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Experimental Studies on Heat Transfer Performance of Double Pipe Heat Exchanger with using Baffles and Nanofluids

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Abstract

Objective: The present study was made to investigate the enhancement in the heat transfer characteristics of CuO water base nanofluids by inserting the baffles in the annulus of the double pipe heat exchanger. **Statistical Analysis:** The experimentation was carried out with distilled water and copper oxide water base nanofluids at 0.1% and 0.2% volume concentration. The effect on heat transfer coefficient and Nusselt number is determined in this experiment at various temperatures. **Findings:** It has been observed that in comparison to the distilled water, copper oxide nanofluids with baffles shows more heat transfer enhancement. The result showed that the Nusselt number increased by 8% without introducing baffles and nanofluids and 10-12% enhancement was observed with baffles and nanofluids. The enhancement of 22-25 % has been observed in the heat transfer coefficient at 0.1% volume concentration and 25-30 % of enhancement 0.2% volume concentration. **Applications:** In automobile radiators, cooling towers, air preheaters, refrigeration, air conditioning, condensers etc double pipe heat exchanger with baffles inserts can be easily implemented.

Keywords: Baffles, Copper Oxide Nanofluids, Double Pipe Heat Exchanger, Heat Transfer Coefficient, Nusselt Number

1. Introduction

In today's era everyone is concern about the energy consumption as the natural resources are vanishing day by day. Due to limitation of natural resources energy consumption enhances in industrial processes. Heat exchanger is the simplest and most effective device in chemical processes. To maximize the heat transfer rate, minimize the heat loss, increase energy, efforts are made such as by increasing area, turbulence, thermal conductivity, by changing flow geometry etc.

Double pipe heat exchanger is the most effective and efficient heat exchanger as the design is easy to service and requires low inventory. In recent researches, so many attempts has been made to improve the performance of double pipe heat exchanger such as change the material of heat exchanger device, modification of heat exchanger with inserting twisted tape in inner pipe but there has no research has been reported to improve the performance with using the baffles in annulus of double pipe heat exchanger[1] the first scientist who introduced the nanoparticles in 1993[2] in this experimentation the pressure drop and the heat transfer characteristics has been evaluated on the horizontal concentric tubes using the twisted wire brushes. The experiment was carried out having the counter flow arrangement. Hot and cold water is taken as the working fluid. Different parameters and pressure drop were studied in this experiment and the result showed that there was large effect on heat transfer enhancement approximately 10-15 % with the use of twisted wire inserts.[3] Experimental work has been carried out in laminar flow region on three different kinds of alumina nanoparticles used in concentric pipe and the improvement in heat transfer rate has been observed.[4] The heat transfer performance was studied with laminar flow arrangement in a vertical double pipe heat exchanger. Aqueous glycol

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fluid was used in a 50% solution with specific values of viscosity and density is dependent on temperature. The cold fluid flows through the annulus space and the mass flow rate of fluid, inlet temperature and the geometry of heat exchanger was kept constant. The result showed the enhancement of 15-20 % in the heat transfer rate.[5] The experimentation has been carried out by using aluminium oxide and copper oxide nanoparticles to study the enhancement in convective heat transfer coefficient and enhancement of convective heat transfer coefficient upto 49% observed[6] with TiO_2 –water nanofluids the enhacement in heat transfer coefficent was reported upto 11% in double pipe heat exchanger[7] experimentally studied the heat transfer coefficient of silver-water base nanofluids in laminar, transition and turbulent flow regions with 0.3%-0.9% volume concentration and the result showed upto 10-12 % enhacement in heat transfer coefficient.[8] In this research work comparasion between the result of smooth tube and two types of twisted tape by varying the flow rates was carried out and result shown that there is improvement in heat transfer with lower twist ratio of twisted tape as compared to the smooth tube because twisted tape gives the turbulance which directly increases the heat transfer.[9] The overall heat transfer characterstics of double pipe heat exchanger has been investigated in this experimental work. The result showed that the in counter flow arrangement inner side heat transfer coefficient is almost 1.5 times larger than that of outer side heat transfer co-efficient[10] with TiO_2- water base nanofluids in double pipe heat exchanger the effect of Reynolds number on Nusselt number was experimentally carried out and the results concluded that Nusselt number incresed with increase Reynolds number 8000- 51000 and particle concentration from 0.002%- 0.02%.[11]In this research work comparision between the alumina nanoparticles thermal conductivity to the transformer oil has been experimentally investigated and the results showed that alumina nanoparticles has higher thermal conductivity as compare to the transformer oil which is used as the base fluid[12] experimentally studied the heat transfer characterstics of alumina and titania in water at 3% volume concentration and the result showed that the heat transfer coefficient was 12% less than the base fluid at constant average velocity[13] under the laminar flow condition in copper tubes the heat transfer performance and the Nusselt number ehancement of Al_2O_3 water nanofluids was studied experimentally. The result showed that at 1.3% volume concentration the enhancement of 47% has been observed.[14] The work represented the effect of temperature on the thermophysical properties of alumina-water nanofluids at 0-0.5 % volume concentrations over a temperature range 25-75 ^{0}C. The results showed that on increasing the nanoparticles concentration density, thermal conductivity and viscosity increased while the specific heat capacity decreased.[15] numerically investigated the effect of flow rate and nanoparticles concentration on heat transfer fluid flow in triangular channel two phase models is used. At the inner wall a uniform heat flux is applied. The results showed that the heat transfer rate enhanced more by using of two phase model as compared to single phase model.[16] The works performed on multi tube copper – nickel with corrugated copper fins in a cross flow heat exchanger to evaluate the heat transfer characteristics with temperature range from 38^{0}C – 64^{0}C. The results showed that the rate of water and air heat transfer coefficient increases constantly on water and air side respectively.

2. Preparation of Nanofluids

For the preparation of nanofluids there are basically two main methods named as one step and two step methods. In this work, nanofluids were prepared by two step methods as it has more advantages on one step method. Two step methods can be use for the metallic as well as for the oxide nanoparticles. The required amount of nanoparticles was calculated with the help of equation (1):

$$\phi = \frac{\dfrac{m_{np}}{\rho_{np}}}{\dfrac{m_{np}}{\rho_{np}} + \dfrac{m_{bf}}{\rho_{bf}}} \tag{1}$$

The size of the nanoparticles was confirmed with the help of the transmission electron microscope (TEM). The average size of the nanoparticles is 20nm was recorded from the TEM test as shown in figure 1. Distribution of the nanoparticles was done with the help of the scanning electron microscope (SEM) as shown in figure 2. An XRD and EDX pattern was shown in figure 3 and figure 4 respectively. For the preparation of nanofluids, nanoparticles were mix thoroughly in the base fluid (distilled water) with the help of the magnetic stirrer. For each sample the stirring was done for about 60-70 minutes.

To reduce the agglomeration and the complete dispersion, the stirred nanofluids was kept under the vibrations for 150 minutes under the ultra sonic rays in the sonicator which increased the stability of the nanofluids. Nanofluids were prepared without using any surfactant. To ensure the stability of the prepared nanofluids, it was kept in a container for one day and there was no sedimentation found. Then the prepared nanofluids was use to conduct the experiment.

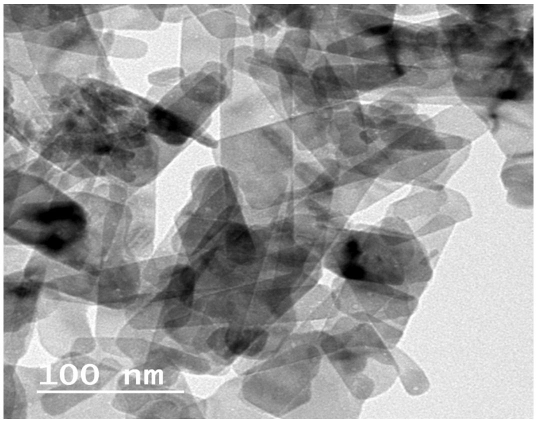

Figure 1. TEM photograph of CuO nanoparticles.

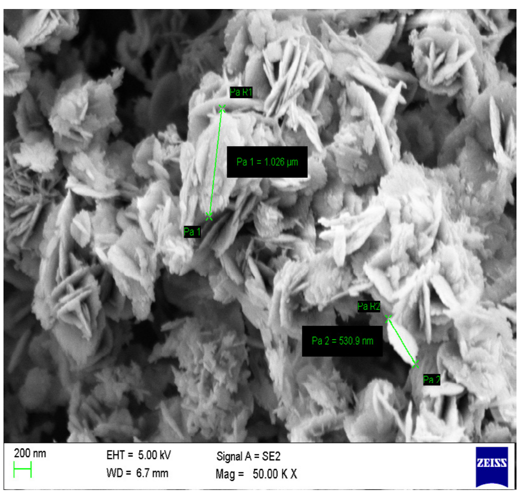

Figure 2. SEM photograph of CuO nanoparticles.

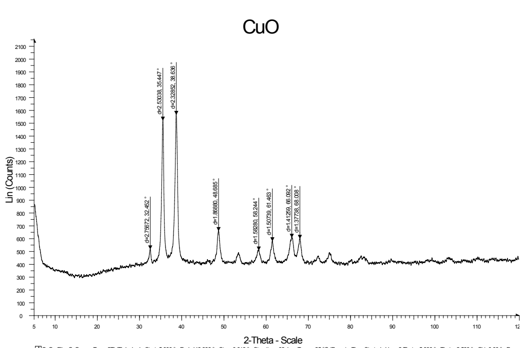

Figure 3. XRD photograph of CuO nanoparticles.

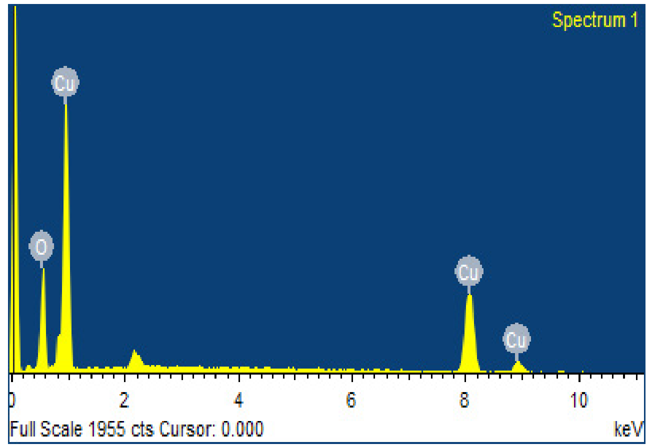

Figure 4. EDX photograph of CuO nanoparticles.

3. Experimental Set Up

The experimentation has been conducted on the test section as shown in figure 5 and figure 6 respectively. Experimental set up consists of two concentric pipes heat exchanger, two fluid tanks of 6 liters capacity each, to raise the temperature of the fluid a heater was installed in hot water tank, proportional derivative controller (PID) was installed to control the temperature of heater. To measure and calculate the pressure drop two U-tube manometers has been connected, the temperature of hot and cold fluid at the inlet and outlet of double pipe heat exchanger were measured with the help of four K-type thermocouples. To measure the surface temperature three K-type thermocouples has been installed on the inner surface of tube, to control the flow rate of water and nanofluids in pipe and annulus spacing two rotameters of range 0-5 lpm was used. To enhance the heat transfer performance modification is done at the outer surface of inner pipe by using

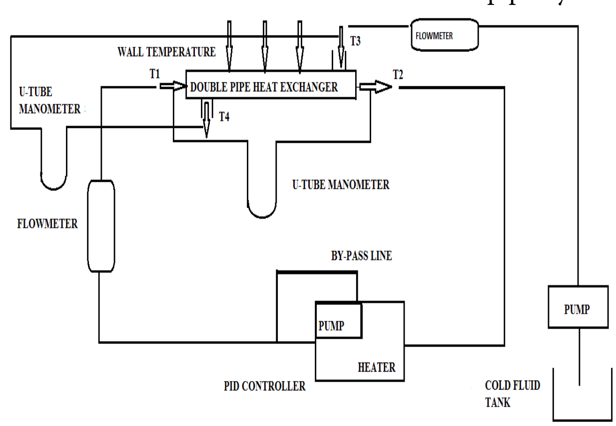

Figure 5. Schematic diagram of Experimental Setup.

baffles and introducing nanofluids, while conducting the experiment hot water flows in the inner pipe and nanofluids flows in the annulus spacing of the double pipe heat exchanger. The experimentation has been conducted with base fluid (water) and then with the nanofluids (working fluid) at 0.1% and 0.2% volume concentrations of copper oxide nanoparticles at the different ranges of hot water temperatures 30^0C, 40^0C, 50^0C and 60^0C.

Figure 6. Photographic view of the Experimental setup.

4. Data Analysis for the Nanofluids Thermophysical Properties

4.1 Nanofluids Thermophysical Properties

In this research, the nanofluids thermophysical properties like viscosity, density, thermal conductivity and were measured and calculated at 0.1% and 0.2% volume concentrations on various temperatures with the help of theoretical models.

Pak and Cho[12] equation was used to calculate the density theoretically:

$$\rho_{nf} = \varphi\rho_p + (1-\varphi)\rho_w \tag{2}$$

A density meter was used to measure the density of the nanofluids.

Wen and Ding[13] equation was used to measure the theoretically viscosity:

$$\mu = \mu_{bf}(1+2.5\varphi) \tag{3}$$

The viscosity was calculated by Brookfield viscometer.

Xuan and Roetzel[17] equation was used to evaluate the specific heat:

$$\rho Cp_{nf} = \varphi\left(\rho Cp)_p\right) + (1-\varphi)\,\rho(Cp)_w \tag{4}$$

The specific heat for nanofluids at 0.1% and 0.2% volume concentrations was measured by a differential scanning calorimeter (DSC).

Yu and Choi[18] equation was used to calculate the thermal conductivity at 0.1% and 0.2% volume concentrations:

$$k_{nf} = k_{bf}\left(\frac{k_s + (n-1)k_{bf} - \varnothing(n-1)(k_{bf}-k_p)}{k_s + (n-1)k_{bf} - \varnothing(k_{bf}-k_p)}\right) \tag{5}$$

The thermal conductivity of nanofluids was measured by KD2-Pro analyzer with accuracy 1.2%.

4.2 Data Processing

In this experimentation, data was evaluated with the help of following relations:

To obtain the Reynolds number following relation was used:

$$Re = \frac{\rho V D_h}{\mu} \tag{6}$$

Where, the hydraulic diameter was calculated by:

$$D_H = \frac{4A_0}{P} \tag{7}$$

To calculate the heat transfer rate following relations was used:

$$Q_h = m_h C_{ph}(T_{h,i} - T_{h,o}) \tag{8.a}$$

$$Q_c = m_c C_{pc}(T_{C,O} - T_{C,i}) \tag{8.b}$$

The overall heat transfer coefficient was calculated by using equation 9:

$$U = \frac{Q_{avg}}{A\Delta T_{LM}} \tag{9}$$

The average heat transfer rate was calculated by using equation 10:

$$Q_{avg} = \frac{Q_h + Q_{nf}}{2} \tag{10}$$

To measure the LMTD (logarithmic mean temperature difference) following equation was used:

$$\Delta T_{LMTD} = \frac{\left(T_{h,i} - T_{c,o}\right) - (T_{h,o} - T_{c.i})}{LN(\dfrac{T_{h,i} - T_{c,o}}{T_{h,o} - T_{c,i}})} \quad (11)$$

To calculate the heat transfer coefficient equation (12) has been used:

$$h = \frac{Q_{avg}}{A(T_b - T_w)} \quad (12)$$

The Nusselt number was calculated by the following relation:

$$Nu = \frac{hD_H}{k} \quad (13)$$

5. Results

The experimentally investigated results on copper oxide water base nanofluids and the nanoparticles volume concentration was taken at 0.1% and 0.2% volume concentrations by inserting baffles and the results has been evaluated in this section.

The results clearly showed that as the temperature of the nanoparticles concentration increases the thermal conductivity also increases. At 0.2% volume concentration maximum enhancement was observed. The variation in temperature with nanoparticles concentration on thermal conductivity ratio was shown in figure 7.

It has been also observed that as the nanoparticles concentration increases the density also increases and decreases with the rise in temperature, the variation of nanoparticles concentrations with temperature on the density ratio was observed in figure 8. Maximum decrement was shown at 60^0C operating temperature.

The result showed that viscosity increases as the nanoparticles concentration increases with the rise in temperature. The variation of viscosity ratio was shown in figure 9. The results showed that the enhancement at 0.2% volume concentration was found maximum at 60^0C operating temperature.

5.1 Variation of Nusselt number on Reynolds number without baffle insertion at 60^0C of operating temperature

The results showed the variation of Nusselt number on Reynolds number of CuO – water base nanofluids at 0.1% and 0.2% volume concentration to the distilled water was

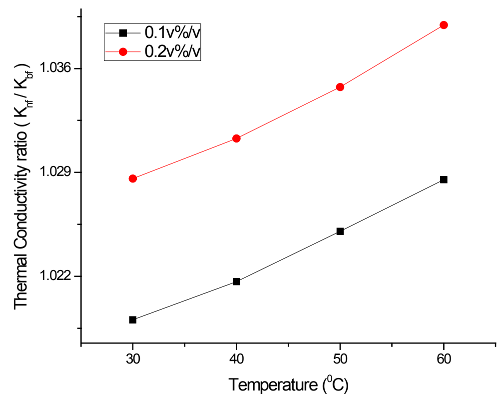

Figure 7. Variation of thermal conductivity ratio with temperature.

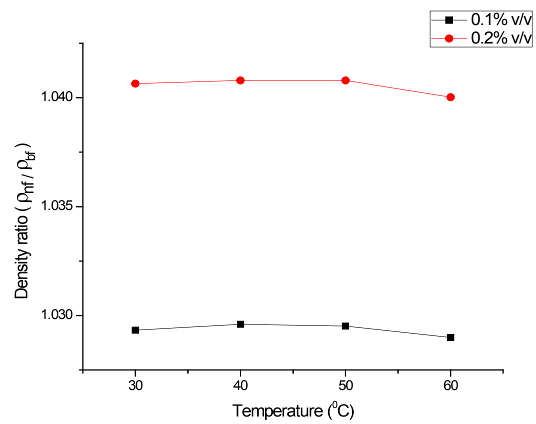

Figure 8. Variation of density ratio with temperature.

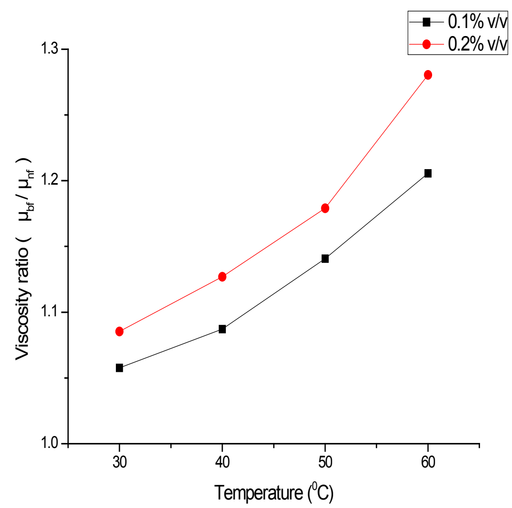

Figure 9. Effect of temperature on viscosity ratio.

shown in figure 10. Reynolds number specific range was maintained from 1000-12000. Maximum enhancement was observed 8% at 0.2% volume concentration.

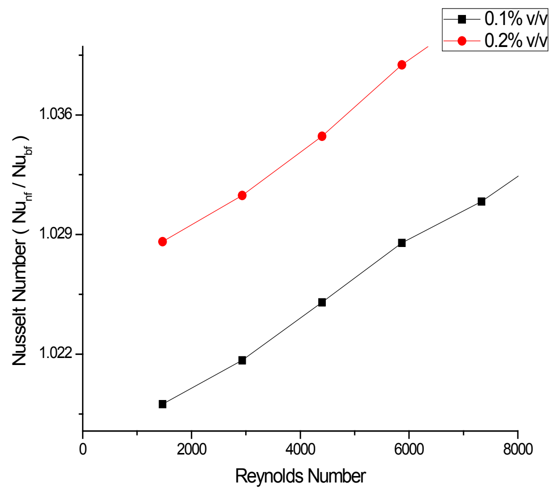

Figure 10. Effect of Nusselt number on Reynolds number on ratio without inserting baffles.

5.2 Variation of Nusselt number with Reynolds number and Baffle Insertion at 60°C of Operating Temperature

Total enhancement of 10-12 % has been observed in the Nusselt number after inserting the baffles in the parallel flow concentric tube type heat exchanger at 0.2% volume concentration as shown in figure 11.

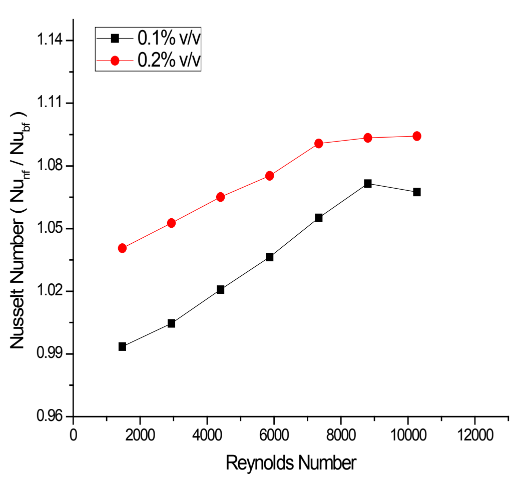

Figure 11. Effect of Nusselt number on Reynolds number ratio with inserting baffles.

5.3 Heat Transfer Coefficient Variation with different Reynolds number without Baffle Insertion at 60°C

The results showed that as the CuO nanoparticles concentration increases the heat transfer coefficient also increases with the Reynolds number. The result was shown in figure 12 at 0.1% and 0.2% volume concentration respectively and the enhancement of 22-25 % has been observed without inserting the baffles.

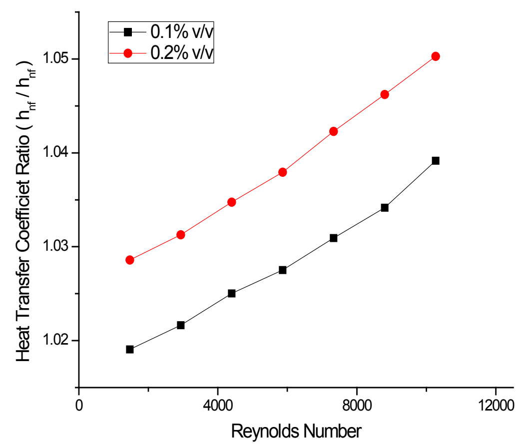

Figure 12. Effect of heat transfer coefficient ratio on Reynolds number without inserting baffles.

5.4 Variation of Heat Transfer Coefficient at different Reynolds number with Baffle Insertion at 60°C

The results showed that as Reynolds number increases the heat transfer coefficient also increases after the insertion of baffles at 60°C and it was found that it is highest for nanofluids at 0.2% volume concentration. Total enhancement of 25-30% approx has been found out in case of nanofluids is shown in figure 13.

6. Conclusion

The present study has been conducted on copper oxide water nanofluids. The main concern of experiment was to evaluate the nanoparticles concentration effect on the Nusselt number and on the heat transfer characteristics with or without inserting baffles. After studied the results it was concluded that the Nusselt number and the heat transfer characteristics increased after inserting the

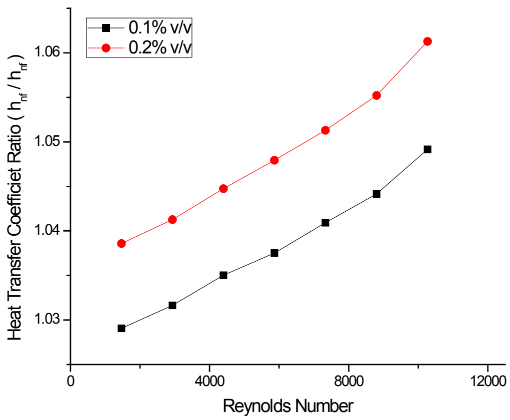

Figure 13. Effect of heat transfer coefficient ratio on Reynolds number with inserting baffles.

baffles. Without inserting the baffles the Nusselt number increased by 8% at 0.2% volume concentration, after inserting baffles the enhancement of 10-12 % has been observed. At 0.1% volume concentration without inserting the baffles enhancement in heat transfer coefficient of 22-25 % has been observed. The enhancement of 25-30 % at 0.2 volume concentrations was observed in the heat transfer coefficient after inserting the baffles.

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