The Effect of Temperature and Twist Ratio from Twisted Tape Insert to Pumping Power in Concentric Exchange Tools using Nanofluida TiO$_2$ and Oli Termo XT-32

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Abstract. The heat exchanger is a device used to heat between two or more fluids. Heat exchangers can use fluid flow or construction. Heat exchangers are widely used in engineering applications. The heat exchanger has long been recognized by industries that relate to heat transmission phenomena. Improve the speed of all types of heat exchangers widely in the industry, in the process of retrieval (heat recovery process), air conditioning, and chemical reactors. Increasing the amount of light flow can be done in several ways, namely: flowing inequality, damaging the boundary layer, changing the fluid flow, and rotating fluid flow (vortex flow). One of the techniques used to increase the heat coefficient of convection is to provide insert material or often called Insert. The research methodology was to determine the effect of the rotational ratio of the insertion bent band on the pumping power of the pipe heat exchanger by using TiO$_2$ nanofluid with a heat transfer oil base fluid (thermo XT32). This research was carried out with experimental methods, as for the tools and research materials in this case: primary fluid of thermo XT32, TiO$_2$ nanoparticles, and an annular channel concentric pipe heat exchanger by inserting a bent band. In and out data (Th, i and Th, o), the temperature of the fluid in and out of the annulus (Tc, i and Tc, o), the outer wall temperature of the inner tube (Tw1, Tw2, Tw3, Tw4), and the water height difference on the manometer. Data collection was carried out with TiO$_2$ particle nano samples with a volume fraction of 0.3% Vol, without a bent band. Insert (plain tube) and rotate the tape with a touch ratio of 3, 6, and 9. The results of the research carried out on the conclusion of the rotational ratio in the band bending the insertion of the pumping power of the heat exchanger. This proved the pumping power increases with decreasing rotational ratio from a bent band, the addition of a twisted tape insert can increase the pumping power when compared to a pipe heat exchanger without concentrically turning the inserted tape (plain tube), this is proven by using a twisted tape insert with a twist ratio of 3. It requires a pumping power of 87.71 W / m$^2$ to be able to drain TiO$_2$ nanofluid, with a volume fraction of 0.3% Vol at a fluid temperature of 60 °C whereas when compared to a heat exchanger without turning the inserted tape (plain tube), it only requires pumping power of 17.73 W / m$^2$. to be able to drain nanofluid in a heat exchanger.

1. Introduction
Murshed et al. [1] conducted a retrospect on the characteristics of heat transfer of TiO$_2$/water nanofluid convection at constant flux conditions. The results obtained that the nanofluid shows an increase in the
coefficient of heat transfer of convection along with the increasing volume of nanoparticles in the solution [2].

Mursheed, et al [3] also conducted research on the thermal conductivity of nanofluids with a temperature range of 20 °C-60 °C with the transient hot-wire method, in his research using the effective thermal conductivity model, concluded that particle size, shape, interfacial layer, and temperature affect the increase in thermal conductivity nanofluid.

Mintsa, et al [4] measured the effective thermal conductivity of nano alumina/water and copper oxide/water fluids in a temperature range of 21 °C to 23 °C with a volume concentration of 0% to 18%, the results showed an increase in effective thermal conductivity influenced by an increase in volume fraction.

Duan and Stephen [5] in their study measured thermal conductivity using Al₂O₃-water nanofluid by transient hot-wire method with temperature variations of 15 °C - 55 °C, nanoparticle concentration 1%, 3%, and 5%, and particle size of 10 nm, 25 nm, and 35 nm conclude that particle size, temperature, and volume fraction increase the thermal conductivity value of nanofluid.

Duanthongsuk and Wongwises [6] conducted a study on the performance of heat transfer and decreasing of tackling of TiO₂ nanofluid in turbulent flow conditions. The results of the study showed that convection heat transfer values increased with an increasing volume concentration of nanoparticles, the value of nanoscale heat transfer coefficient was higher than that of the base fluid, and the heat transfer value increased with increasing Reynolds number and particle concentration used around 26% more height of the base fluid.

Naphon [7] conducted a study to investigate the characteristics of heat transfer and pressure drop in double pipe heat exchangers without twisted insert tape and compare them using twisted tape insert with various pitch twist values. The test section used is a straight copper pipe with a length of 2000 mm and a diameter of the inner tube and outer tube are 8.10 mm and 9.54 mm, respectively. Twisted tape insert is an aluminum strip with a thickness of 1 mm and a length of 2000 mm. In this test the fluid used was hot water at a temperature of 40 °C and 45 °C and cold water at a temperature of 15 °C and 20 °C, and twisted tape insert made two variations of twist pitch which were 2.5 mm and 3.0 mm. The results show that twisted tape insert has a significant influence on increasing the heat transfer rate, but the pressure drop that occurs also increases. The greater the Reynolds number, the higher the heat transfer rate, where twisted tape inserts with a 2.5 cm twist pitch has the highest heat transfer rate. This phenomenon also occurs in the heat transfer coefficient, the higher the Reynolds number, the higher the heat transfer coefficient, where the twisted tape inserts with a 2.5 cm twist pitch has the highest heat transfer coefficient. While the higher the Reynolds number, the friction factor will also be higher. In this study, the influence of the presence of twisted tape insert on the friction factor is clear, but the difference in twist pitch does not have a significant effect on the friction factor.

Noothong et al. [8] conducted a study to investigate the effect of twisted tape insert on concentric pipe heat exchangers. Pipes are made of Plexiglas material which is connected by a flange at 1 m intervals. The inner diameter of the outer tube is 50 mm, and the flow path is annulus 20 mm in the radial direction of the center of the inner pipe. Water as a cold fluid is pumped from a cooling machine with a capacity of 0.3 mm³, while an electric heater is controlled according to the input voltage. Hot air flows in the inner tube from a blower with a capacity of 7.5 kW with a variation of Reynolds number of 2000-12000. The twisted tape is made of stainless-steel strips with a thickness of 1 mm and width of 19.5 mm with a twist ratio (y); amounting to 0.6 and 0.8. The results showed that the increase in heat transfer rate due to the twisted tape insert was strongly influenced because twisted tape caused swirl motion or vortex motion. The maximum Nusselt number with a twist ratio (y) = 5 is 188% and for y = 7 is 159% higher than the pipe without twisted insert (plain Tube) tape. Friction factor decreases with increasing flow velocity or Reynolds number, but the efficiency increase will be higher. Heat exchanger with twisted tape inserts with twist ratio (y) = 5 has the highest efficiency increase compared to a heat exchanger with twisted tape insert with twist ratio (y) = 7 and plain tube.
2. Materials and Methods

![Figure 1. Schematic concentric pipe tool with twisted tape insert](image)

The research equipment consists of 3 systems, namely the measurement system, the inner tube trajectory system, and the flow trajectory system in the annulus. The inner pipeline is a closed path. The TiO$_2$ / Termo XT32 oil Nanofluid in a heater-heated tank is circulated by the pump, flowing through the test section and back to the TiO$_2$ Nano/thermo XT32 nanofluid tank. An electric heater is controlled by a thermo controller to maintain the temperature of the TiO$_2$ / thermo XT32 nanofluid in a constant tank. The flow path on the annulus is an open path, the flow of cold water comes from the water reservoir installed above which flows due to gravity (gravity method), the cold water coming out of the test section is immediately discharged into the sewer.

This testing phase is carried out using Termo XT32 oil base fluid added TiO$_2$ nanoparticles (0.3% Vol volume fraction) and this test is carried out. Pump to circulate oil in the test section and adjust the flow rate of the thermo XT32 oil fluid (2 LPM). Water flows through the annulus and regulates the flow rate of cold water (2 LPM). Temperature hot fluid used is 80 °C, this test section uses a twisted insert tape, the first twisted tape insert has a twist ratio 3, twisted tape insert second with a twist ratio 6, and a third twisted tape insert with a twist ratio of 9, data retrieval using U Manometer. This study will examine the effect of twist ratio variation of twisted tape insert in the inner pipe of the annular channel concentric pipe heat exchanger on Pumping Power.

### 2.1. Physical Properties of Nanofluid

The TiO$_2$ nanofluid composed of base fluid thermo XT32 oil and TiO$_2$ is adopted in this study. The diameter of the nanoparticle is set to be 18 nm. Table 1 lists the physical properties of thermo XT32 oil and nanoparticle. A single-phase model and constant physical property are adopted. The nanoparticle is assumed to be spherical and homogeneously suspended in oil.

| Substance | Temperature °C | $\rho$(kg/m$^3$) | $C_p$(kJ/kg.$^\circ$C) | $k$ (W/m.$^\circ$C) | $\mu$ (kg/m.s) |
|-----------|----------------|-----------------|------------------------|-------------------|---------------|
| Naofluid TiO$_2$ with base fluid termo XT32 oil at 0.3 % fraksi volume. | 30 | 846.2 | 1569.8134 | 0.11784 | 0.0407 |

3. Results and Discussion

The test was carried out with the temperature of the Nano TiO$_2$ / Heat fluid transfer XT32 thermo oil in the inner tube at 120 °C. Whereas the cold water entering the annulus is kept constant at a temperature
of ± 29 °C, with the flow rate of the TiO$_2$ Nanofluid / Heat thermo XT32 transfer oil in the inner tube is kept constant, namely: 2 LPM and the flow rate of the fluid in the annulus is kept constant, namely: 2 LPM. The data that will be obtained in this test is a pressure drop (ΔP) in the inner tube. Each test data was taken at steady state (steady state). This test was carried out on the volume fraction of TiO$_2$ Nanofluid of 0.3% Vol and varying the twisted tape inserts with a twist ratio of 3, 6, and 9.

From the observation of the rate of water mass flow in annulus and pressure drop in the inner tube, the temperature of the TiO$_2$ Nanofluid in and out of the inner tube, and the temperature of cold water in and out of the annulus, and the average temperature of the outer wall of the inner tube obtained data research as follows:

3.1. Pressure Drop on the Inner Tube of Heat Exchanger

The results of a pressure drop on the inner tube of a concentric heat exchanger are obtained using the following pressure [9]:

\[ \Delta P = \rho m . g . \Delta h \]  

(1)

| Fraksi vol | Temperatur (°C) | Pressure Drop on the Inner Tube |
|-----------|----------------|---------------------------------|
|           | Plain tube     | Twist ratio 3 | Twist ratio 6 | Twist ratio 9 |
| 0.3 %Vol  | 60             | 4446.27       | 6079.45       | 5671.75       | 4975.74       |
|           | 80             | 3206.97       | 5224.28       | 4419.29       | 4016.54       |
|           | 100            | 705.65        | 1898.79       | 1578.60       | 1182.60       |
|           | 120            | 387.24        | 1086.45       | 930.79        | 698.00        |

Table 3. Descriptive Statistics Pressure Drop on the Inner Tube

|                           | Mean  | Std. Deviation | N  |
|----------------------------|-------|----------------|----|
| Nusselt number             | 1.9458| .10624         | 24 |
| Reynolds Number            | 2.3000| .12511         | 24 |
| Prandtl                    | 2.3708| .13015         | 24 |
| Twist ratio                | 1.6667| .20990         | 24 |
| Fraksi Volume              | -.7500| .25538         | 24 |

Figure 2. The relationship of pressure drop with temperature variation

In Figure 2 it can be concluded that the addition of a twisted tape insert will result in an increase in pressure drop (ΔP) in the inner tube of a concentric pipe heat exchanger, this is due to the addition of a twisted tape insert the resistance of flow rate will increase as the twist ratio decreases twisted tape
3.2. Relationship of Convection Heat Transfer with Pumping Power

By using the equation found in the two-phase flow heat exchanger book in S. Kakac's chapter on pressure drop [10] and pumping power heat exchangers, Bergles et al. [11] obtained the equation of pumping power heat transfer area as follows:

1) **Pumping Power Heat Exchanger**

\[
\dot{P} = \frac{m \Delta P}{\rho \eta p} 
\]  

(2)

2) The relation between *Heat Transfer* and **Pumping Power** (\(\dot{p}/A\)):

\[
h = (\mu \cdot \text{cp}) Pr^{-2/3} \left( \frac{Re}{Dh} \right) \phi h
\]  

(3)

3) The equation of *Heat Transfer Surface Area*

\[
\frac{\dot{P}}{A} = \frac{m \Delta P}{\rho \eta p} A
\]  

(4)

4) By substituting equation 3 to the equation 4, we get:

\[
\frac{\dot{P}}{A} = 8 \left( \frac{\mu^3}{\rho^2 \eta p^2} \right) \left( \frac{1}{Dh} \right)^3 Re^3 \phi f
\]  

(5)

\[
\phi h = \frac{Dh}{\Delta P} \left( \frac{D}{d_i} \right) \left( \frac{\eta p^2}{2} \right)
\]  

(6)

\[
\phi f = \frac{C h^2 \mu^{0.53} D h}{k^{3.35} cp^{2/3} \rho^{2/3} \eta p}
\]  

(7)

Equations 6 and 7 are characteristic of fully developed laminar flow in fine pipes. By substituting into equation 5, the equation for pumping power per unit heat transfer area is as follows:

\[
\frac{\dot{P}}{A} = \left( \frac{C h^2 \mu^{0.53} D h}{k^{3.35} cp^{2/3} \rho^{2/3} \eta p} \right)
\]  

(8)

With \(C = 9.56, Dh = 0.011\ m, \) dan \(\eta p = 80\%\). From the equation of *pumping power per unit heat transfer area* (8), we obtained the following results:

| Fraksi vol | Temperature (°C) | Plain Tube | Twist ratio 3 | Twist ratio 6 | Twist ratio 9 |
|------------|------------------|------------|---------------|---------------|---------------|
| 0.3 % Vol  | 60               | 17.73      | 87.71         | 53.69         | 37.46         |
|            | 80               | 6.56       | 35.13         | 21.06         | 19.81         |
|            | 100              | 2.74       | 15.19         | 10.11         | 8.65          |
|            | 120              | 1.01       | 5.20          | 3.56          | 3.29          |

**Table 5. Results of Convection Heat Transfer.**

| Fraksi vol | Temperature (°C) | Plain Tube | Twist ratio 3 | Twist ratio 6 | Twist ratio 9 |
|------------|------------------|------------|---------------|---------------|---------------|
| 0.3 % Vol  | 60               | 756.0      | 1681.5        | 1315.6        | 1099          |
|            | 80               | 655.3      | 1516.5        | 1174.2        | 1138.6        |
|            | 100              | 574.3      | 1351.6        | 1102.5        | 1019.6        |
|            | 120              | 539.2      | 1224.5        | 1013.5        | 974.38        |

Figure 3 shows that the smaller the twist ratio of the twisted tape inserts causes, the higher the convection heat transfer coefficient (h). However, this increase in heat transfer of convection is followed by an increase in pumping power per unit of heat transfer area. This happens, with the smaller the twist ratio of the twisted tape insert causing the more significant the frontal area, resulting in greater
interference and obstacles that occur in fluid flow. As a result, the flow of TiO$_2$ Nanofluid with the same discharge requires higher pumping power.

From Figures 3, it can be concluded that the use of twisted tape insert is very influential on pumping power, it can be seen that with the same convection heat transfer coefficient ($\Delta h$) requires a more considerable pumping power per unit heat transfer area.

![Figure 3](image.png)

**Figure 3.** Relation of heat transfer rate with pumping power on TiO$_2$ nanofluid with a volume fraction of 0.3% Vol

4. **Conclusion**
The smaller the twist ratio of the twisted tape inserts, the higher the pumping power needed to drain the fluid. The most substantial pumping power occurs in the 0.3% volume of the nanofluid at the temperature of the incoming TiO$_2$ nanofluid ($T_{h,i}$) 60 °C and the use of twisted tape insert with a twist ratio 3 of 87.71 W/m$^2$.

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