CPDLR

CFD Analysis Of Heat Transfer Enhancement Using Al_2O_3-Water Nanofluid In Flat Tube Of A Car Radiator

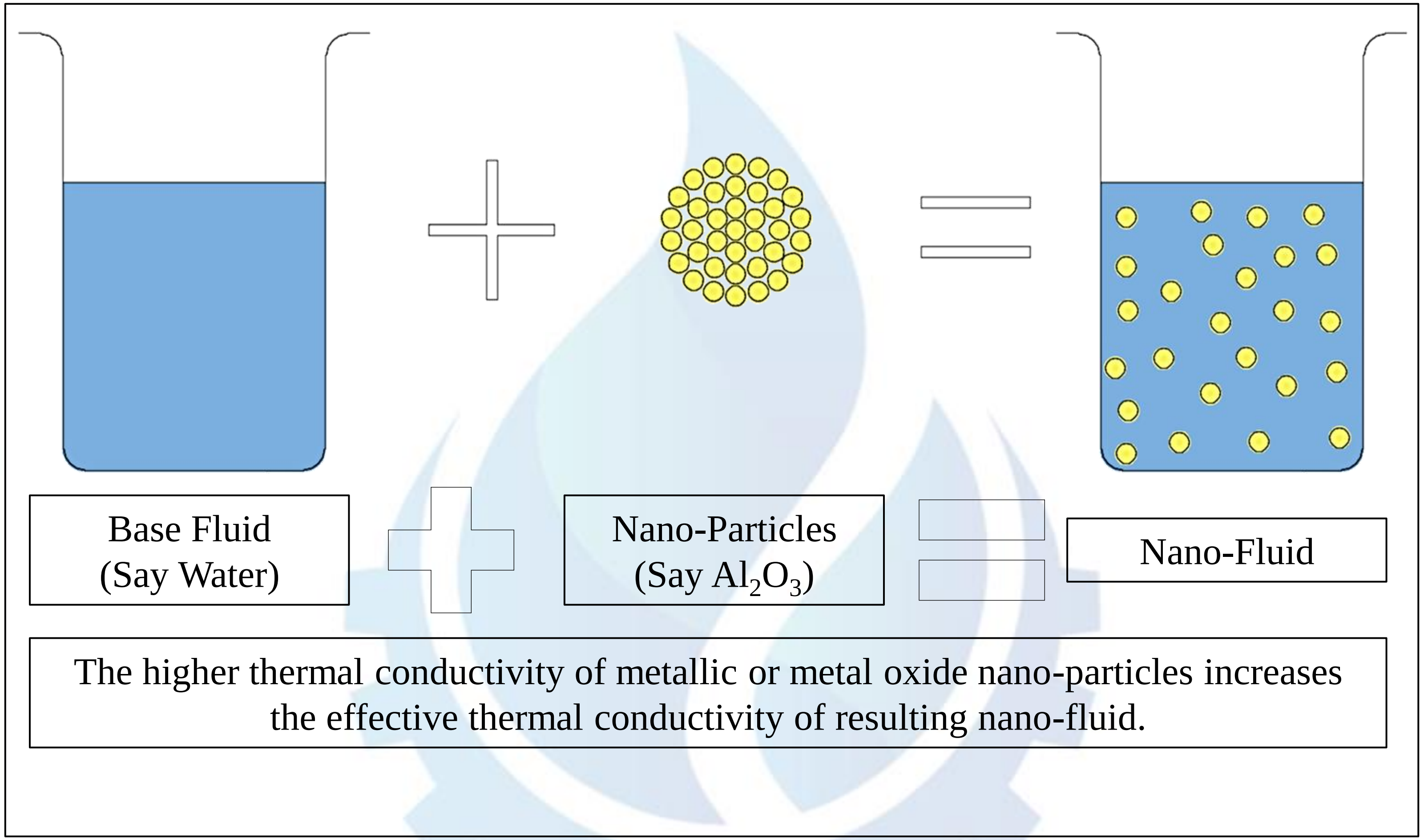
Objective Of The Case Study

- The primary objective of this case study is to analyze the effect of using nano-particles in water (base-fluid) on heat transfer.

- To model nano-particles in water in ANSYS Fluent, both the single phase as well as multiphase approach was used in this study and a comparison was made at the end.

What is Nano-fluid?

- Metal or metal oxides particles of size typically less than 100nm when suspended in a base fluid such as water forms nano-fluid.



- ✓ Conventional heat transfer fluids such as water have low thermal conductivity.
- ✓ Metal or metal oxide nano-particles suspended in water helps to increase the effective thermal conductivity and therefore heat transfer rate.

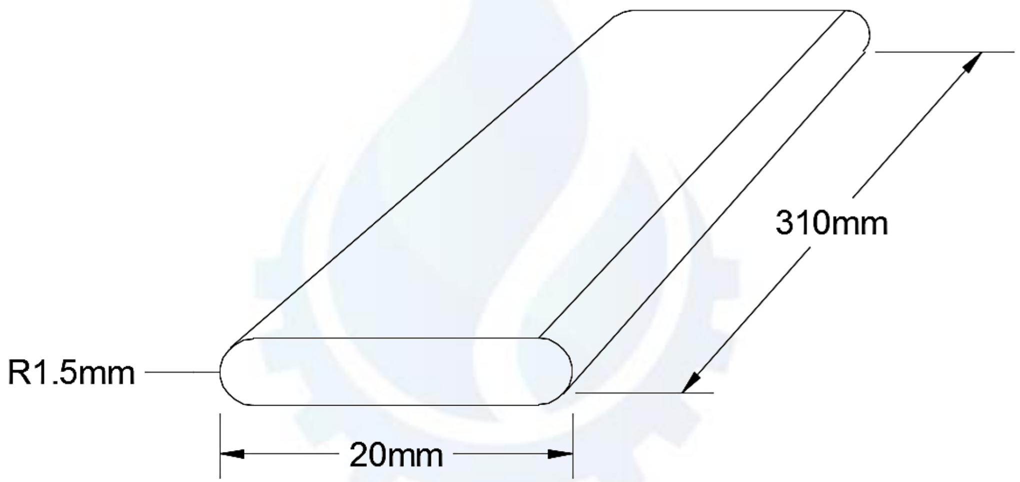
Geometry Details

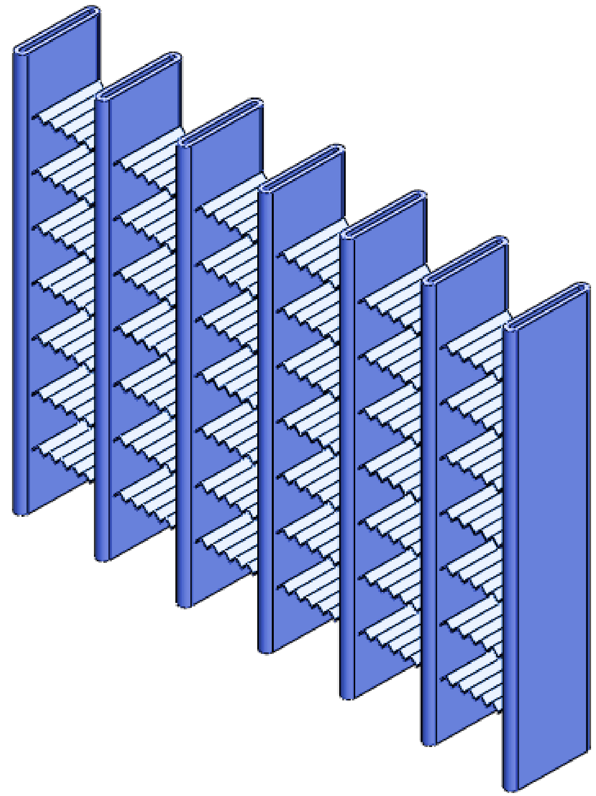
- The car radiator consists of multiple vertical flat tubes with fins attached between them.
- Single flat tube of length 310mm is taken for the CFD analysis.
- The other dimensions are shown below in the picture.

- As the fins were not modeled in the geometry taken for the CFD analysis therefore the heat transfer coefficient of the surrounding air was applied on the outer walls to simulate the heat transfer loss from the walls to the surrounding.

- Heat transfer coefficient of 150W/m^2k was applied at the external walls with surrounding temperature of 303K.

CFD analysis were performed on a single flat tube (below) of the car radiator (on right) to see the effect on heat transfer.



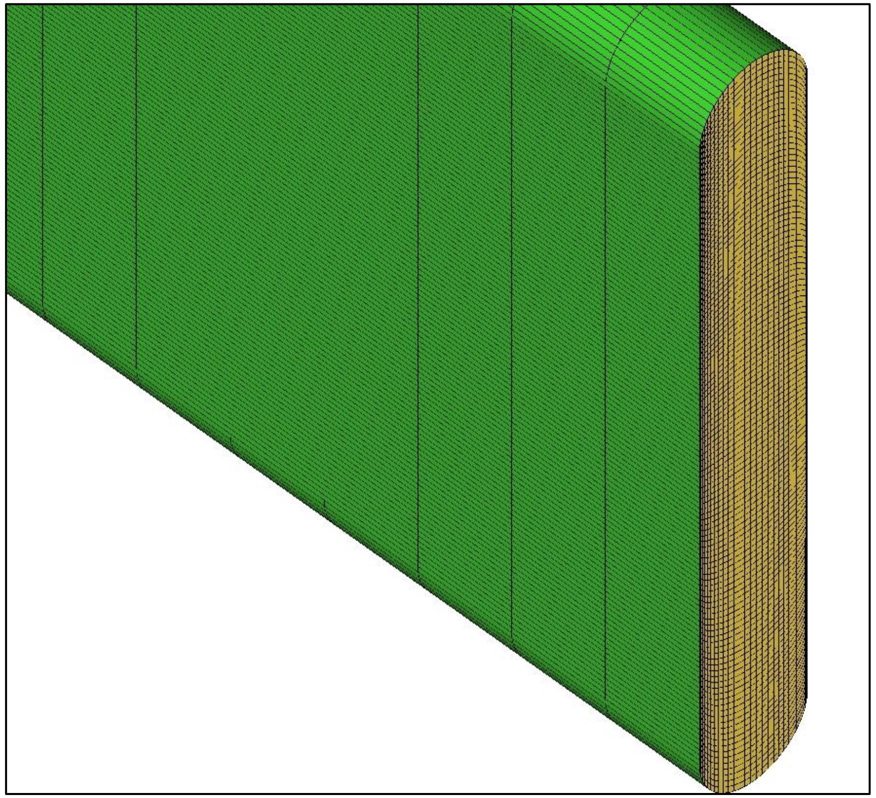


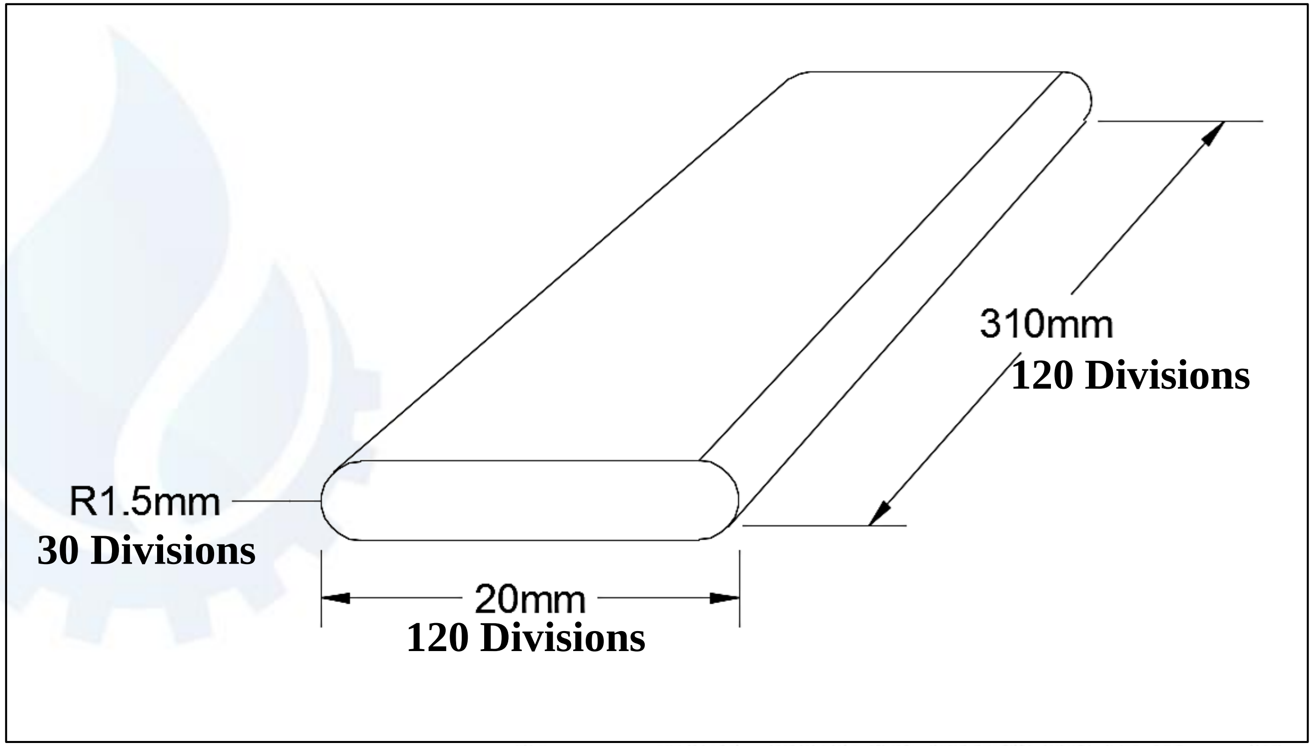
Car Radiator

Mesh Details

- Structured mesh was generated on the flow domain in ANSYS ICEM.
- 120 number of divisions were used to discretize the flow domain along the length and width of the tube.
- 30 number of divisions were used along the height of the tube.
- Y plus was maintained below 5 as the boundary layer was resolved up to laminar viscous sub-layer.

Number Of Nodes	453276	Number Of Elements	432000	Y Plus	<5



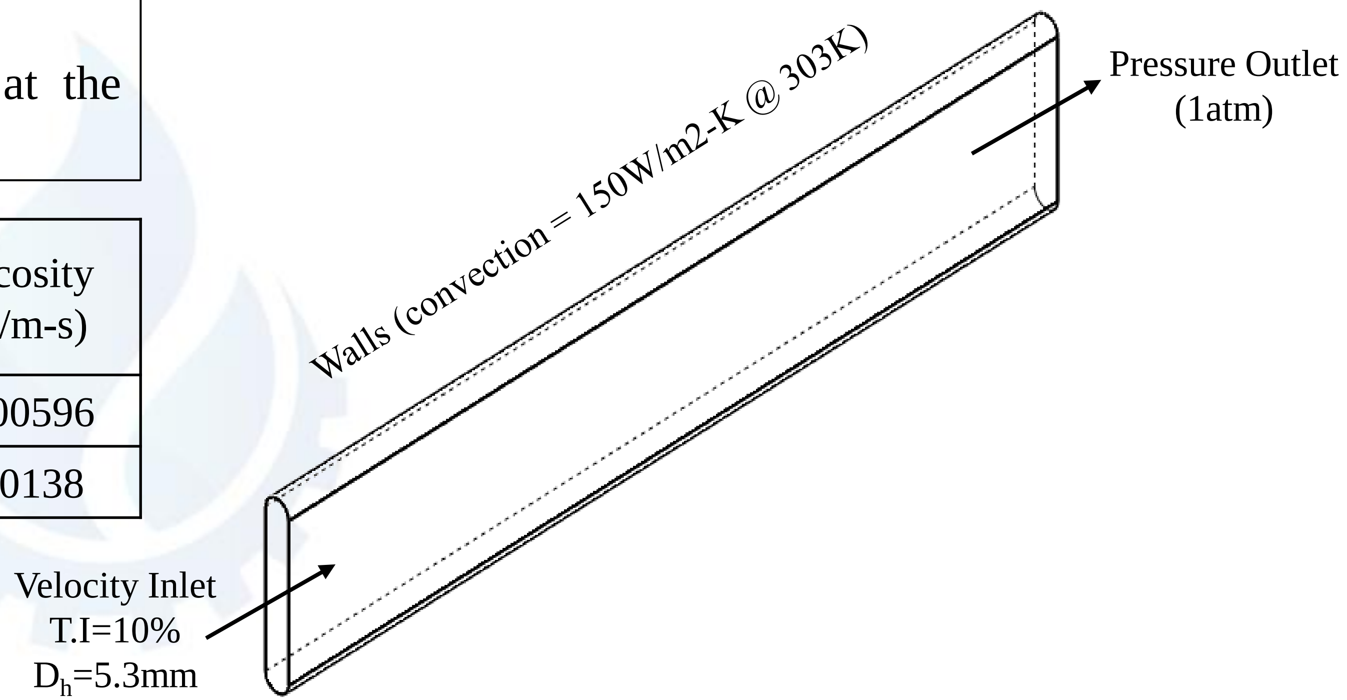


Case Setup

- Standard k-epsilon turbulence model was used with enhanced wall treatment.
- Energy equation was used for modeling heat flow.
- Second order upwind for discretization of all the equations and SIMPLE algorithm was used for the Pressure-Velocity coupling.
- Residuals for all the equations were taken below 10e-06.

- Velocity inlet (turbulence intensity of 10% and hydraulic diameter of 5.3mm) & Pressure outlet combination was used.
- Convective heat transfer coefficient of 150W/m^{2}k at the walls and the air temperature of 303k.

Fluid/Properties	Density (kg/m3)	Conductivity (W/m-k)	Specific Heat (j/kg-k)	Viscosity (kg/m-s)
Pure Water	990.2	0.638	4066	0.000596
Al_2O_3	4000	40	779	0.00138



Effective Properties Of Nano-Fluids For Single Phase Approach

- At low concentration of the nanoparticles, it can be assumed that nanofluid will behave like a single-phase fluid.
- For such single phase behavior, the effective properties of the nanofluid are considered from correlations.
- Nanofluid properties depends on the volume fraction of the nano-particles as well as on the corresponding properties of the base fluid.

$$Density \quad \rho_{nf} = \varphi\rho_{np} + (1-\varphi)\rho_{bf}$$

Fluid/Properties	Density	Conductivity	Specific Heat	Viscosity
Water & Al_2O_3 (1.0%)	1020.3	0.6564	3937.608	0.0011

$$Specific\ Heat \quad C_{pnf} = \frac{\varphi\rho_{np}C_{pnp} + (1-\varphi)\rho_{bf}C_{pbf}}{\rho_{nf}}$$

Properties of nano-fluid calculated using the given correlations for 1% concentration of nano-particles.

$$Thermal\ Conductivity \quad k_{nf} = \frac{k_{np} + (\emptyset - 1)k_{bf} - \varphi(\emptyset - 1)(k_{bf} - k_{np})}{k_{np} + (\emptyset - 1)k_{bf} + \varphi(k_{bf} - k_{np})} k_{bf}$$

$$Viscosity \quad \mu_{nf} = \mu_{bf} + \frac{\rho_{np}V_B d^2{}_{np}}{72C\delta} \qquad V_B = \frac{1}{d_{np}}\sqrt[3]{\frac{18K_bT}{\pi\rho_{np}d_{np}}} \qquad \delta = \sqrt[3]{\frac{\pi}{6\varphi}}d_p \qquad C = \frac{a\varphi + b}{\mu_{bf}}$$

$$K_b = 1.38 \times 10^{-23} \qquad a = -0.00004 \quad b = 7.13 \times 10^{-7}$$

Validation Of Two Phase Approach

- ❑ For the validation purpose of two phase approach, pure water with zero percent concentration of nano-particle was simulated using multiphase mixture model.

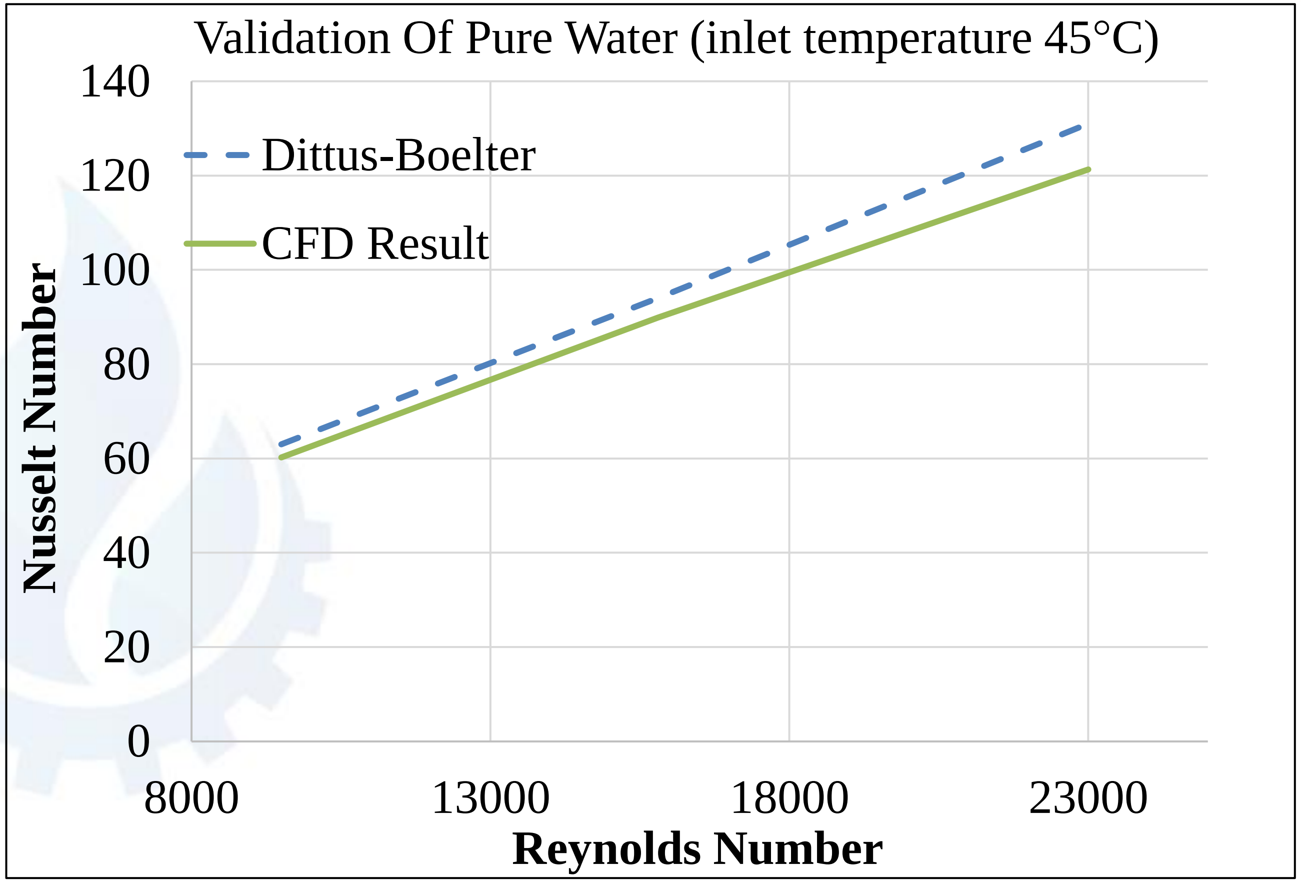
- ❑ The CFD results were compared with the correlation given by Dittus-Boelter for validation.

Dittus-Boelter Correlation:-

$$Nu = 0.023Re^{0.8}Pr^{0.3}$$

- ✓ The CFD results are in good agreement with the correlation given by Dittus-Boelter.

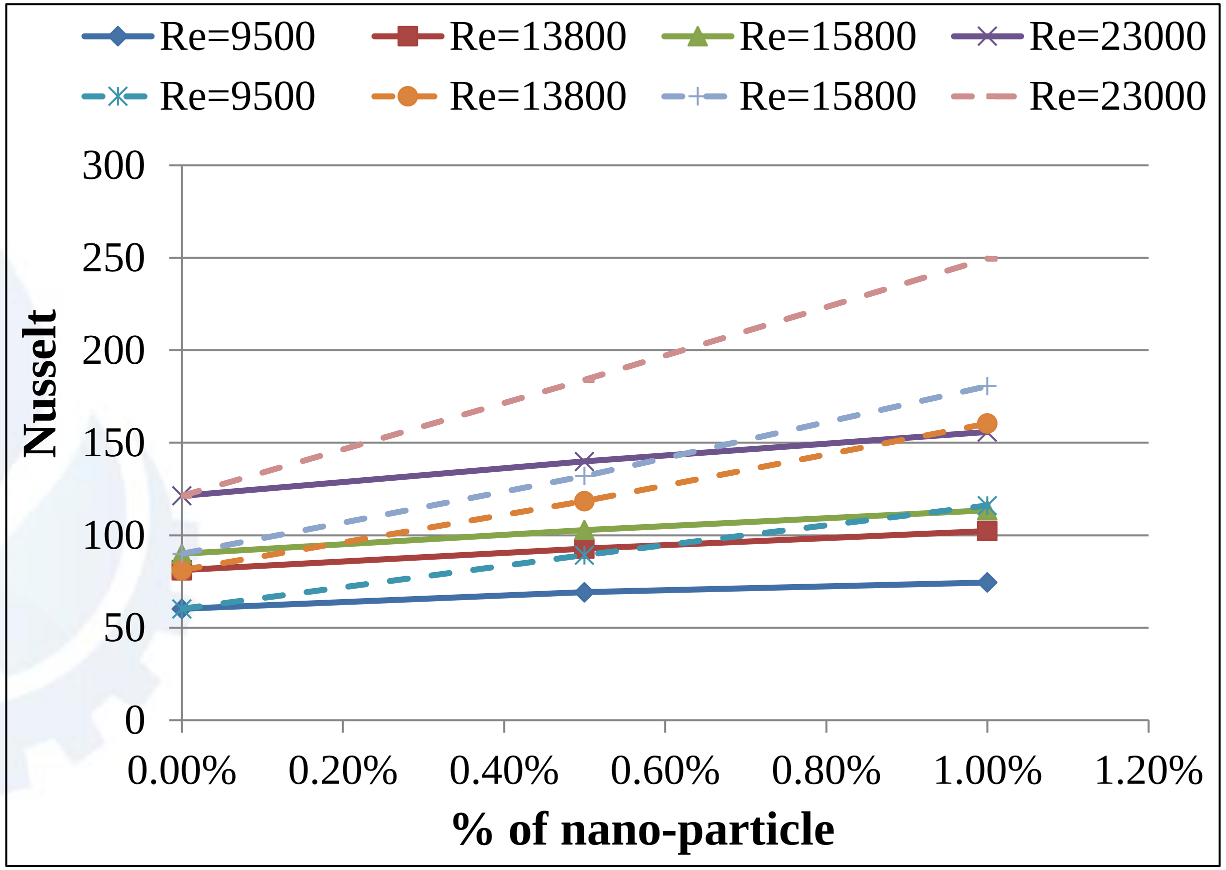
- ✓ The % error was found to be less than 6%, therefore single-phase approach was used for further studies.



Results & Discussions (In Terms Of Heat Transfer)

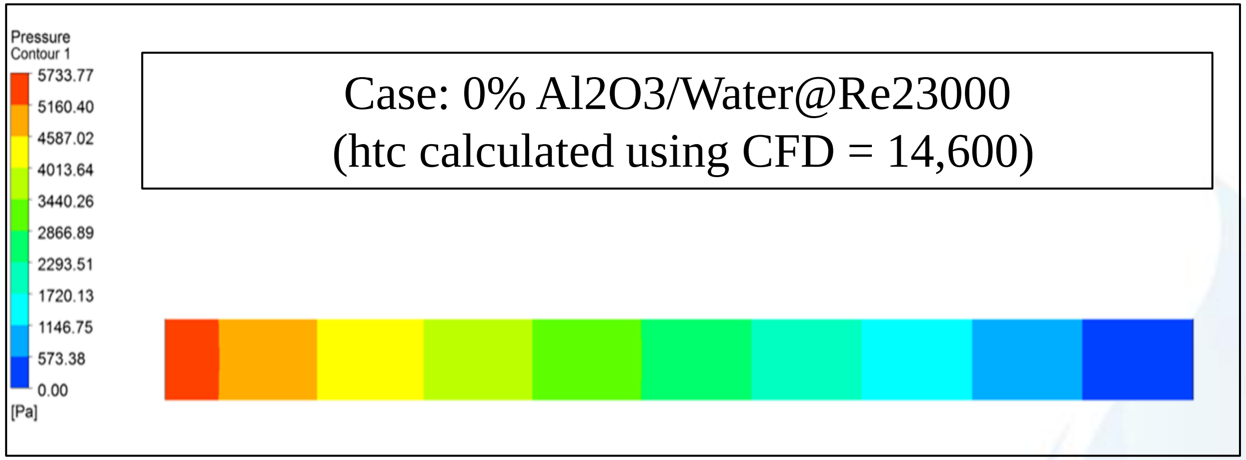
- The table below shows the Nusselt number for the single-phase & two-phase approaches at same Reynolds number.
- In the chart, it can seen that the Nusselt number increases uniformly as the concentration and Reynolds number are increases.
- It was found that the numerical results of the two-phase approach were 33%-60% greater than that of single phase as claimed in the previous researches.

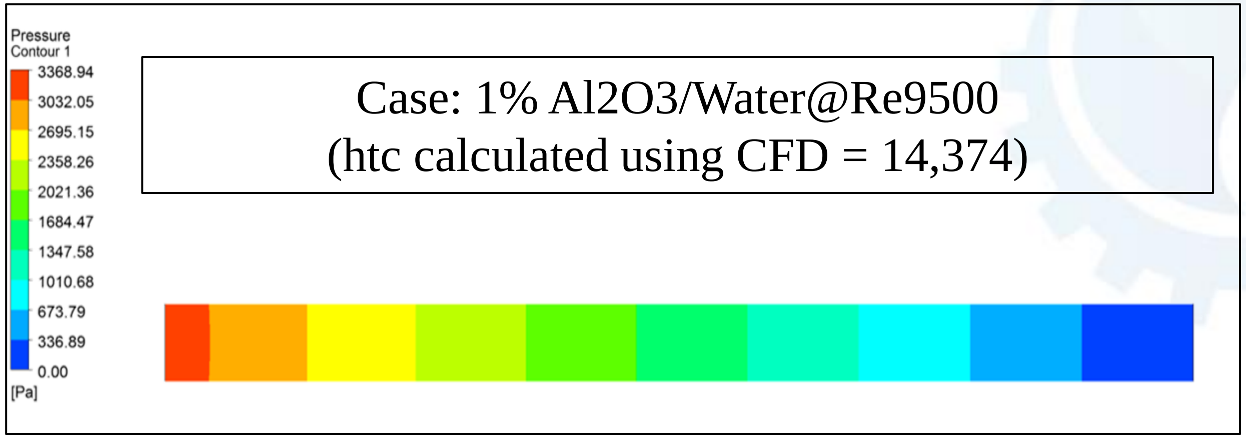
	Reynolds Number	0%	0.50%	1%
		Nusselt		
Single Phase Approach	23,000	121.28	139.93	155.82
	15,800	89.93	102.83	113.52
	13,800	81.13	92.77	102.32
	9,500	60.2	69.16	74.45
Two Phase Approach	23,000	121.28	184.04	249.52
	15,800	89.93	132.05	180.67
	13,800	81.13	118.5	160.41
	9,500	60.2	89.21	116.06



Results & Discussions (In Terms Of Pumping Power)

- The pumping power required by 1% nano-fluid at Re9500 is 56.12% lower than that of pure water at Re23000 for same heat transfer rate.
- This shows that nano-fluids requires less pumping power at lower Reynolds to produce same level of heat transfer rate.
- The pressure contour is shown for the comparison of the two cases delivering same heat transfer rate at completely different pumping power.





Type Of Nano-fluid	Al2O3/Water		
Concentration (%)	0	0.5	1.0
h(W/m2-k)	14600	14470.31	14374.2
Reynolds,Re	23000	13800	9500
Density (kg/m3)	990.2	1005.25	1020.3
Viscosity (kg/m-s)	0.000596	0.000839	0.0011
Velocity (m/s)	2.612	2.173	1.932
Skin Friction, C_f	0.0072	0.0078	0.00802
Pressure Loss, Pa	5708.8	4383	3446.18
Power (W)	29.4	18.8	12.9
%Power Reduction	-	36.05	56.12

Conclusion

- In the present case study, the nanofluid in flat tube of car radiator was simulated using ANSYS Fluent software in steady state mode.
- It was found that the heat transfer rate predicted using two phase approach is higher than that of single phase approach as claimed in the previous researches.
- The heat transfer rate increases with increases in concentration of nano-particles in water as well as with Reynolds number.
- The nanofluid at lower Reynolds provides better heat transfer performance at lower pumping cost.