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Research Article

Experimental investigation for heat transfer augmentation method of jet impingement using a fluid of different concentrations of water and ethylene glycol (EG)

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ABSTRACT

In the modern world, with rapid inventions in microscale electronics, devices suffers undesirable internal heat generation and, due to their tiny shapes, undergo large heat flux conditions. This emphasizes the development of effective and efficient heat dissipation methods to boost their performance and keep them in safe working conditions. The jet impingement cooling method is used for cooling purposes in many engineering applications, and is popular for quick removal of heat from the solid surfaces. The present experimental study is an investigation of effect impingement of jet of water and ethylene glycol mixture over a heated surface. The blending of ethylene glycol ($C_2H_6O_2$) with water (H_2O) as a base fluid enhances the average (convective) heat transfer coefficient (HTC). The cooling fluid with different concentrations of $C_2H_6O_2$ varying from 10%, 25%, 50%, and 100% shows higher values of average convective coefficient at similar flow conditions than pure water. The fluid having mixture proportions 50% $C_2H_6O_2$ and H_2O shows an optimum value for heat transfer enhancement in the range of 30% to 75% than pure water at the same flow rates. It can be noted that based on mechanical stability and the cost associated, the experimental results reveal that the optimum value of the concentration of $C_2H_6O_2$ in water is 50% for maximum heat transfer and at higher values of $C_2H_6O_2$ hamper the mechanical stability and causes higher pumping power due to increase in viscosity of the fluid.

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INTRODUCTION

Heating or cooling in the industries like Electronics, Auto-sector, and various manufacturing sectors have the important challenging task related to heat transfer. To achieve high heat transfer, the smaller units become an increasing demand from commercial applications. The heat transfer fluids such as ethylene glycol ($C_2H_6O_2$), pure H_2O, and oil mixtures are innately less heat removal fluids. With increasing global demand and competition, energy-efficient devices have an essential need to emerge with an advanced fluid having significantly more thermal conductivity than pure water. The thermophysical properties like thermal conductivity, thermal diffusivity etc. which assist the heat transfer rate need to add in cooling or heating medium and forms foundations for the development of energy efficient systems.

Many studies have been presented in the literature on external flow in the form of jet impingement over heated surfaces for effective and efficient heat transfer augmentation. An experimental study of convective heat transport characteristics in the jet impingement with constant heat flux was considered by R. Dhotre and S. Shashtri [1]. The authors presented the experimental investigation on purified water, $C_2H_6O_2$, and a mixture of $C_2H_6O_2$ and distilled water (40% and 80% by volume). The experimental results reveal that the HTC of a mixture of $C_2H_6O_2$, and H_2O rises with Reynolds number (*Re*) as well as with the proportion of $C_2H_6O_2$ in the mixture. The authors studied a heat transfer characteristic to comprehend the mechanism of heat transfer enhancement. The authors stated that the pumping power is a predominant factor in deciding the concentration of the $C_2H_6O_2$ mixture due to significant changes in fluid properties at different concentrations of ethylene glycol. P. Selvaraj et al. [2] reported an experimental investigation on Nusselt number, friction factor and thermal-hydraulic performance of rough tubes i.e. internally grooved tubes. The working fluid was a mixture of $C_2H_6O_2$ and water mixture 10:90 (by weight). The heat transfer enhancement in comparison with the smooth tube was observed to be around 36%, 55 %, and 10 % for the tube with circular groove, square groove, and trapezoidal groove for turbulent flow conditions.

T. S. O'Donovan and D. B. Murray [3] studied a jet impingement mechanism for local and average enhancement of heat transfer over the solid surface. The authors reported that jet impingement method which provides higher values of local and area averaged based HTCs. These variations of local and average values of HTCs were observed to be a function of *'Re'*, and non-dimensional ratio of distance between the solid surface and location of jet exit. The authors concluded that at low nozzle to surface spacing less than 2 diameters of nozzle exit causes secondary peaks in the radial heat transfer distributions and these peaks were attributed to a sudden rise in turbulence in the wall jet.

S. Ingle and S. Borkar [4] has studies performed on automotive radiators by means of a detailed overall Heat Transfer Coefficient (HTC) in an $C_2H_6O_2$ and water mixture circulating through the circular tubes of an automobile radiator. The study provides an overall behavior for the performance of automobile radiators at a normal range of operating conditions; also significant skill-based design recommendations have also been reported in the article. The authors provide investigations on effects of various blends of water and $C_2H_6O_2$ with respect to temperature difference and corresponding heat transfer. The experimental results indicate that as the coolant percentage of $C_2H_6O_2$ increases, the overall HTC decreases. Also, time for a drop of 1°C temperature from 81°C to 80°C increases, and hence better value of average was reported for water at flow rates of coolant.

K. Sirisha and P. Kumar [5] presented the heat transfer enhancement mechanism using a fluid mixture containing nanofluid like Al_2O_3, ethylene glycol (EG) and water as a new generation of heat transfer fluids, in applications like heat exchangers of chemical plants, automotive cooling, building heating, etc. As a reference case, pure water is mixed with glycol at standard proportions 70:30, 60:40 and 50:50 mixture was used in an automotive radiator and its performance was studied. The performance comparison has been made between pure water and $C_2H_6O_2$ tested in an automotive radiator. The experiments were conducted on fabricated model of the experimental setup using water as base fluid, with 30%, 40%, and 50% of ethylene glycol and Al_2O_3 nanofluids as test fluids. The authors observed the convection heat transfer performance and fluid flow characteristics of $C_2H_6O_2$ flowing through an automotive radiator. The heat transfer enhancement was observed to be around 4.56% for 0.025% $C_2H_6O_2$ at 80°C, 12.4% for 0.1% $C_2H_6O_2$ at 80°C. The authors reported that $C_2H_6O_2$ has a high potential for heat transfer augmentation can be effectively used for different concentrations along with the base fluid.

M. H. Esfe et al. [6] studied the effects of a fluid mixture of $C_2H_6O_2$and H_2O added with sample of MgO nanoparticles at changed solid concentrations 0.1%, 0.2%, 0.5%, 0.75%, 1%, 1.5%, 2% and 3%. The study was executed for different temperature rangesof 20°C-50°C, using a prothermal analyzer with a transient hot wire to quantity the thermal conductivity. The authors concluded that there was an improvement in nanofluid thermal conductivity with rise in solid volume fraction due to addition of nanoparticles. M. Gayatri and D. Sreeramulu [7] described experimental study of a single-phase liquid cooling system in a mini channel. The mini channels were chosen to provide higher heat transfer coefficient than conventional channel. The experimental reports show that the mini channel liquid cooling system with water as a coolant has better performance than diluted $C_2H_6O_2$ as coolant at different flow rates. The phenomenon of hydraulic jump using obliquely inclined circular liquid jets was reported by D. P. Kulkarni et al. [8] under specific conditions of jet impingement. The authors further stated that these patterns are distinctly different from the usual elliptical or oblate shaped variations that were normally observed at higher angles of jet inclination. The authors stated the theoretical predictions which were very close to the experimental results, and phenomenological explanation was reported by drawing analogies for twin-jet interaction mechanisms with the fundamentals of shockwave interactions of compressible fluid mechanics.

Microchannel heat sinks are widely reported as effective heat transfer techniques for compact electronic devices. The pumping requirements for flow through micro channels are also very high, and none of the micro-pumps in the literature is truly suitable for this application. S. Garimella and B. Nenaydykh [9] described an elaborative research program for microchannel heat sinks and micro-pumps to comprehend fluid flow and heat transfer in microchannels and to estimate pumping requirements and appropriate mechanisms for pumping in micro channels. The authors proposed the conventional correlations for heat transfer and fluid flow to satisfactorily predict the behavior in microchannels of very small hydraulic diameters. The pumping requirements of micro-channel heat sinks have been studied, and the optimum size of the micro-channels for requirement of minimum pumping power. The authors also provided a broad review of micro-pumping technologies.

P. Naphon and S. Wongwises [10] presented an experimental study for heat transfer features over a mini-rectangular fin heat sink under the action of liquid jet impingement. The mini-rectangular fin heat sink is an integral part of the central processing unit of a personal computer. The experimental runs were carried out at zero load and at full load operating conditions and at three different channel geometries. The authors concluded that this technique of liquid jet impingement has scientific reputation for an efficient and compact design of heat transfer systems utilized for electronic devices.

M. Kumar et al. [11] presented a study on heat transfer enhancement in laminar and turbulent flow of varying compositions of $C_2H_6O_2$ mixed with water using miniature double tube hair-pin heat exchanger. The authors stated that the HTC of a mixture of $C_2H_6O_2$ and water increases with flow *'Re'* and with increases in $C_2H_6O_2$ concentration. The authors attributed this rise to improved fluid properties which were mainly responsible for enhancement in heat transfer. X. Liu et al. [12] presented an experimental analysis on convective heat transfer enhancement due to an impinging liquid jet of sub cooled liquid over a heating surface which was kept at an unfluctuating heat flux condition. The authors concluded that as a result of the radial development of the viscous and thermal boundary layer, several heat transfer characteristic regions developed compromising of different local Nusselt number. They presented the local heat transfer over the solid surface as a function of flow Reynolds number *'Re'*.

J. Albadr et al. [13] stated an experimental investigation on the forced convection heat transfer and flow characteristics of a nanofluid Al_2O_3 embedded in water at varied volume concentrations 0.3–2%. The investigations were presented for flow in a shell and tube heat exchanger with a counter flow arrangement under turbulent flow conditions. The values of convective HTC using nanoparticles were marginally higher than the base liquid at similar inlet flow conditions of rate of mass flow and temperature. The authors concluded that the HTC of a nanofluid increases with an increase in the fluid flow rate, with an increase of the volume concentration of the Al_2O_3 nanofluid, however, large friction factor values were reported for the fluid condition having higher volume concentration.

V. Narayanan et al. [14] performed an experimental study on the fluid flow field, heat transfer rates of a submerged slot jet impinging perpendicular to a flat plate for two different parameters of nozzle to surface spacing. The local HTCs were determined from detailed surface temperature measurements, and the local heat transfer results show a similar trend, high heat transfer rates near the impingement area for transitional jet impingement with gradual reduction in HTC for core region of jet impingement. The authors put a comprehensive local heat transfer analysis over the surface of the solid plate.

M. A. Teamah and S. Farahat [15] described numerical and experimental investigation on heat transfer and fluid flow characteristics due to the impingement of vertical circular single jet on a horizontal heated surface. The numerical results were presented for a range of *'Re'* between 1000 and 40000, showing the variation of segment and average segment Nusselt number as well as the velocity and temperature distribution in the film region. The authors concluded that for all *'Re'* range both segment and average segment Nusselt numbers were reduced with increasing radius ratio especially in the shooting flow region. K. Jambunathan et al. [16] reported a comprehensive review of rate of heat transfer data for single circular jet impingement phenomenon. The authors presented a correlation for local HTC expressed for Nusselt number as a function of nozzle exit *'Re'*. However, the available empirical data suggests that apart from nozzle exit *'Re'*, the Nusselt number should also be a function of nozzle to plate spacing, and distance relative to the stagnation point. The authors also observed that the independence of heat transfer rate for the parameter nozzle to plate spacing up to a value equal to 12 times nozzle diameters. This is valid over the region of solid boundary till the radii are more than six times the diameter of the nozzle from the stagnation point.

T. Nontula et al. [17] studied the jet impingement approach for effective heat transfer in cooling of gas turbine blade. The effect of set of a circular jet impingement were investigated for rotating flow channel. The effect of channel rotation on local heat transfer in comparison with the stationary channel is reported. The authors also presented the heat transfer in leading and trailing side of the channel at different streamwise location within the channel. H.A. Hasan et al. [18] presented a numerical study on jet impingement of water on photovoltaic solar cell. The study includes the investigation of the effect of various parameters such as Reynolds number, distance of the impingement, nozzle diameter on heat transfer. The authors concluded that increase in heat transfer occurs at higher value of Reynolds number, and at low distance between nozzle and the surface of impingement. C. Aroonrujiphan and C. Nuntadusit [19] reported submerged impingement of bubbly jet of water, at fixed jet to plate distance and at different air volume fractions from 0 to 0.7. The authors reported that the heat transfer increases with addition of air into water for almost all volumetric fractions studied, are observed to be higher than jet impingement of water.

It has been identified from the literature review that experimental study involving heat transfer using a cooling fluid at different mixture proportions of water and $C_2H_6O_{2,}$ such as 40% and 75% by volume, 90% by weight, 5 to 7% by volume in mini channels. This provides an insight that few attributes, such as $C_2H_6O_2$ concentration in water as 0, 10, 25, 50, 100 % by volume, at different flow *'Re'* are still required investigation. Also, the heat transfer enhancement method incorporating jet impingement of a mixture of different proportions of $C_2H_6O_2$and water over a heated surface needs experimental investigation.

The objectives of the present experimental study are to investigate the effect of impingement of jet of cooling fluid i.e. a mixture of water and ethylene glycol over the heated surface. The effect of mixture proportions, flow Reynolds number, on average surface temperature, average surface heat transfer coefficient, and pumping power are presented. The optimum value of mixture proportion for maximum heat transfer is also proposed.

EXPERIMENTAL SETUP AND METHODOLOGIES

A schematic of the experimental set-up is shown in Figure 1 and was commissioned with all required instruments to control and measure the various fluid flow parameters. The photographic view of experimental set up is shown in Figure 2. A centrifugal pump having a prime mover of capacity 0.5 HP, was used for delivering water and mixture of water & $C_2H_6O_2$ in the manner of jet at predetermined rate of flow. A rotameter of flow measurement range 0 – 5.0 LPM, was attached to a nozzle arrangement through the piping to measure the fluid flow rate. A nozzle of exit inner diameter '*D*' equal to 6 mm, was placed normal to the surface of the copper plate at a distance, '*z*' equal to 12 mm, as shown in Figure 1 and attached at the exit of the supply pipeline. A provision in the form of mechanical linkage was made to alter the vertical positions of nozzle to obtain the experimental study for different '*z/D*' ratios i.e. different height of nozzle exit to the nozzle diameter.

The tube length to diameter ratio was kept above 50 to ensure a fully developed flow condition at the exit. A nozzle made up of stainless steel of diameter 6mm was used to create a jet of the fluid.Nozzle selection is a vital factor to obtain fully developed flow, and to avoid effect of nozzle inlet on the nozzle exit. Minimum nozzle height to diameter ratio required to obtain the desired flow conditions and was maintained equal to 50. To avoid nozzle entry effect on nozzle exit, the nozzle length was kept as 40 cm. A jet releasing from the nozzle was made to impinge on heated circular copper plate of 2 mm thickness and 30 cm diameter, mounted on fixed leveled surface. The material for copper was selected as it has high thermal conductivity & good corrosion resistance. The jet impinging on the disc surface spreads radially and falls freely into collecting tray. The entire unit was mounted on a heavy frame to avoid the effect of external vibrations. The fabrication of the test facility was to carry out the local temperature of the disc is measured at 8 various locations and these temperatures were recorded using a calibrated digital indicator. A variable transformer was used to vary the voltage across the electrical terminals connected to the copper plate to obtain the vary surface temperature of copper plate. During the experimentation, a horizontal arrangement of the copper plate was ensured with the aid of spirit level. In addition, the free fall of the liquid was also noted to be identical to all the edges of the plate to ensure that there was no detectable error due to lack of uniformity of the copper plate. Eight calibrated 'J' type thermocouples were brazed beneath the plate for measurement of the average surface temperature of the plate. These types of thermocouples were selected because of its small tip size, good sensitivity and more accurate for temperature range from 0 to 100°C. A digital temperature indicator of least count of 0.1°C was used to record the temperature readings.

The copper plate was placed over the heater plate and the entire assembly was enclosed in wooden box to avoid direct contact with water and heater plate. Silicone sealant is used to fix heating assembly on a wooden box and to avoid leakage of fluid ensure a leak proof assembly. A circular plate electrical resistance heater of capacity 1550 watts of diameter 280 mm & plate heater thickness 2 mm, as shown in Figure 3, was used for the heating of copper plate. Mica sheets were used as an insulating material is placed near the heater, and the whole assembly was enclosed as one unit to avoid hazards. The maximum temperature of the copper plate was restricted to 80°C to avoid subcooled boiling of water. A stepped-down variable transformer was connected to the heating element. The working fluid of pure water and its mixture with $C_2H_6O_2$ were collected in the metallic tank after the impingement with the copper plate. The collecting tank was made up of high-conductivity metal so that heat can be dissipated quickly to the ambient conditions.

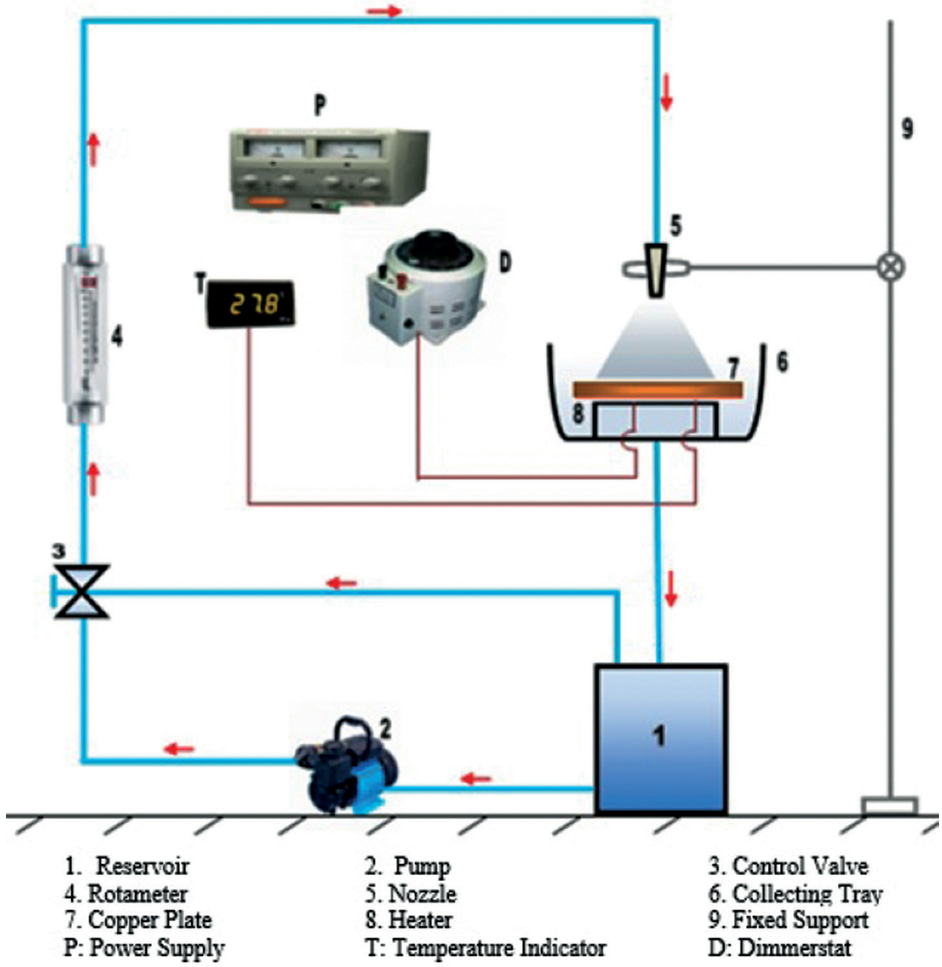

Figure 1. Schematic of experimental test setup.

Figure 2. Photographic view of experimental setup.

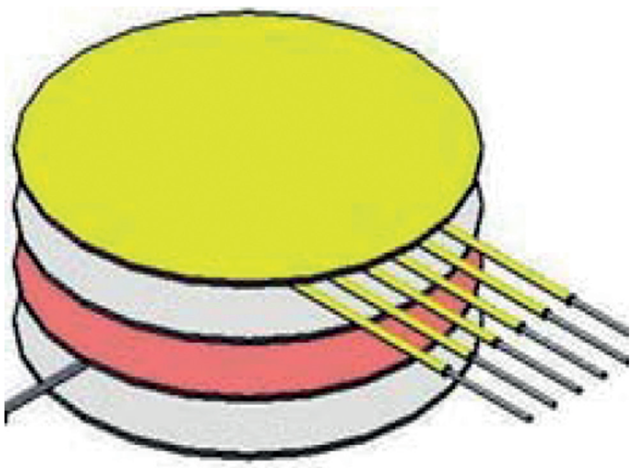

Figure 3. Plate, heater and mica sheet assembly.

Table 1. Property of water and ethylene glycol mixture - specific heat C_p (J/KgK)

Temperature (°C)	Ethylene Glycol Solution *(% by volume)*			
26.7	3856	3777	3412	2470
29	3861	3782	3419	2479
48.9	3906	3831	3484	2562
71.1	3936	3873	3559	2680
93.3	3990	3919	3622	2763

Table 2. Property of water and ethylene glycol mixture -density ρ (Kg/m^3)

Temperature (°C)	Ethylene Glycol Solution *(% by volume)*			
20	998	1038	1079	1125
29	995	1034	1073	1123
40	993	1029.5	1067	1121
60	987	1026	1063	1118
80	980	1022	1061	1115

An energy meter is attached to the pump to measure pumping power. The constant for meter, '*C*' is 3200 impulses per kWh. Power required to pump the fluid can either be measured by meter attached to it or time, 'τ' required for number of blinks, '*N*' equal to 10 in present case, can be measured with stopwatch and using a conversion formula the power for the pump can be measured. Therelation is specified in Equation(4).

Properties of water and ethylene glycol mixture

In the present study, various properties such as specific heat '*Cp*', Density 'ρ', Dynamic Viscosity 'μ' need to consider for experimental data reduction. The properties specific heat '*Cp*', Density 'ρ', areshown in Table1 andTable2 respectivelyfordifferenttemperature ranges.

Experimental methodology

In the present work plain $C_2H_6O_2$was used as a reference fluid and mixed with the base fluid water at different proportions. At the beginning of the experimental run, the control valve was used to maintain the required flow rate through the rotameter and in turn through the nozzle. The initial temperature of the fluid, 'T_f' was measured. The flow was allowed for few minutes to obtain steady hydrodynamic conditions and then surface temperature. Then, the power supply was turned ON, with an appropriate value of voltage, '*V*' and the current '*I*'. The flow conditions are maintained for at least 40 to 45 minutes to reach a steady state condition. Initially, the experiments were conducted for pure water, ethylene glycol, then later for mixture of water and ethylene glycol. The temperatures of the surface of the plate, rotameter reading, voltage and current values were recorded at steady-state conditions. The experimental runs were carried out at different flow rates like 2,3,4 LPM and at five different fluid mixture compositions like 100% pure water, 100% ethylene glycol, and at three different concentrations 10,30, and 50% of $C_2H_6O_2$mixture with water by volume. The *'Re'* at different flow rates of the fluid and at different mixture proportions was determined at the outlet of the nozzle was used for physical interpretation for the associated heat transfer enhancement mechanism.

The average surface temperature of copper plate, $T_{s\,Avg}$ is given by Equation (1) as:

$$T_{s\,Avg} = \frac{1}{8}\sum_{i=1}^{8} T_i \tag{1}$$

The heat supplied to the copper plate; Q is given by Equation (2) as:

$$Q = V \times I \tag{2}$$

The heat transfer coefficient, h can be obtained as given by Equation (3) as:

$$h = \frac{Q}{A.(T_{s\,Avg} - T_f)} \tag{3}$$

The requirement of pumping power is another vital parameter for the centrifugal pump in the present study due to the viscous nature of the fluid with an increase in the concentration of $C_2H_6O_2$ in water.

$$p = \frac{N \times 3600}{\tau \times C} \tag{4}$$

RESULTS AND DISCUSSION

The investigation of various parameters related to heat transfer and fluid flow associated with the present experimental study is presented in this section. The flow rate of fluid is varied from 2 to 4 liters per minute. The vertical distance of nozzle exit from disc surface is maintained at 12 mm and the nozzle with 6 mm diameter will be considered for this experiment. Initially plain water and $C_2H_6O_2$ has been impinged upon disc and temperature variation is recorded for three flow rates as mentioned earlier. Same operating parameters are maintained for the mixture with volume proportion of $C_2H_6O_2$ of 10%, 25%, 50% and 100% and temperature variation has been recorded. The effect of different concentration of mixture and different flow rate of mixture, over average convective HTC is analyzed post-experimentation. The experimentation was carried out for the parameters listed in Table 3.

Effect of mixture proportions and flow conditions on surface temperature

The variation of average surface temperature of copper plate with five fluids of different mixture proportions at three different flow rates is shown in Figure 4.The maximum temperature is observed for the fluid with 0% of $C_2H_6O_2$i.e., pure water and the average surface temperature of the plate drastically reduces with increase in % of $C_2H_6O_2$till it becomes 25% in the mixture. These reductions suggest the more heat transfer with increases in $C_2H_6O_2$percentage in pre water and thus signify its application as a cooling fluid for jet impingement. It is observed from Figure 4 that there is no further reduction in the surface temperature of the plate with increase in % of $C_2H_6O_2$in water and it can be concluded that a mixture of 25% $C_2H_6O_2$is suitable to obtain effective jet impingement cooling of flat copper plate. A similar trend is observed for all three different flow rates.

Thevariation of averagesurface temperature with three different *'Re'* at the exit of the nozzle at five different mixture proportions is shown in Figure 5. It is observed that based on the mixture fluid properties, a fluid with 100% EG i.e., flow of pure $C_2H_6O_2$ falls in laminar fluid flow conditions. It is observed that at low value of *'Re'* the plate surface temperature is higher, and it gradually reduces with increases in value of *'Re'*. The laminar flow condition helps for better utilization of cooling medium and favors for maximum transfer of heat from the copper plate, and therefore results in lower surface temperature of the plate.

The other mixture proportions with % of EG varying from 0 to 50% show the turbulent flow conditions at the exit of the nozzle with *'Re'* ranging from 5000 to 50000. The similar trend of reduction in surface temperature with rise in the value of *'Re'* at respective mixture proportions. It is observed that the fluid with percentage of $C_2H_6O_2$ 0% i.e., pure water, 10% of $C_2H_6O_2$ and water, shows higher values of average surface temperatures which shows poor rate of heat dissipation from the solid surface. The fluid with mixture proportions 25% EG & water and 50% EG & water shows lower surface temperature similar to the flow of pure ethylene glycol. It can also observe from Figure 5 that there is gradual reduction of surface temperature of the plate with increases in the value of Reynolds number, *'Re'*.

Effect of mixture proportions on mean film temperature

It is essential to present a variation of the mean film temperature of the fluid near the heated surface in the prevailing experimental heat transfer and fluid flow conditions. The mean film temperature is an estimation of fluid temperature within a convection boundary layer, and it is determined as the arithmetic means of free-stream temperature and the temperature at the surface of the solid boundary wall. The mean film temperature is often used as the temperature at which fluid properties are calculated to calculate a heat transfer coefficient because it is a reasonable first approximation to the temperature within the convection boundary layer. Figure 6 shows mean film temperature with mixture proportions, and it can be concluded that there is a minimum variation of mean film temperature at different mixture proportions. Also, from the Figure7, it can be concluded that the mean film temperature remains

Table 3. Range of experimental parameters

Sr. No.	Volume flow rate, Liters per minute (LPM)	Reynolds number, *Re*	% of $C_2H_6O_2$by volume
1	2	25461	0 % (100 % Water)
2	3	38192	
3	4	50923	
4	2	20870	10 %
5	3	31305	
6	4	41740	
7	2	13543	25 %
8	3	20315	
9	4	27087	
10	2	6562	50 %
11	3	9843	
12	4	13124	
13	2	1273	100 % (0 % Water)
14	3	1910	
15	4	2546	

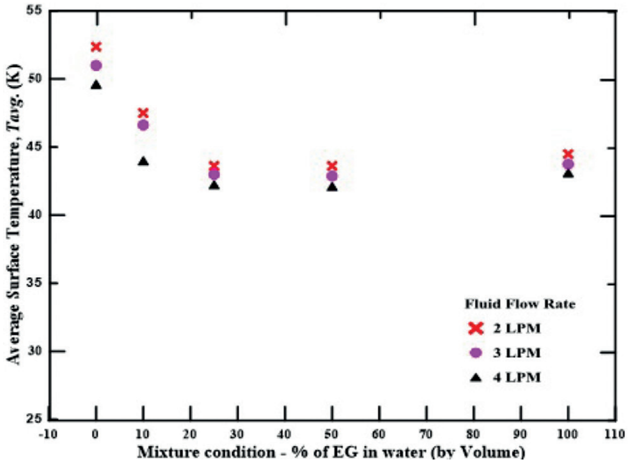

Figure 4. Average surface temperature Vs Mixture proportions.

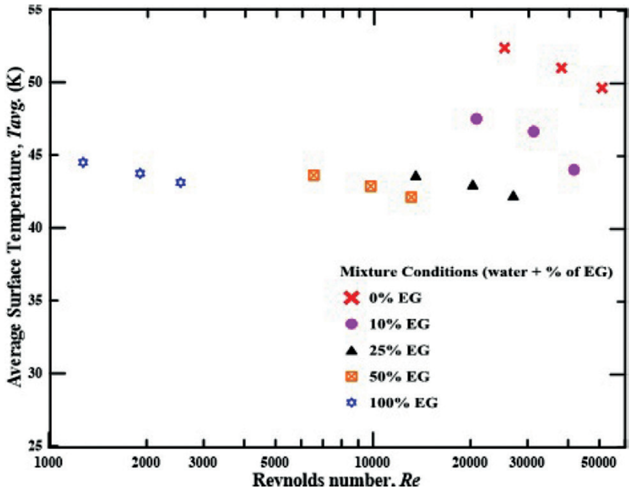

Figure 5. Average surface temperature Vs Reynolds number, *Re*.

almost constant with respect to *'Re'* for the same concentration fluid.

Effect of mixture proportions and flow conditions on surface heat transfer coefficients

Convective heat transfer is a quantitative characteristic of amount of heat transfer between the jet fluid and the solid surface over which it strikes, and its value largely depends on both the thermal properties of the fluid, the hydrodynamic conditions of the flow. Figure 8 demonstratesthe behavior of increased % of EG on surface HTC and it is observed that its value increases with an increase steadily with EG concentration in water till 50% concentration. However, it can be clearly observed that at 100% concentration of EG, HTC value slightly decreases. This trend is observed for all three mass flow rates studied.

The average coefficient was obtained over the entire surface of the disc. This average coefficient was, estimated from the local coefficients. As there could be innumerable local convective coefficients and calculation of heat transfer rate may become a laborious task, therefore for the sake of convenience the average value of convective HTC was calculated.

The variation of average surface HTCs with *'Re'* at the exit of the nozzle at different mixture proportions is shown in Figure 9.

In the present study, cooling fluid in the form of high velocity jet strikes at the center of the plate i.e. stagnation point, causing local retardation of the fluid. The temperature difference between the fluid and the plate is very small, causing a large heat transfer coefficient at this point due to constant heat flux boundary conditions. The fluid after striking moves in the radial direction over the plates. Since

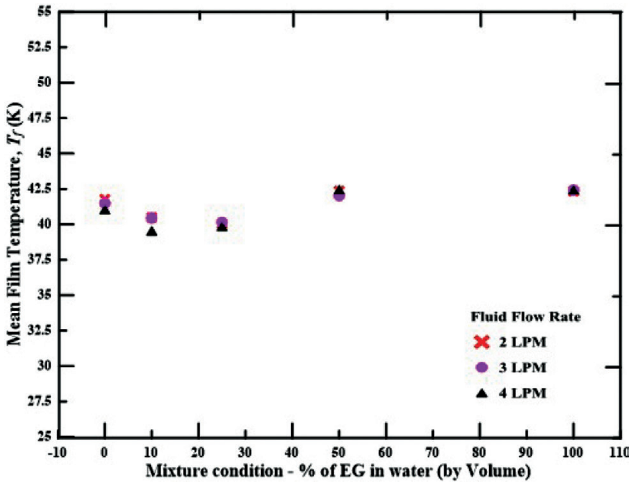

Figure 6. Mean film temperature Vs mixture proportions.

there is a variation of fluid velocity when it moves across the surface of the plate, the local heat transfer values reduce from maximum at the center and minimum at the plate periphery.

It is observed that the value of average HTC increases with increase in the *'Re'* at all proportions of the fluid. With increase in the *'Re'* significant quantity of fluid with large flow inertia encounters the heated plate, causing bulk mixing of fluid after striking the heated surface, and hence more heat convection from the surface. It can be concluded from the figure that the maximum heat transfer occurs at highest *'Re'* and the fluid having mixture proportions 50% of EG and water provides effective cooling over the surface.

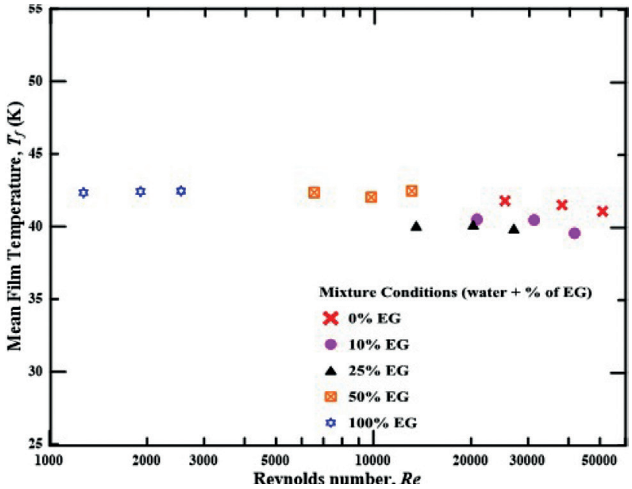

Figure 7. Mean film temperature Vs Reynolds number, *Re*.

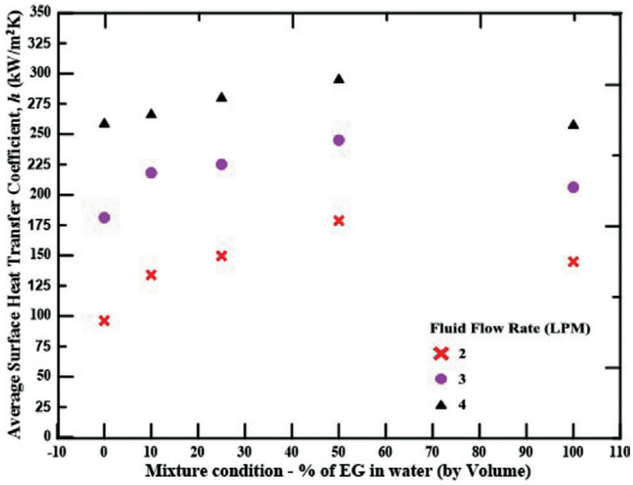

Figure 8. Surface heat transfer coefficient Vs. Mixture proportions.

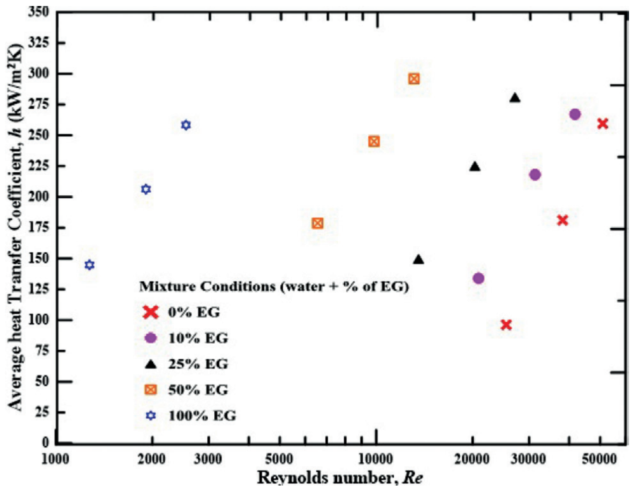

Figure 9. Surface heat transfer coefficient Vs. Reynolds number, *Re*.

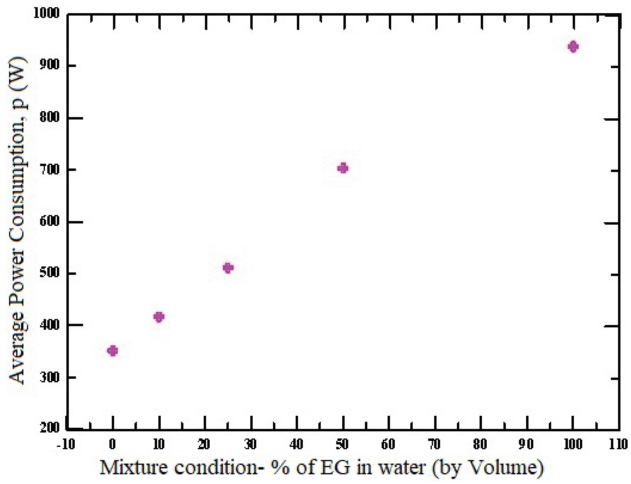

Figure 10. Variation of Power Consumption, *p* at different Mixture proportions.

Pumping power requirement

The performance of centrifugal pumps largely affected by the viscous nature of the working fluid. As the percentage of $C_2H_6O_2$ increases density as well as the viscosity of the working fluid. These two properties are dominant in deciding the pumping power required for flow to establish at desired flow rates. Figure 10 shows variations of experimental pumping power values at different concentrations of $C_2H_6O_2$ in the water.

It is observedfrom the figure that there is linear rise in pumping power with an increase in % of ethylene glycol. From the previous discussions, it is concluded that the fluid with 50% EG concentration offers best heat transfer than other proportions and as observed in Figure 10 the power requirements for this proportions is relatively low in comparison with the fluid if blended with more concentration of EG than this with the water.

CONCLUSIONS

In the present study, experimentation is carried out to investigate the effect of jet impingement of water and $C_2H_6O_2$ mixture on a copper plate. The experimental results clearly reveal that the addition of $C_2H_6O_2$ enhances the average convective heat transfer coefficient. The following conclusions are drawn from the results obtained.

- The jet impingement of $C_2H_6O_2$ percentage in the mixture increases the average HTC over the disc surface as compared to plain Ethylene glycol.

- The fluid having $C_2H_6O_2$ concentrations of 10%, 25%, 50%, and 100% shows higher values of average convective coefficient than similar flow conditions when plain water is used as a cooling medium.
- The value of average HTCs increases with an increase in the mass flow rate of the fluid from 2 to 4 LPM, and it is observed that mass flow rate plays an important role in HTC enhancement.
- The maximum HTC is obtained at the center as the stagnation point of the jet has the maximum heat transfer rate and is confirmed with the lowest temperature at this point.
- The temperature of the disc surface increases up to 20 % towards the outer periphery as flow retards, and therefore causes a reduction in heat transfer values.
- The addition of $C_2H_6O_2$ reduces the temperature of the disc surface; however, the temperature rise from the point of impingement towards the outer radius is found to be increased. This rise in temperature is due to increased viscosity because of the addition of ethylene glycol.
- It can be noted that based on mechanical stability and the cost associated, the concentration of $C_2H_6O_2$ cannot be increased above 50% because more concentration provides a higher pumping cost.

NOMENCLATURE

A	Surface area of the copper plate,
r	Radius of the copper plate, m
C	Energy meter constant (=3200 impulses /kWh)
D	Nozzle diameter, m
h	Heat transfer coefficient, W/m^{2}K
I	Current, A
N	Number of blinks of energy meter (=10 for present work)
P	Pumping power, W
Q	Rate of heat transfer, W
T	Temperature, °C
V	Voltage, V
v	Average fluid velocity, m/s

Greek symbols

τ	Time for 10 blinks of energy meter, sec
ρ	Fluid density, kg/m^3
μ	Dynamic Viscosity, Pa s

Subscripts

f	Refers to fluid
s	Refers to surface

Dimensionless numbers

z/D	Ratio of height of nozzle exit to the nozzle diameter
Re	Reynolds number, $\frac{(\rho.v.D)}{\mu}$

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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