An experimentation on gravity influence in concentric tube heat pipe heat exchanger using various working fluids

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Abstract. In present work the experimentation is carried out in the heat pipe introduce inside concentric-tube heat exchanger. Methanol, Acetone as working fluids, and water as heat transport fluid. The investigation is done by different mass flow rates and temperatures of the fluids. The effect of gravitational angles for 0º and 90º are experimented. The maximum heat transfer performance is obtained at angle is 0º. In this investigation for acetone as working fluid there is an increment of 30.42% for effectiveness, 2.5% for Reynolds number and 21.57% decrease in thermal resistance than with methanol. This experimentation clearly shows that heat pipe heat exchanger with acetone exhibits enhanced performance when related with methanol.

Keywords: Heat pipe, Heat exchanger, Gravitational angle, Working fluid, Heat transport fluid

1. Introduction

The enhancement of heat transfer is improved using the heat pipe. The heat pipe techniques were used for industrial and domestical applications [1-2]. This investigation concludes that the gravity influence and segments in the adiabatic section makes better performance in the results [3]. The gravity-assisted heat pipe heat exchanger shows better performance [4-5].

The waste heat recovery system with acetone concentric-tube heat pipe heat exchanger, which shows superior heat transfer efficiency [6]. The vital feature affecting the heat transfer performance was capillary pumping limitation till 45º, and the effective operating range was around 45º to 90º of inclination angle [7]. The heat pipes with different wicks and water/alcohol binary mixture for gravitational angles [8]. The rotating heat pipe (RHP) with a conical condenser, studied numerically by using a Navier-Stokes equations [9]. The investigation shows that introduction of multiple heat pipes improves the efficiency, which was quantified by dimensionless heat pipe’s efficiency using thermal network model [10].

Investigation reveals the decrease in the thermal resistance leads to the enhancement in the heat transfer; this increment was achieved when there was increment in the numbers of mesh layer of a
wick [11]. The water heat pipes, at various angles with 30°, 60° and 90°. The efficiency of a wicked heat pipe has significantly improved, while the heat pipe in a vertical position [12]. The thermal behaviour of a condenser and evaporator region of a height one-meter clogged two-phase thermosyphon with water. The results show that in a plain pipe, there was an increment in thermal performance [13]. The mathematical model for fluid flow circulation in the simulated calculation. This provided a theoretical base for the protection of every row of the heat pipe with cohesion in various regions [14]. The efficiency of Pulsating Heat Pipe with Methanol, Ethanol, and Cetyltrimethyl ammonium chloride and related to De-ionised water with various concentrations and fill ratios of 50% [15].

The experimentation and numerical analysis to check the condensation process by employing R134a in a heat pipe. The boyko, shah and shah correction model gave minimum covenant [16]. The satellite heat pipe with ammonia and methanol as working fluids. The analysis results that fewer thermal resistance when compared with an ammonia heat pipe [17]. In this investigation for methane the best performance was occurred at different heat loads, which attains a several heat transfer capacity at different temperatures of the heat sink [18]. A heat pipe heat exchanger for analysing an exhaust gas in the automobiles [19]. The hydrofluorocarbon as a refrigerant (HFC 134a) and compared their results with new global warming potential hydro fluoro-olefin [HFO 1234 Ze (E)] [20]. The gravity copper heat pipe for different working fluids such as water, CuO/DI water for 1.5 wt.% concentration possess maximum heat transfer coefficient at 60° angle [21]. The study reveals that acetone heat pipe with 45° inclined possesses maximum performance [22]. The gravity effect on CLPHP with working fluids of water, ethanol, R-123 with 50% of fill ratios. The horizontal and vertical orientation gives maximum performance than with inclined angles [23]. The LHP for heat transfer in spacecraft shows that connected along main stream where the heats from various locations were collected by thermal control techniques [24]. The pulsating heat pipe with various refrigerants show that heat transfer performance of R134a is higher than R404A and R600a [25]. The investigation reveals that performance of the variable conductance heat pipe air preheater was maximum than regular system [26].

In the literatures presented in this sections shows that prior studies were limited with the heat pipe using heat exchanging applications, with limited geometrical and parametrical constraints. The constraints for the analysis such as working fluids, heat transport fluids, gravitational effect and geometrical influence in the heat pipe heat exchanger. In this experimentation, the heat pipe is designed and analysed for 0° and 90° angle, water, methanol and acetone as heat transport and working fluids. The various mass flow rates as 40 to 120 LPH, and 20 to 60 LPH for hot and cold fluid, input temperatures are 50ºC to 70ºC and 30.5ºC. This parameter enhances the heat transfer at optimum condition.

2. Experimental Rig details and Procedure

2.1 Fabrication details

The test rig is designed with heat pipe and introduce in the heat exchanger, this replaces the transport tube of a conventional concentric tube heat exchanger. The parameter of an experimental setup is given in Table 1. Copper as the material for heat pipe, stainless steel as wick material. Wrapped screen wick inserted inside the heat pipe. Acetone and Methanol, and Water as Working Fluid (WF) and Heat Transport Fluid (HTF). Hot and cold fluid baths are 5 litres capacity and insulated. The hot fluid bath has an immersion coiled electric heater with 2000 W ±10 W capacity and a controller to monitor and regulate the hot fluid temperature. Similarly, cold fluid bath temperature also monitored and controlled.

Two scientific rotameters with a capacity of 0.1 to 3 LPM with ±0.1 % full scale to measure and control the flow of both hot and cold fluid regions. A Monoblock - Crompton 0.5 HP pump with 230 Volts, 50Hz, 1Φ, 15 Amps pump the fluid from the hot fluid bath to the rotometer, where the mass flow rate of the hot fluid measure and control before entering into the evaporator region of the heat exchanger and come out at another end and reaches the hot fluid tank.
At the evaporator and condenser sections, two thermocouples at each section used to measure the entry and exit of hot and cold fluid. Two thermocouples measure the surface temperatures of the shell at condenser and evaporator sections to observe the heat interaction in the system with the surrounding environmental temperature condition. T- Type thermocouples of six numbers with ± 0.2 °C measures the temperature gradients for heat pipe at condenser and evaporator sections which is welded at the outer wall and pasted with thermal resistance glue. The thermocouples are fixed over the heat pipe, at the evaporator section three thermocouples are arranged at the distance of 350 mm, similarly in the condenser section also three thermocouples are arranged at 90 mm distance each, by leaving the 15 mm at either ends of the condenser section. All thermocouples are connected with the data acquisition system (DAQ-Agilent 34972A model with accuracy of ± 0.2 °C) and a variable transformer to measure and record the temperatures it is connected with the computer.

The Model Selec MV 15 voltmeter with 0 – 480 Volts of ± 0.5% full scale and Model Selec MA 12 ammeter with 0 – 20 Amps of ±0.5% full scale measure the heat input. The influence of gravity in the heat pipe is observed by pivoting evaporator section end and moving condenser section end concerning the horizontal axis of 0°. Instead of the evaporator end, if condenser end pivoted, there exists a resistance to the flow of condensate towards the evaporator section.

### Table 1. Parameters of an Experimental Setup

| Parameters                                      | Experimental Test Rig |
|------------------------------------------------|-----------------------|
| Material of Heat pipe                          | Copper                |
| Evaporator and Condenser shell Material        | Galvanized Iron       |
| Wick material                                  | Stainless steel       |
| Heat pipe working fluid                        | Methanol and Acetone  |
| Heat transport fluid                           | Water                 |
| Total length (L) and diameter (D_e) of the shell at evaporator | 1000 and 50 mm        |
| Total length (L) and diameter (D_c) of the shell at condenser | 300 and 35 mm        |
| Heat pipe outer diameter (D_o) and an inner diameter (D_i) | 19 and 17 mm        |
| Heat pipe Total length (L)                     | 1000 mm               |
| Condenser Length of Heat pipe (L)              | 300 mm                |
| Evaporator Length of Heat pipe (L)             | 700 mm                |
| Number of wires/unit length of mesh            | 2000 m⁻¹              |
| Wick permeability (K)                          | 1.3 x 10⁻⁹ m²         |
| Wick porosity (ϕ)                              | 0.7                   |
| Mesh size                                      | 50 holes/inch         |

2.2 Experimental Procedure

In the test setup, the concentric-tube heat pipe heat exchanger is investigated and given in Figure 1, in which red and blue line indicates the hot and cold fluid flow path. Similarly, T_h and T_c are the hot and cold fluid temperatures at the tank, T_hi and T_ho are the temperatures of the hot fluid inlet and outlet, surface temperature of the shell (T_{sw}) of evaporator section, heat pipe inner temperatures at evaporator section are denoted as (T_{e1}, T_{e2}, T_{e3}), T_{o} and T_{o1} are the cold fluid inlet and outlet temperatures, heat pipe inner temperatures at condenser section are given as (T_{c1}, T_{c2}, T_{c3}), surface temperature of the shell (T_{sc}) of condenser section.
The vacuum pump evacuates the unwanted gas present inside the heat pipe. The absolute vacuum is ensured at 0 PSI with the 30 inches of Hg vacuum gauge connected with the heat pipe. Then the required quantity of WF is injected and properly shields the suction line with gate valve. The methanol and acetone are the working fluid for preliminary and secondary investigation, respectively. The working fluids are filled with fifty percent of evaporator zone volume, the properties of WF is shown in Table 2 [27].

| Properties                        | Methanol | Acetone |
|-----------------------------------|----------|---------|
| Boiling point                     | 65°C     | 56°C    |
| Melting point                     | -97.9°C  | -94.9°C |
| Latent heat of evaporation (λ)    | 1055 kJ/kg | 534 kJ/kg |
| Density of liquid (ρ_l)           | 792 kg/m³ | 784 kg/m³ |
| Density of vapour (ρ_v)           | 1.47 kg/m³ | 1.52 kg/m³ |
| Thermal conductivity of liquid (k) | 0.201 W/m °C | 0.18 W/m °C |
| Vapor pressure (at 293 K)         | 12.87 kPa | 24.40 kPa |
| Viscosity of liquid (μ_l)         | 0.314 x 10⁻³ Ns/m² | 0.309 x 10⁻³ Ns/m² |
| Surface tension of liquid (σ)     | 1.85 x 10⁻⁴ N/m | 2.30 x 10⁻⁴ N/m |
| Molecular weight (M)              | 32 g/mol | 58.07 g/mol |
| Specific heat ratio (ν_v)         | 1.33     | 1.38    |

In the preliminary test, at a 0° angle (horizontal reference) for methanol. The hot fluid maintained as 40 LPH and 50°C respectively and for cold fluid 20 LPH and 30.5°C. The hot water flow rate along the evaporator section of the heat exchanger controlled using rotameter and allowed to reach a steady-state. Hot water bath temperature is maintained using temperature controller at the evaporator section. The thermocouples are employed to measure and record the temperature at inlet, and outlet of hot and cold fluid. The condenser surface temperatures for the heat pipe and shell section also recorded at the steady-state situation. The same procedure repeated for various flow rates and temperature of hot and cold fluid.

Further, the investigation made with vertical inclined angles of 90°. The mass flow rates for hot fluid as 60, 80, 100, 120 and cold fluid 30, 40, 50, 60 LPH, respectively. The entry of hot and cold zones temperatures are 55°C, 60°C, 65°C, 70°C and 30.5°C. The similar parameters are repeated for acetone and investigated. The whole length of an outer circumference of the heat exchanger shell is insulated using the 30 mm thickness of styrofoam material to minimize the heat dissipation to the surrounding environmental conditions, and surface temperature is observed between the shell and ambient.
condition as ±0.5°C at 70°C of input temperature of hot fluid, as negligible amount of heat dissipation for this experimentation.

3. Results and discussion
The experimentation is made by the parameters, hot fluids as 40, 60, 80, 100 and 120 LPH. The cold fluid as 20, 30, 40, 50 and 60 LPH. Temperatures of hot fluid at the inlet of evaporator region as 50°C, 55°C, 60°C, 65°C and 70°C; cold fluid temperature fixed as the ambient environmental temperature of the environment during the investigation at the condenser region was 30.5°C. Inclination angles are 0° and 90°. Heat Transport Fluid (HTF) as water. The Working Fluid (WF) for first test rig as methanol and second test rig as acetone.

In the first test in Figure 2, water HTF and methanol as WF. In the given WF, the observed result shows that at Thi as 60°C and mhi as 100 LPH the achieved effectiveness is higher while comparing with other hot fluid inlet temperature, the observed values are 38.98% and 37.96% for 0° and 90°, respectively. Increase in effectiveness is achieved from Thi as 50°C to 60°C after that heat absorption capacity for methanol gets reduced, so effectiveness decreases for 65°C and 70°C. This is due to the dry out condition of working fluid above 60°C and 100 LPH for all the inclination angles. In all the conditions the maximum effectiveness achieved at Thi as 60°C and 100 LPH, so further pictorial representations are made with 60°C temperature.

![Figure 2](image1.png)

**Figure (2).** Variation of effectiveness with mass flow rate of hot fluid (ψ = 0° and 90°, Methanol)

In Figure 3, for inclination angles of ψ as 0° and 90° for Thi as 60°C and mhi ranges from 40 to 120 LPH for methanol as WF. Initially setup is kept at horizontal and vertical positions such as 0° and 90° the observed effectiveness is 38.98% and 37.96%, is 2.63% of increment in effectiveness than 90° while comparing with 0°, because of the capillary action of the wick and faster movement of WF from evaporator to condenser zone and vice-versa, due to the pumping force of heat transport fluid (water) to the evaporator zone, were uniform heat is supplied and vapour formation was uniform and maximum heat transfer is observed at this orientations, so maximum effectiveness is occurred. When tilting the angle from 0° to 90°, there is reduction in the performance, due to the sudden effect of gravity leads to the increase in thermal resistance and restriction in the flow of WF because of the friction force, this leads to the short fall of observed result at 90° while comparing with 0°. While increasing the mhi, the effectiveness gets increased until 40 to 100 LPH, but after 100 LPH the effectiveness gets reduced at 120 LPH. This is observed as 29.49% and 28.18% for ψ as 0° and 90°. This decrement in effectiveness at 120 LPH is because of the smallest heat absorption and discharge capacity of the WF at evaporator and condenser zones of the heat pipe.
In the second test shown in Figure 4, acetone and water. In this test also similar results are obtained, the observed result shows that at \( T_{hi} \) and \( m_{hi} \) are 60°C and 100 LPH the achieved effectiveness is higher while comparing with other hot fluid inlet temperature, and the observed values are 50.84% and 45.76% for 0° and 90°, respectively. Increase in effectiveness are achieved from \( T_{hi} \) as 50°C to 60°C after that heat absorption capacity for acetone gets reduced, so effectiveness decreases for 65°C and 70°C. This is due to the dry out condition of acetone above 60°C and 100 LPH for all the inclination angles. In all the conditions, the maximum effectiveness achieved at \( T_{hi} \) as 60°C and 100 LPH, so further representation are made with 60°C. In the above figure, same similar trends of graphs are observed while comparing with this figure, but while comparing with methanol, acetone possesses maximum effectiveness.

In Figure 5, shows the acetone as WF by comparing all the gravitational angles from \( \psi \) as 0° and 90° at \( T_{hi} \) as 60°C and \( m_{hi} \) from 40 to 120 LPH. This graph reveals that for 60°C and 100 LPH condition, while tilting the heat pipe heat exchanger form 0° and 90° orientation the obtained values was 50.84% and 45.76%, this is 11.10% of increment in effectiveness than 90°. Similarly, for 120 LPH the decrement in effectiveness are observed for all tilt angles from 0° and 90° are 43.72% and 36.27%. In this analysis also similar results are observed like methanol, but while relating both the working fluids, acetone possesses higher heat transfer characteristics and transfers the maximum heat attained from working fluid to heat transport fluid at either side of condenser and evaporator zone, so maximum effectiveness are obtained.
Figure 5. Variation of effectiveness with mass flow rate of hot fluid (T_{hi} = 60ºC, \psi = 0º - 90º,
Acetone)

Figure 6, shows the comparative analysis of methanol and acetone. This figure represents that acetone
has higher effectiveness than methanol for all the conditions such as temperatures, mass flow rates and
inclination angles. Acetone has a minimum latent heat of vaporization at 57ºC, this leads to the lower
evaporator temperature, liquid acetone changed to vapour suddenly. In case of methanol takes
maximum time due to maximum boiling temperature and latent heat of vaporization. In both working
fluids will induce the nucleate boiling at minimum temperature at less heat dissipation condition.
Therefore, acetone possesses quick phase change from evaporator to condenser and vice-versa this
leads to the maximum effectiveness in the system.

In this analysis, m_{hi} as 100 LPH, T_{hi} as 60ºC and \psi as 0º has the highest effectiveness along with the
system as 50.84% for acetone this is 30.42% increase in effectiveness than methanol. Similarly, during
\psi as 90º it was 45.76%, this is 20.54% increase in effectiveness than methanol, and this clearly shows
that at the vertical and horizontal axis of heat pipe the influence of wick makes capillary action which
increases the movement of WF in the system. Investigated results show from m_{hi} as 40 to 100 LPH
there are increasing trends of effectiveness are achieved and then starts decreasing at 120 LPH, in T_{hi}
also there is an increment in values are observed from 50ºC to 60ºC after attaining the optimum
temperature, effectiveness decreases for 65ºC and 70ºC.

The increase in effectiveness is observed while comparing with methanol, this significance in
increasing trends were observed because of the effect of gravitational the movement of WF as high
grade energy from evaporator to condenser and after condensing the low grade energy returns back to
evaporator, this happens inside the heat pipe because of the capillary force and pressure variance in the
heat pipe in effect of gravitational also induce the movement, this increases the heat pipe heat
exchanger performance while tilting from horizontal to vertical orientation angle. This effect occurs
due to the maximum quantity of WF from the condenser reasons overstated inception of the fluid this
embarks the vapour flow and increases the thermal resistance.
Figure 6. Variation of effectiveness with mass flow rate of hot fluid (T_{hi} = 60^\circ C, \psi = 0^\circ - 90^\circ, Methanol and Acetone)

At 90^\circ orientation angle, the plenty of the liquid at the evaporator zone of the heat pipe heat exchanger inclines to increment the surface temperature for both methanol and acetone working fluid.

In Figure 7, the inlet conditions for the inclination angles from 0^\circ and 90^\circ. The temperature of T_{hi} as 60^\circ C and m_{hi} from 40 to 120 LPH and water as HTF. At this condition, methanol used as WF. The observed value for \psi = 0^\circ and 90^\circ shows 0.00664 and 0.00681 \degree C/W, there is 2.40% decrement in result than 90^\circ. In this analysis (R_h) gets decreased from 40 to 100 LPH but at 120 LPH thermal resistance gets increased for all hot fluid inlet temperature and various gravitational angles this is observed as 0.00687 and 0.00685 \degree C/W for \psi = 0^\circ and 90^\circ. This reveals that at 100 LPH, tilt angle of 0^\circ and 60^\circC, the observed thermal resistance is minimum when compared to other angles and mass flow rates. Hence this shows that the reduction in thermal resistance indications to an increase in performance of the concentric tube heat pipe heat exchanger.

Figure 7. Variation of thermal resistance with mass flow rate of hot fluid (T_{hi} = 60^\circ C, \psi = 0^\circ and 90^\circ, Acetone)

At Figure 8, the inlet conditions for the inclination angles from 0^\circ and 90^\circ. The temperature of T_{hi} as 60^\circ C and m_{hi} from 40 to 120 LPH, and water as HTF. At initial condition, acetone used as WF. The observed value for T_{hi} as 60^\circC and m_{hi} as 100 LPH for tilt angles of \psi as 0^\circ and 90^\circ the observed values is 0.00547 and 0.00595 \degree C/W, there is 8.77% decrement in result than 90^\circ. In this analysis also a similar type of trends are achieved at 100 LPH for acetone, but while comparing with methanol,
acetone has minimum thermal resistance. Similarly for 120 LPH the observed values for tilt angles of $\psi$ as 0º and 90º are 0.00569 and 0.00612 ºC/W. In this above results also there is increase in trends are observed while comparing with 100 LPH. This is due to the decrease in thermal performance indications to growth in thermal resistance for 120 LPH for both the working fluids.

The thermal resistance of the heat pipe is reduced slowly with increase in heat flux from tilt angles $\psi$ as 0º to 90º. This reduction happens for of dense liquid film formed by the WF above the wick surfaces at the evaporator zone produced radial heat drop and this indication to maximum thermal resistance, this film is removed subsequently by increasing the hot fluid inlet temperature and mass flow rate at evaporator zone. After reaching the 100 LPH and 60ºC it’s the saturated condition for this experimentation, the thermal resistance starts increasing, and this is represented in the graphs.

In Figure 8, this graph shows for both methanol and acetone. The observation of methanol shows for various $T_{hi}$ as 50ºC to 70ºC and $\psi$ as 0º and 90º for 40 to 120 LPH. The minimum $R_{th}$ values observed at 60ºC, 100 LPH for 0º was 0.00665 ºC/W. Similarly, for acetone as WF for same above revealed conditions, the stated $R_{th}$ was 0.00547 ºC/W this is 21.57% decrease in result is observed than methanol. Similarly, for 90º inclined angle there is decrease in results of 14.45%, this shows that acetone has minimum thermal resistance than methanol for all the above conditions, this leads to increase in thermal performance for acetone. Hence this clearly shows that at 60ºC and 100 LPH the HTF transfers heat to the WF. This achieved heat converts the liquid WF to vapour and reaches the condenser zone. At condenser zone, the absorbed heat released to the cold fluid, and sensible heat transfer obtained. While increasing the temperature to 70ºC, there is minimum heat absorption capacity of working fluid is achieved; thus, there is an inadequate release of sensible heat at the condenser section. At both the tests the thermal resistance observed for acetone at 100 LPH, $\psi$ as 0º, $T_{hi}$ as 60ºC is minimum when compared to methanol, this shows that friction at this condition is minimum, and the movement of working fluid was at a higher rate. Hence it is evident that growing mass flow rate of hot fluid transfers maximum heat to the working fluid and which results in high heat absorption capacity.

![Figure 8. Variation of thermal resistance with mass flow rate of hot fluid ($T_{hi}$ = 60ºC, $\psi$ = 0º and 90º, Acetone)](image-url)
Hence this graph depicts maximum heat transfer enhancement achieved. While inclination angles at 0° shows a minimum thermal resistance, but at 90° tilt angle the thermal resistance was maximum due to the plenty of the liquid working fluid at evaporator zone of the heat pipe tends to rise the surface temperature for both methanol and acetone working fluids. This effect leads to the development of the liquid film in the condenser, in-turn heat transferred from WF to HTF get reduced, thus inferior results observed at this angle.

Figure 10, observes the variation of Reynold’s number ($R_e$) with hot fluid flow rate. The temperature of $T_{hi}$ as 60°C and $m_{hi}$ from 40 to 120 LPH and water as HTF. At this condition, methanol used as WF. The observed value for $\psi$ as 0° as 914 and for 90° as 902. In this analysis ($R_e$) gets increased from 40 to 100 LPH but at 120 LPH Reynold’s number gets decreased for all hot fluid inlet temperature and for various gravitational angles this is observed as 771 to 768 for 0° and 90°. This reveals that at 100 LPH, tilt angle of 0° and 60°C, the observed $Re$ is maximum when compared to other angles and mass flow rates. Hence this represents the increment in Reynold’s number causes an increment in performance.

Figure 11, represents the variation of Reynold’s number with hot fluid flow rate. The temperature of $T_{hi}$ as 60°C and $m_{hi}$ from 40 to 120 LPH, and water as HTF. Acetone used as WF. The observed value...
for $T_{h,i}$ as 60ºC and $m_{h,i}$ as 100 LPH for tilt angles of $\psi$ as 0º and 90º it is 937 and 931. In this analysis also a similar type of trends are achieved at 100 LPH for acetone, but while comparing with methanol, acetone has maximum Reynold’s number. Similarly for 120 LPH the observed values for tilt angles of $\psi$ as 0º and 90º are 782 and 778. In this above results also there is decrease in trends are observed while comparing with 100 LPH. While increasing the mass flow rate from 100 LPH to 120 LPH for both the working fluids the Reynold’s number gradually decreases.

**Figure 11.** Variation of Reynold’s number with mass flow rate of hot fluid ($T_{h,i}$ = 60ºC, $\psi$ = 0º and 90º, Acetone)

Figure 12, this graph shows the variation of Reynold’s number for both methanol and acetone as working fluids. The observation of methanol shows for various $T_{h,i}$ as 50ºC to 70ºC and $\psi$ as 0º and 90º for 40 to 120 LPH. The maximum (Re) values observed at 60ºC, 100 LPH for 0º was 914 for methanol. Similarly, for acetone as WF for same above revealed conditions, the stated (Re) is 937 this is 2.51% increase in result than methanol. Hence this clearly shows that at 60ºC and 100 LPH the HTF transfers heat to the WF, thus phase transform happens from liquid to vapour WF and similarly vice-versa at condenser zone thus performance of the system increases.

**Figure 12.** Variation of Reynold’s number with mass flow rate of hot fluid ($T_{h,i}$ = 60 ºC, $\psi$ = 0º and 90º, Methanol and Acetone)

Figure 13, shows the Nusselt number with respect to Reynold’s number for both the conditions of acetone and methanol. This graph represents highest Reynold’s number is obtained for acetone with 60ºC, 100 LPH and 0º angle. Hence for above similar condition Nusselt number obtained as 16.2 and
Reynolds number is 937. This reveals that at optimum condition, the Reynold’s number rise induce the rising outcome of Nusselt number for both the working fluids, but while comparing acetone possess maximum than methanol.

![Figure 13](image-url)

**Figure 13.** Variation of Nusselt number with Reynold’s number ($T_{hi} = 60\, ^\circ C$, $\psi = 0^\circ$ and $90^\circ$, Methanol and Acetone)

4. Conclusion
In this concentric tube heat pipe heat exchanger investigation, the effect of working fluids and gravitational effect (Inclination angles) are experimentally analysed.
The optimum revealed conditions for hot fluid mass flow rates ($m_{hi}$) as 100 LPH and cold fluid ($m_{ci}$) as 50 LPH, ($T_{hi}$) as 60$^\circ$C for both the working fluids.
Thermal performance observed maximum for $0^\circ$ angle when compared with $90^\circ$.
In this analysis, while comparing the working fluids methanol and acetone, for optimum parameters, acetone exhibits superior performance than methanol. For optimum conditions, increase in effectiveness obtained as 30.42% and 20.54% for the inclined angles of $0^\circ$ and $90^\circ$. Similarly for Reynold’s number also increase in values is observed as 2.5%.
Thermal resistance ($R_{th}$) observed for both the tests infer that methanol has higher thermal resistance compared to acetone. The thermal resistance of acetone shows less than methanol as 21.57% and 14.45% for $\psi$ as $0^\circ$ and $90^\circ$.
The acetone filled heat pipe heat exchanger shows better results than methanol, because of lowest thermal resistance and highest effectiveness, heat transfer coefficient, heat transfer rate for this fabricated setup and experimentation.
The concentric tube heat pipe heat exchanger charged with methanol and acetone can be used at minimum heat dissipation regions because of less saturation temperature leads to affect dry out limitation, the suitable inclination angle and working fluid can be chosen according to the required applications.

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