

# Design and Development of a model to verify enhancement in heat transfer rate using jet impingement

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**Abstract** - In application like nuclear reactor and turbine blade very large amount of heat flux is generated and to carry out huge heat flux to heat sink due to inability of other mode of heat transfer, jet impingement is used in current investigation through academic perspective. We have developed design procedure for jet impingement and set specification of various component of test rig for jet impingement.

We also investigate relation between velocity at nozzle exit and velocity over copper plate on the basis of experimental data to predict proportional constant relating them. We have validated enhancement of heat transfer rate by various fluids and conclude superiority of nanofluid with additional power loss due to viscosity.

We also investigate effect of flow rate and nozzle diameter over heat transfer coefficient and proportional constant with the help of various graphs and result tables.

**Key Words:** nanofluid, Heat Transfer, Ethylene Glycol, Jet Impingement, Jump Profile, Microprocessors.

## 1. INTRODUCTION

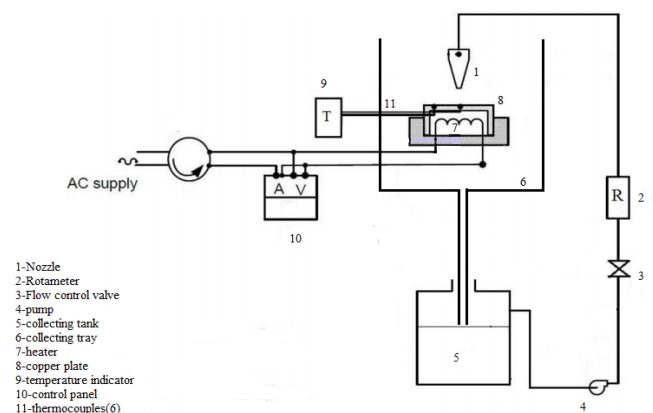
Jet impingement is one of method of increasing heat transfer at tremendous rate. Jet impingement can be either air-powered or use some form of liquid, typically water jet. It is a process in which a jet of fluid coming out of a nozzle at very high velocity impinges on the surface from which heat has to be removed. As these high jet velocity is normal to the plane, it will not get affected by friction of surface plate to the extent as the velocity is affected in forced convection with horizontal movement of fluid, due to less velocity, heat transfer rate is also less in forced convection. Therefore jet impingement is more preferred over forced convection

technique. Due to high relative velocity heat transfer rate will be maximum; as heat transfer coefficient is maximum By Newton law of cooling  $Q=hA(\Delta T)$ , as A and  $\Delta T$  will remain constant, heat transfer rate will increase due to increase in heat transfer coefficient only.

There are three common jet configurations: free surface jet that uses dense liquid in a medium which is less dense such as air; submerged jet which allows the fluid to impinge in the same fluid medium; and the confined submerged jet.

Jet impingement technique is one of the passive methods of convective heat transfer. The convective heat transfer in this type of cooling is based on the jet impingement velocity, adjacent jet distance to jet diameter (S/d), number of jets (n), distance between two rows of jet, jet diameter (d), target distance to jet diameter (z/d), Reynolds number (Re), Prandtl number (Pr) and physical geometry of heat sink.

## 2. EXPERIMENTAL SETUP



Ethylene glycol or nano-fluid or water flows from collecting tank (5) using a pump driven by 0.5hp motor. The flow rate is controlled and measured by FCV (3), and rotameter (2)

respectively. The ethylene glycol (water or nanofluid) jet emerges from nozzle (1) and impinges on a circular copper plate disc(8) of 200mm diameter. The falling liquid is collected in a collecting tray (6). The circular plate is heated using an electric heater (7) of 550 watt as shown in the figure. The power of the heaters is controlled using a dimmerstat (10). The voltage across the heater, the current through the heater, and the electric power are measured by a power meter (10). The temperatures of the hot circular plate are measured using platinum thermocouples (11) which is made up of platinum material having range up to 600°C and temperature readings are noted for further analysis using 6-point temperature indicator(9) (up to range of 1200°C) which are mounted in radial direction over a copper plate symmetric about centre of a copper plate disc each 3.33cm apart.

Two nozzles of different diameters are used in the current investigation as 6 and 8mm. The height of the nozzle above the hot Plate is maintained at three different heights during this investigation. The circular plate used in the investigation is copper in order to have better heat transfer rate. A plaster of paris and glass wool insulation are used to enclose the circular heater plate as shown in Figure. The thickness of the copper plate is 1 mm. The electric heaters used are round plate heater as heating elements. The heater is placed inside a cylindrical sheet of metal filled with plaster of paris as shown in Figure. Mica can be used to keep the heater and copper plate separate from each other to avoid physical contact between them for avoiding electrical shocks. The thermocouples are impeded in 3 mm diameter holes in the copper plate using adhesives.

### 3. METHODOLOGY

#### 3.1 For transient cooling

- [1] Measure the atmospheric temperature with the help of thermometer.
- [2] Measure the temperature of fluid with the help of thermometer.
- [3] Switch on the temperature indicator.

- [4] Switch on the heater.
- [5] Measure the time for heating from 36°C to 60°C .
- [6] Measure the voltage and current from control panel.
- [7] Switch on the motor, Adjust the flow with the help of flow control valve by pointing the jet away from copper plate in the tank.
- [8] Point the jet on the centre of copper plate for 11 seconds as soon as 60°C temperature of copper plate is achieved.
- [9] Switch off the motor after 11 seconds.
- [10] Note down the temperature T<sub>1</sub>,T<sub>2</sub>,T<sub>3</sub>,T<sub>4</sub>,T<sub>5</sub> and T<sub>6</sub> as steady state is achieved.(approximately by 30 seconds).
- [11] Repeat the same experiment for following
  - [1] Flow rate: 400,500 and 600lph
  - [2] Nozzle diameter: 6mm and 8mm
  - [3] Various z/d ratios
  - [4] for various fluids- water, ethylene glycol, 0.1% nanofluid and 0.3% nanofluid

#### 3.2 Relation between v<sub>jet</sub> and v<sub>over copper plate</sub>

Q<sub>nozzle exit</sub> = Q<sub>over copper plate at (D<sub>1</sub>=12cm)</sub>

$$\frac{\pi}{4}d^2v_{jet} = \pi D_1 H v$$

$$v_{jet} = \frac{4D_1 H v}{d^2}$$

$$v_{jet} = K v$$

$$K = \frac{4D_1 H}{d^2}$$

D<sub>1</sub>=Diameter of circle at which height (h) is measured=120mm

H=height of fluid flow

d=nozzle diameter

### 4. OBSERVATIONS

Table No.-1 Relation between v<sub>jet</sub> and v<sub>over copper plate</sub>

Flow rate	D <sub>1</sub> (mm)	Height of flow over copper plate(mm) for 6mm nozzle dia.	Height of flow over copper plate(mm) for 8mm nozzle dia.
400	120	4.5	7
500	120	3.5	5.5
600	120	3	4.5

**Table No. 2- Observation for water jet impingement**

6mm nozzle diameter

z/d	6.2			4		
Lph Temp.(°C)	400	500	600	400	500	600
1	44	40	42	39	39	39
2	44	40	41	40	39	40
3	45	39	40	39	39	39
4	46	39	39	40	38	39
5	45	40	40	40	39	40
6	54	45	46	46	44	45
7	29	29	29	29	29	29

$$\frac{T - T_{\infty}}{T_i - T_{\infty}} = e^{\frac{-hA}{\rho v c t}}$$

Characteristic length(v/A)=length of copper plate=1mm

$$\frac{46.33 - 29}{60 - 29} = e^{\frac{-h}{8954 \times 383 \times 10^{-8} \times 11}}$$

h=181.3 w/m<sup>2</sup> k

## 6. RESULTS AND DISCUSSION

**Table No.4- Relation between v<sub>jet</sub> and v<sub>over</sub> copper plate**

For 6mm

Flow rate	K	Flow rate×K
400	60	24000
500	46.66	23333.5
600	40	24000

**Table No.5- Relation between v<sub>jet</sub> and v<sub>over</sub> copper plate**

For 8mm

Flow rate	K	Flow rate×K
400	56.25	22500
500	41.25	20625
600	33.75	20250

**Table No. 3- Observation for water jet impingement**

8mm nozzle diameter

z/d	6.2			4		
Lph Temp.(°C)	400	500	600	400	500	600
1	41	39	37	39	37	39
2	41	40	39	39	38	37
3	40	39	39	40	39	38
4	38	39	40	37	37	36
5	42	40	42	39	39	40
6	52	48	48	44	46	50
7	31	31	31	32	32	32

## 5. SAMPLE CALCULATIONS

Given data: d=6mm (nozzle diameter)

Time of cooling, t=11 seconds

K<sub>copper</sub>=386 W/m K

ρ=8954 Kg/m<sup>3</sup>

D=200mm

θ = 1.006 × 10<sup>-6</sup> m<sup>2</sup>/sec

C<sub>p</sub>=383 J/KgK

Thickness of copper plate (l) =1mm

Q=400 lph

T<sub>i</sub>=60°C

T<sub>∞</sub> = 29°C

Z/d=6.2

T<sub>avg</sub> = T<sub>1</sub>+T<sub>2</sub>+T<sub>3</sub>+T<sub>4</sub>+ T<sub>5</sub>+T<sub>6</sub> /6

T<sub>avg</sub>=46.33°C

It is observed that as the flow rate increases height of the flow over copper plate decreases due to increase in diameter of Newtonian profile. It is generally circular in shape for normal impingement. Proportional constant has less value for 8mm nozzle as compared to 6mm nozzle at same flow rate due to decrement in velocity of jet emerges out from nozzle exit hence profile has smaller diameter and height of fluid flow is large.

**Table No. 6- Heat transfer coefficient for water jet impingement**

z/d ratio	Flow rate	$h_{exp}$ for 6mm nozzle	$h_{exp}$ for 8mm nozzle
6.2	400	181.30	342.72
	500	309.16	337.28
	600	287.43	337.28
5	400	323.02	302.22
	500	352.73	313.77
	600	337.52	353.56
4	400	304.85	376
	500	332.81	388.91
	600	313.8	364

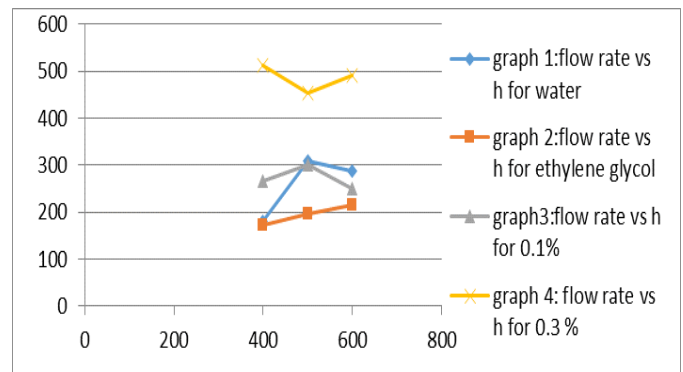
**Table No. 7-  $h_{theo}$  for all fluid**

nozzle diameter	z/d	flow rate	$h_{theo}$ for water	$h_{theo}$ for ethylene glycol	$h_{theo}$ for 0.1% conc.
6mm	6.2	400	235.08	77.57	1832.94
		500	300.94	98.69	2331.84
		600	356.27	116.66	2756.44
8mm	4.625	400	183.95	60.08	1419.78
		500	240.06	78.76	1860.92
		600	290.89	95.25	2250.62

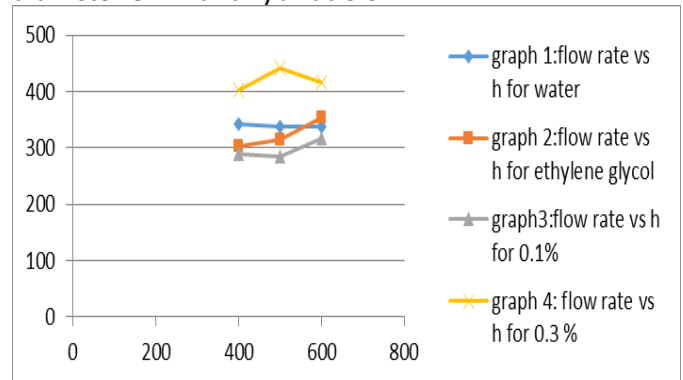
**Table No.-8 Reynold number for all fluids**

nozzle diameter	z/d	flow rate	Re for water	Re for ethylene glycol	Re for 0.1% conc.
6mm	6.2	400	3876.73	308.22	272.69
		500	6274.35	498.84	441.34
		600	8789.2	697.05	616.7
8mm	4.625	400	2343.27	184.93	163.61
		500	3990.6	317.7	281.08
		600	5859.47	464.7	411.14

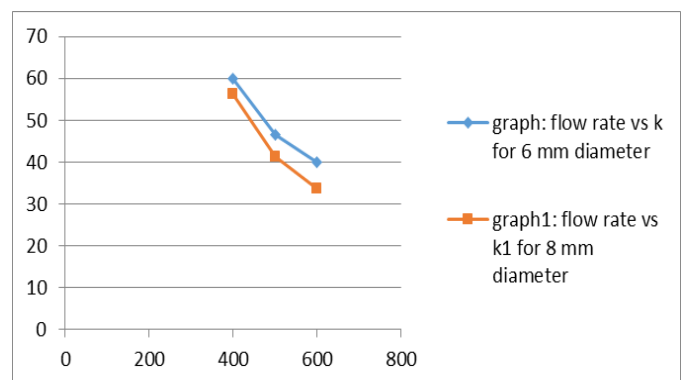
**Graph No.1- Graph of flow rate vs  $h_{exp}$  for nozzle diameter 6mm and z/d ratio 6.2**



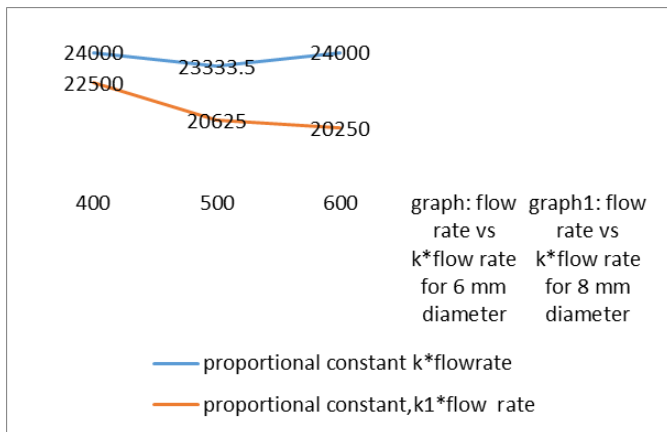
**Graph No. 2- Graph of flow rate vs  $h_{exp}$  for nozzle diameter 8mm and z/d ratio 6.2**



**Graph No 3- Graph of flow rate vs K for nozzle diameter 6, 8mm and z/d ratio 6.2&4.625 resp.**



**Graph No.4- Graph of flow rate vs flow rate×K for nozzle diameter 6,8mm and z/d ratio**



### 7. CONCLUSION

For laminar flow, it is concluded that jet impingement is superior to all modes of convective heat transfer and also heat transfer coefficient for jet impingement is maximum for nanofluid and increases with nanoparticle concentration which is followed by water and ethylene glycol. Nusselt number, reynold number and heat transfer coefficient varies directly with flow rate for same nozzle diameter, z/d ratio and varies inversely to nozzle diameter for same flow rate. Heat transfer coefficient found to be varies inversely with z/d ratio for z/d ratio less than 5 and directly with z/d ratio for z/d ratio greater than 5, for same nozzle diameter. Also found to be directly proportional to z/d ratio for nozzle diameter varies keeping z constant. Product of proportional constant k and flow rate in lph is approximately constant for same nozzle diameter and varies inversely with nozzle diameter for same flow rate. Theoretical relation for turbulent flow obtained is as follows,

$$h = .0366 * (\rho * V * L_c / \mu)^{.8} (\mu * C_p / k)^{.33} (k / L_c)$$

From above relation, it is conclude that heat transfer rate can be increased by significant increase in density, velocity of fluid flow and decrease in characteristic length of fluid flow, boundary layer thickness, which can be achieved by jet impingement over normal forced convection and conduction and varies as per change in nozzle diameter and z/d ratio. For various fluids to give better performance for jet impingement, it should have high thermal conductivity,

specific heat capacity, thermal diffusivity and less prandtl number.

### 8. FUTURE SCOPE

Current study is done on plate of size 20cm, but the study can be further extended by increasing the plate size. Current study consist of temp. of 6 point, but for better results point of temperature measurement can be increased. Various concentration can be studied, rather than concentration that are used in the current investigation. The present works can be extended for the computational analysis for future study. Various Nanofluid can be used for the experimentation purpose. Ex. Al<sub>2</sub>O<sub>3</sub> Circular plate of different diameter can be used for experimentation.

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