Heat transfer enhancement with titanium nitride nanofluid in a shell and tube heat exchanger

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Abstract. The heat transfer enhancement in shell and tube heat exchanger can be done by adding Nano particles to the base fluid. The heat transfer rate between hot and cold fluid shows increasing sign with low to high mass flow rate. Mass flow rate can be controlled and monitored with the help of valve fixed to the shell inlet. Comparing volume concentration of Titanium Nitride from low to high heat enhancement lies linearity. As volume concentration rises in base fluid affect the viscosity of exchange fluid in turn friction of contact fluid increases. Increased mass flow rate and heat transfer helps to find efficiency. The result shows for the controlled same flow rate with common inlet temperature transfer rate of nano fluid is slightly higher with water. Efficiency increase for about 7.47% for water to nanofluid. The effectiveness increase for about 36.6% for water to nanofluid. The LMTD increased for about of 33.6ºC and heat transfer rate increases for about 0.4879 kW for three concentrations at one flow rate. Rising the mass flow rate of nano fluid inference in increasing heat transfer.

1. Introduction
Heat exchangers are the devices used by many industries for heat exchanging processes due to its simple working procedure with less maintenance. Considering operational cost is also comparatively lessor for Shell and tube heat exchanger. In high pressure application industries like oil refineries and chemical processing units commonly prefers Shell and tube exchanger. Main parts in setup arrangements includes shell which is cylindrical in nature, number of tubes bundled inside shell, baffle holding tubes with constant pitch. Heat transfer phenomenon in shell and tube will varying with factors like temperature, pressure, baffle spacing, shell diameter and number of tubes etc. Most of the cases hot fluid runs through the tube and cold fluid flows over the tubes for transferring heat between the two fluids. Tubes in this shell may plain or with extended surfaces. Baffles maintain proper space between tubes by holding tubes inside shell and it directs fluid inside it. A Nanofluid is a liquid where nano sized particles are typically made of metals, oxides, carbides, nitrides dis-pressed in base liquids. Due to its novel heat transfer enhancement ability applied in many applications. Thermal properties of nano fluids shows betterment compare to base liquids. Many researchers using nano based fluid in the field of heat transfer in past decades because of their physical properties which enhancing heat transfer compare to other base fluids. In this paper titanium nitride powder is used to prepare nano fluid.

2. Literature review
Many researchers carried work using nanofluid in shell and tube heat exchanger presented here NaderVahdatAzad et al[1] shell and tube exchanger optimum designs with nanofluid using genetic
algorithm method studied with different nano fluids. Alumina based nano fluid rises the Nusselt Number in turn increases the heat transfer coefficient. Effects the efficiency increases in exchanger with nano fluids. Roghayeh Lotfi et al[2] Experimental study on multi-walled carbon nanotube(MWNT) in horizontal shell and tube heat exchangers. using of MWNT enhances heat transfer ability with base fluids. DhineshKumar ,Devendiran et al[4] reviewed the preparation,properties,characterization of nano fluids. The results shows that adding of nanoparticles in base fluid improves the nanofluid properties like thermal conductivity,heat transfer coefficient. Raju and Srinivasulu [11] studied the Thermal Analysis with Titanium Carbide, Titanium Nitride and Zink Oxide Nanofluids in Shell and Tube Heat Exchanger. Titanium Nitride nano fluid with copper tubes gives higher heat flux compared with other fluids in ansys software.

3. Experimental investigation
3.1. Preparation of Nanofluid
For experimentation three concentrations of nano fluid is prepared by weight concentration basis. Nanoparticles to be added with 2000ml of water for each concentration. Synthesis of nano fluid should be with low agglomeration. To ensure low agglomeration mixing of nanoparticles with base fluid is done with the help of magnetic stirrer. water is collected into a glass beaker which has more capacity to absorb heat. Stirrer magnet is attached with the hot plate and it helps to mix surfactant fluid with water. NaOH is used as a surfactant fluid for preparation. NaOH helps as a binder to mix water and nanoparticles strongly. Nano particle have more tendencies for sedimentation not stable with base fluid. So, NaOH helps to reduce the surface tension of water and mix titanium nitride properly with water to make this Nanofluid. For 0.5% concentration making 10 ml of NaOH is added with 2 liters of water and stirred for 15 minutes. For 0.5% of volume concentration 10 gms of TiN nano particle powder added and its mixed in stirrer for 30 minutes to get the proper Nanofluid. Two more concentrations made with same method for with 1% and 2% volume concentration.

Figure 1. Magnetic Stirrer.  
Figure 2. Mixed Nano fluid.
3.2 Experimental setup

Table 1. Physical properties of Fluids.

| Fluids                        | Thermal conductivity, k(W/m.K) | Density, ρ(kg/m³) | Specific Heat, Cp(kJ/kg.K) |
|-------------------------------|-------------------------------|-------------------|----------------------------|
| Water at 25°C                 | 0.607                         | 995               | 4.183                      |
| Titanium Nitride 0.5% Weight Concentration | 0.7838                        | 1404.15           | 2.772                      |
| Titanium Nitride 1.0% Weight Concentration | 1.04597                       | 1793.72           | 2.011                      |
| Titanium Nitride 2.0% Weight Concentration | 1.832                         | 2612.04           | 1.153                      |

Figure 3. Layout of heat exchanger.

The figure-3 is the layout of shell and tube heat exchanger setup made for carry out experiment. Water is heated with the help of heater 1000 watts operated by thermostat controller maintaining 60°C in the hot water tank of capacity 5 liters. Cold nano fluid is stored in 2 liters capacity tank. Both fluid is circulated to the heat exchanger with pump of capacity 550 LHP. Connections of all lines are shown in diagram. Flow control valves are fixed in hot water inlet and nanofluid tank inlet to regulate flow rate. Experiment is carried out with 0.5 kg/s to 1.5 kg/s mass flow rate for both fluids under 60°C. Temperature sensors are connected at inlet and outlet points of heat exchanger for both hot and cold fluids.
4. Procedure and Calculations
In this chapter we present the basic calculations and formula relates to find physical properties in heat exchanger setup for hot and cold side.correlation to find energy analysis also included.

4.1. Physical properties
Calculations were used to find properties by models developed in many research articles.

4.1.1. Density of Nanofluid. It is calculated based using nanoparticle density, $\rho_p$, and base fluid density, $\rho_b$, using the mixture rule as follows

$$((\rho_{nf}) = (1 - \phi)\rho_b \phi + \phi \rho_p)$$

where, $\phi$ is the fraction of nanoparticles in the base fluid.

4.1.2. Heat capacity

$$((\rho C_p)_{nf} = (1-\phi)(\rho C_p)_{bf} + \phi(\rho C_p)_{np})$$

4.1.3. Viscosity
\( \mu_{nf} = \mu_{bf}(1+2.5\varphi) \) \hspace{1cm} (3)

4.1.4. Thermal conductivity

\[
(K_{nf}) = \frac{K_{np} + 2K_{bf} + 2(Kp - Kbf)f}{K_{np} + 2K_{bf} - (Kp - Kbf)f}
\]

where, \( k_{nf}, k_{np}, \) and \( k_{bf} \) are thermal conductivities of nanofluids, nanoparticles and base fluid respectively.

4.2. Thermal performance

4.2.1. Overall convective heat transfer coefficient

\[
U = \frac{Q}{A*\text{LMTD}}
\]

where, \( A \) is heat transfer area in \( m^2 \), \( Q \) is heat transfer from hot fluid into cold fluid in \( W \), \( \text{LMTD} \) is logarithmic mean temperature difference in \( \text{K} \).

\[
Q = (V\rho Cp)_{nf}(T_{h1} - T_{h2})
\]

where, \( V \) is volumetric flow rate in \( m^3/hr \).

\[
\text{LMTD} = \frac{(T_{h1} - T_{c2})(T_{c2} - T_{c1})}{\ln\left(\frac{T_{h1} - T_{c2}}{T_{c2} - T_{c1}}\right)}
\]

where, \( T_{c1}, T_{c2} \) are inlet and outlet temperatures of cold fluid (shell side).

4.2.2. Thermal efficiency

The thermal efficiency of the hot side \( \eta_{hot} \) is the ratio of the temperature difference of the hot side to the maximum temperature difference between the hot and cold sides in a perfect heat exchanger.

\[
\eta_{hot} = \frac{T_{h1} - T_{h2}}{T_{h1} - T_{c1}}
\]

The thermal efficiency of the cold side \( \eta_{cold} \) is the ratio of the temperature difference of the cold side to the maximum temperature difference between the hot and cold sides in a perfect heat exchanger.

\[
\eta_{cold} = \frac{T_{c1} - T_{c2}}{T_{h1} - T_{c1}}
\]

The mean thermal efficiency, \( \eta_{mean} \).

\[
\eta_{mean} = \frac{\eta_{hot} + \eta_{cold}}{2}
\]

5. Results and discussion

It's observed clearly in Figure 5 that the efficiency increases with increase in the weight concentration. In comparison to 0.5% weight concentration efficiency with nano fluid shows more variation between 1% and 2% of weight concentration. If the adding of nanoparticle to the base fluid increases automatically efficiency also increases. Blue line indicates the efficiency for flow rate1 and orange line indicates the efficiency for flow rate2 and grey line indicates the efficiency for flow rate3. When flow rate in heat exchanger increases the efficiency also increases.
The effectiveness for the weight concentration based nano fluid shows variation under different concentrations. The nano fluids passed through the shells under certain flow rates shows effect of effectiveness. If volume flow increases with concentration effect in rising of the effectiveness of exchanger. In comparison with 0.5% to 2.0% the effectiveness changes 23.5%.
The effect of mass flow rate with different weight % on Logarithmic mean temperature difference showed in figure 7. Nano fluid with highest weight concentration pumped in tube side with low temperature in contact with shell fluid transfers heat to it. Temperature difference between two fluids happens by heat exchanged among them. Lower concentration nano fluid having higher LMTD under different flow conditions.

Figure 7. Graph between Weight Concentration and LMTD

6. Conclusion
From the comparative values, calculations and graphs, it is evident that the heat transfer rate increased compare to base fluid. The heat transfer rate shows linearity with mass flow rate. The efficiency of heat transfer increases as weight concentration of nanofluid varies from 43.82% to 49.83% for flow rate 1, 44.56% to 50.4% for flow rate 2, 45.32% to 51.3% for flow rate 3. The effectiveness shows variation with rise in weight concentration of nanofluid from 54.545% to 75.595% for flow rate 1, 66.67% to 79.39% for flow rate 2, 2.12% to 81.81% for flow rate 3. The efficiency and effectiveness also increased when flow rate is increased. The LMTD increases with increase in the weight concentration of nanofluid from 10.62°C to 7.99°C for flow rate 1, 9.287°C to 7.32°C for flow rate 2, 8.623°C to 6.981°C for flow rate 3. Titanium nitride based nano fluid shows betterment in thermal behaviour as compared to the normal base fluids.

7. References
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