that the nanofluids remove more heat from the heated block compared to deionized water and keep the interface temperature minimum.

Xinwei Wang et al [11] conducted Thermal Conductivity of Nanoparticle–Fluid Mixture using Al2O328 nm, and CuO23nm, dispersed in water, vacuum pump fluid, engine oil, and ethylene glycol, for vol fraction 2-8% for aluminum,5-10% for CUO. The experimental results show that the thermal conductivities of nanoparticle–fluid mixtures increase relative to those of the base fluids.

SandeshS.Chougule, Mayank.Modak[12] conducted(2016), Heat Transfer characteristics of CUO-water nanofluids jet impingement on a hot surface using, CuO-water nanofluids +0.2 wt.% SDS for (ϕ= 0.15%, 0.6%) concentration and (5000≤Re≤13000) The time taken to cool the hot foil from 500°C to 100°C is found to be 0.375 s, 0.35 s and 0.3 s for water, ϕ =0.15% and ϕ=0.60 % CuO-water nano fluids, respectively.

3. Methods of Preparation of nanofluids-

There are mainly two methods of nanofluids preparation-

I. Two-step method

II. One-step method

I. The Two-Step Method

The 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 nano-sized 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.

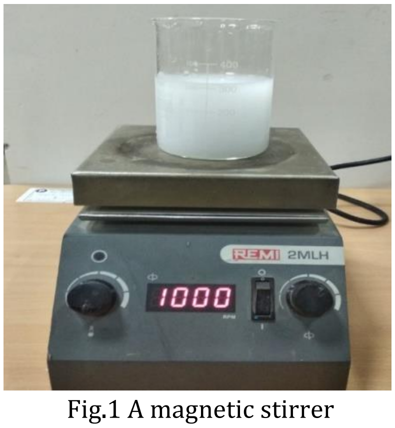


Fig.1 A magnetic stirrer

The two-step method is the most economic method to produce nanofluids on a 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 temperatures is also a big concern, especially for high-temperature applications.

Due to the difficulty in preparing stable nanofluids by the two-step method, several advanced techniques are developed to produce nanofluids, including the one-step method. In the following part, we will introduce the one-step method in detail

Fig. 2 An Ultrasonic Vibrator

II. One-Step Method

To reduce the agglomeration of nanoparticles, Eastman et al. developed a one-step physical vapor condensation method to prepare Cu/ethylene glycol nanofluids. The one-step process consists of simultaneously making and dispersing the particles in the fluid. In this method, the processes of drying, storage, transportation, and dispersion of nanoparticles are avoided, so the agglomeration of nanoparticles is minimized, and the stability of fluids is increased. The one-step processes can prepare uniformly dispersed nanoparticles, and the particles can be stably suspended in the base fluid. The vacuum-SANSS (submerged arc nanoparticle synthesis system) is another efficient method to prepare nanofluids using different dielectric liquids. The different morphologies are

Mainly influenced and determined by various thermal conductivity properties of the dielectric liquids. The nanoparticles prepared exhibit needle-like, polygonal, square, and circular morphological shapes. The method avoids the undesired particle aggregation fairly well.

The one-step physical method cannot synthesize nanofluids on a large scale, and the cost is also high, so the one-step chemical method is developing rapidly. Zhu et al. presented a novel one-step chemical method for preparing copper nanofluids by reducing $C u S O4 \cdot 5 H2O$ with $N an H2P O2 \cdot H2O$ in ethylene glycol under microwave irradiation. Well-dispersed and stably suspended copper nanofluids were obtained. Mineral oil-based nanofluids containing silver nanoparticles with a narrow size distribution were also prepared by this method. The particles could be stabilized by Korantin, which coordinated to the silver particle surfaces via two oxygen atoms forming a dense layer around the particles. The silver nanoparticle suspensions were stable for about 1 month. Stable ethanol-based nanofluids containing silver nanoparticles could be prepared by the microwave-assisted one-step method. In the method, polyvinylpyrrolidone (PVP) was employed as the stabilizer of colloidal silver and reducing agent for silver in the solution. The cationic surfactant octadecyl amine (ODA) is also an efficient phase-transfer agent to synthesize silver colloids. The phase transfer of the silver nanoparticles arises due to the coupling of the silver nanoparticles with the ODA molecules present in the organic phase via either coordination bond formation or weak covalent interaction. The phase transfer method has been developed for preparing homogeneous and stable graphene oxide colloids.

PREPARATION OF NANOFLUIDS

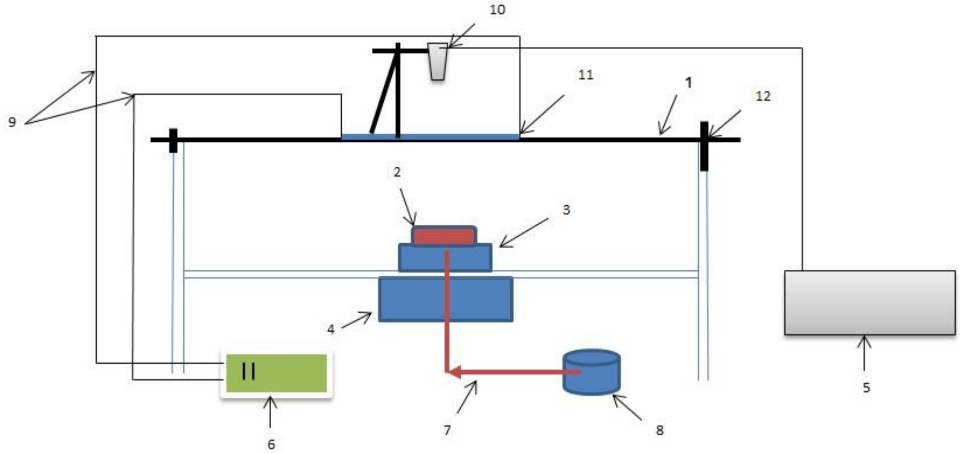
Nanofluids are prepared using various equipment such as a magnetic stirrer, an Ultrasonic bath sonicator, and a PH meter.

The preparation of nanofluid must ensure proper dispersion of nanoparticles in the liquid and a proper mechanism is needed to attain the stability of the suspension against sedimentation. The size of nanoparticles is 50-100 nm. Under atmospheric temperature conditions, these particles form loose agglomerates, which are of the order of micrometers. However, they can be dispersed in the fluid quite successfully which results in the breaking of the agglomerates by sonication.Al2O3 nanoparticles are dispersed in deionized water using a magnetic stirrer. The dispersion of the particles is achieved by first mixing the required volume of the powder in the chemical measuring flask with distilled water.

The weight of the nanofluid powder is measured by using a precise and accurate weighing scale. After preparing the proper mix of the nanoparticles and water, the flask is placed on the dimmer-controlled magnetic base and another different pole magnetic strip is placed inside the flask. By supplying the voltage to the base magnet the strip present in the nanofluid starts rotating. During the process, Sodium Dodecyl Sulphate (SDS) surfactant is added to the solution in proper proportions to ensure the stability of nanofluid. Mingzheng Zhou et al conducted experiments on different kinds of surfactant solutions and reported that SDS surfactant had better properties than other types of surfactants. After stirring the sample is allowed to place in an Ultrasonic bath sonicator for a period of 30 minutes.

1. Exposure to Experimental Analysis-

An attempt has been made to do analyze the phenomenon of heat transfer of hot surfaces by round jet impingement using water as a coolant.



1	Run-out table	6	Auto Transformer
2	Multiple Nozzle	7	Gear Pump
3	Gear box	8	Coolant Sump
4	Collecting Tank	9	Cables
5	Personal Computer	10	IR Camera
11	Test specimen	12	Stepper motor

Fig.3 Schematic of existing test facility

The schematic of the test facility developed for the present experimental analysis is depicted in Fig. 1. The experimental system consisting a heating system, test specimen, liquid flow system, and instrumentation system for temperature measurement. A matt finish SS304 foil (length 250mm, width 60mm, thickness 0.15mm) has been used as the test specimen. The test foil is clamped lengthwise between two copper bus bars. In order to hold the specimen properly, 10mm of the SS foil is sandwiched between copper bus bars on either side. Which also ensures the uniformity in the electrical current flow across the ends of the foil, by dropping the thermal contact resistance. The whole assembly including test specimen and copper bus bar is clamped between L shape aluminium frames. During electrical heating, to avoid any short circuit, a 5 mm thick Bakelite sheet is used between aluminium frame and copper bus bars. Teflon bushes are also used to avoid direct contact of bolts with the aluminium frame. Due to heating / quenching, there is some thermal expansion/ contraction, hence to avoid effect of this expansion/ contraction, the test specimen is stretched using SS tightening screws after each set of experiments. The frame with test foil assembly is mounted on the moving plate of the run-out table. A 3-axis gear box is used to provide movement to the brass nozzle, and also adjust the distance between jet and plate.

Heating of the test foil is done by an AC auto-transformer (3ϕ AC, 24 volts, 400 amps). Current supply and voltage drop across the foil are measured with the help of a digital multimeter. A calibrated gear pump (Micro pump, Model: GJ-N27-DEELE) is used to feed water from the coolant storage tank to the test specimen. A controller (12V Arduino-UNO) is used to control the water flow rate of the gear pump. Here, an aluminium nozzle assemble with multiple holes at different spacing between two nozzles has been used (1 mm internal diameter (d)) is used as the impinging nozzle from the bottom side of the test specimen. A collecting tank is used to collect the residual water after the impingement.

The IR thermal imaging camera (FLIR, Model: A655sc) which is able to measuring the temperature in the range of $0^{o}\mathrm{C}-2000^{o}\mathrm{C}$ with a scanning rate of 200 frames per second, is used to record the local temperature distribution on the test specimen. Thermal camera is positioned on the top of the test specimen opposite to the impinging side. The maximum Biot number in the lateral direction for the SS foil (thickness 0.15mm) is of the order of 0.0059 (<<0.1). So, from the lumped heat transfer assumption temperature gradient in that direction can be neglected. Experiments have been performed to calculate the temperature loss across the test specimen during transient cooling. By these experiments, the value of temperature loss was found to be less than 0.25 ºC. Due to this small temperature difference, temperature measured on the opposite side of the test specimen by the thermal camera is considered as the temperature of the side exposed to water jet. While using the thermal camera, it is necessary to calibrate the emissivity (ε) of the SS foil. Therefore, for uniform emissivity over the surface, foil is painted with a heat resistant (flat black) paint on one side and was spot welded on the surface on the other side by one calibrated thermocouple (K- type). The foil is heated with help of an autotransformer and once the plate temperature reaches to value of 530°C, the electrical power supply is switched off. Subsequently, the temperature of the foil decreases, and a temperature drop of 429°C is noted within duration of 2.5 minutes. The thermal response of the test foil and the readings of thermocouple are measured (by using an infrared camera and Data Acquisitions System) in this time duration. After this, an appropriate value of emissivity is fitted in the thermal camera software to get the same temperature as read by the thermocouple. For different values of test foil surface temperature the procedure is repeated. The emissivity value of the surface is fixed to 0.97. The uncertainty in the temperature measurement is found to be $\pm 1.5^{\circ} C$.

Tests are carried out for the transient condition in the present experiment. The parameters like emissivity of the target plate, scanning rate of the imager, and distance from IR camera to the target plate are fixed and are input parameters in this investigation (Table 1).

Table 1. Parameters used for the temperature measurement

Parameter	**Magnitude**
image object parameters	
Emissivity, ε	0.97
reflected ambient temperature	$32^{\circ} C$
atmospheric parameter	
atmospheric temperature	$28 \pm 2^{\circ} C$

relative humidity	0.55
distance from IR camera to test specimen	0.5m
Transmission	0.99
IR Camera parameter	
temperature range	$150-650\ ^{\circ}C$
Resolution	640×480 pixels
scanning rate	100 fps
distance between each pixel	0.35 mm
focal length	24.6 mm

The rotational speed of the gear pump is controlled by the controller. To provide the desired flow rate and the coolant is directed to flow through a 4 mm internal diameter tube. An auto transformer provides electrical power to the target plate under dry condition. Once the steady state condition is achieved, the electrical power supply is switched off, and through a multiple jet nozzle (1mm ID) made of aluminium, the water is allowed for impingement on the plate.

The surface heat flux (q) of the test specimen under transient condition is assumed to be proportional to the temperature gradient and can be written as:

$$q = -\left(\frac{V}{A}\right)\rho c_p \frac{dT}{dt} \quad (1)$$

Where, dT/dt is the change in surface temperature of the foil at a particular location with time. In the present investigation, the initial temperature of the target surface was around 300^0C. The change in density (ρ) and specific heat capacity (c_p) are found to be negligible. Thus, in this analysis values of density and specific heat capacity are considered as the constant. Dimensions and the thermo-physical properties of the foil are listed in Table 2.

Table 2. Dimensions and thermo-physical properties of the test specimen

Material of test specimen	AISI-304
area (A), mm^2	250 × 60
thickness (δ), mm	0.15
density (ρ), kg/m^3	8000
specific heat capacity (c_p), J/kgK	500

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