Enhancement of the Performance of Thermal Control Systems Using Nanofluids

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Presented By
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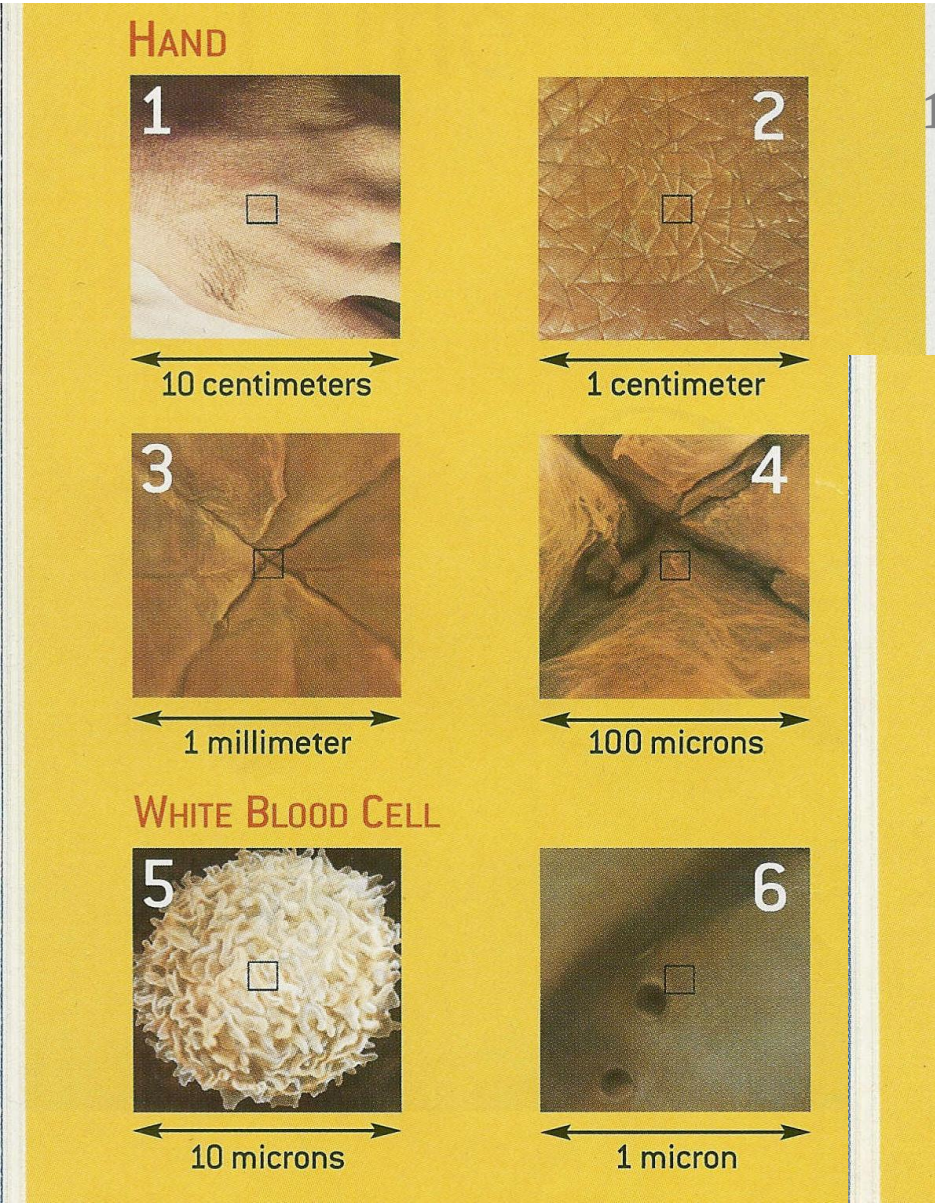
Topics of Discussion

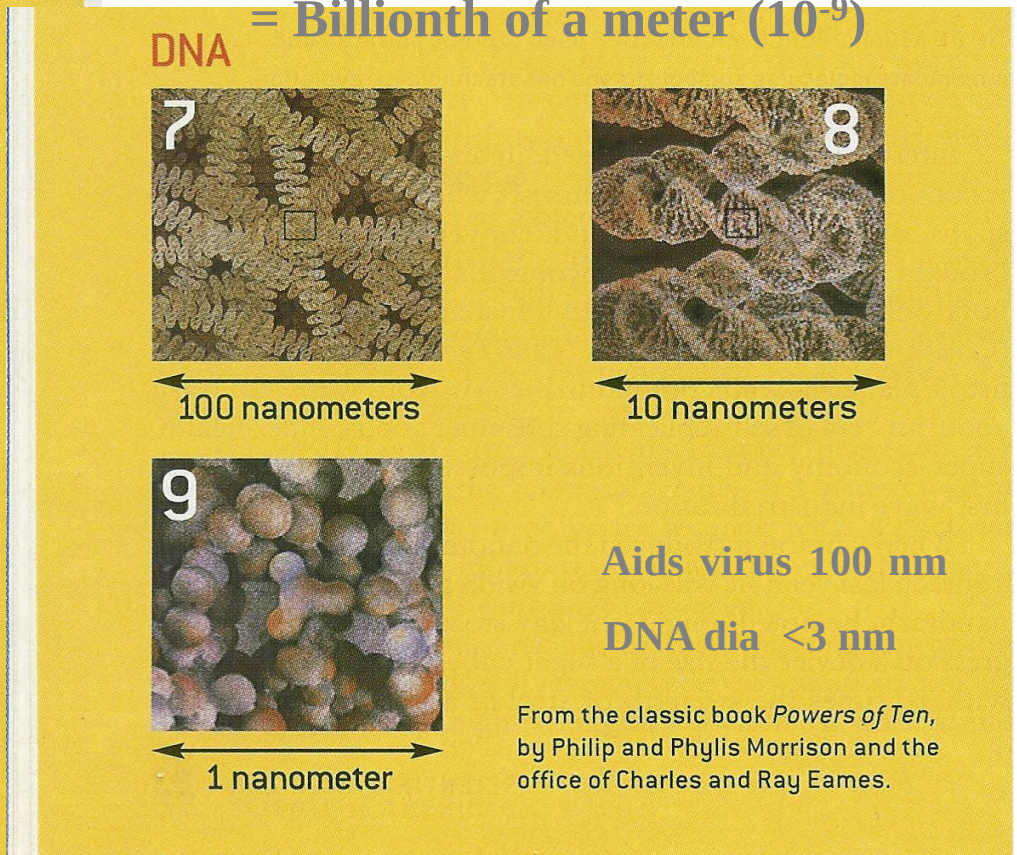
- Nanoscale Objects
- Advantages of Nanofluid
- Rheology of Nanofluids
- Effect on the Prandtl Number
- Heat Transfer and Fluid Dynamic Performance of SiO_2 , CuO and Al_2O_3 nanofluids
- Performance Comparison of Nanofluids in Heat Exchangers
- Acknowledgements

Nanoscale Objects

Miniaturization : Richard Feynman, 1959
micromachine

1 Micron=millionth of 1 m, Red Blood Cell
100 Micron=Human Hair
1 Nanometer=Millionth of a pinhead
=10 H_2 Atoms = Dia. of water molecule
= Billionth of a meter (10^{-9})





Aids virus 100 nm

DNA dia <3 nm

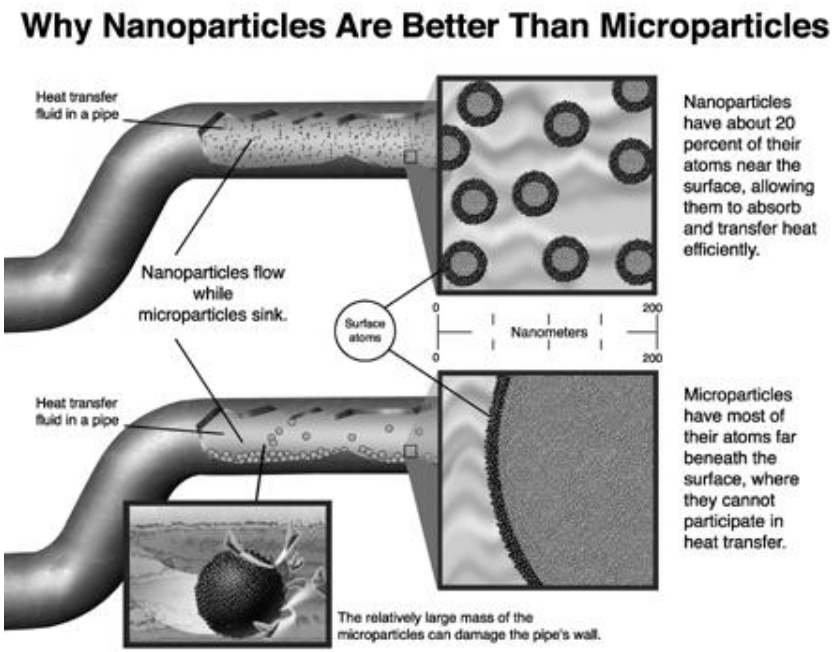
What is Nanofluid?

- The concept was proposed by Choi, U.S., Argonne National Lab, 1999
- Dispersion of metallic nanometer sized particles (<100nm) in liquid

Significance of Nanoparticles

•Microparticles settle at the bottom due to gravity, leading to clogging and wear

•Nanoparticles are permanently suspended by Brownian motion and when there is no flow they are distributed in balance between buoyant weight and thermal agitation.

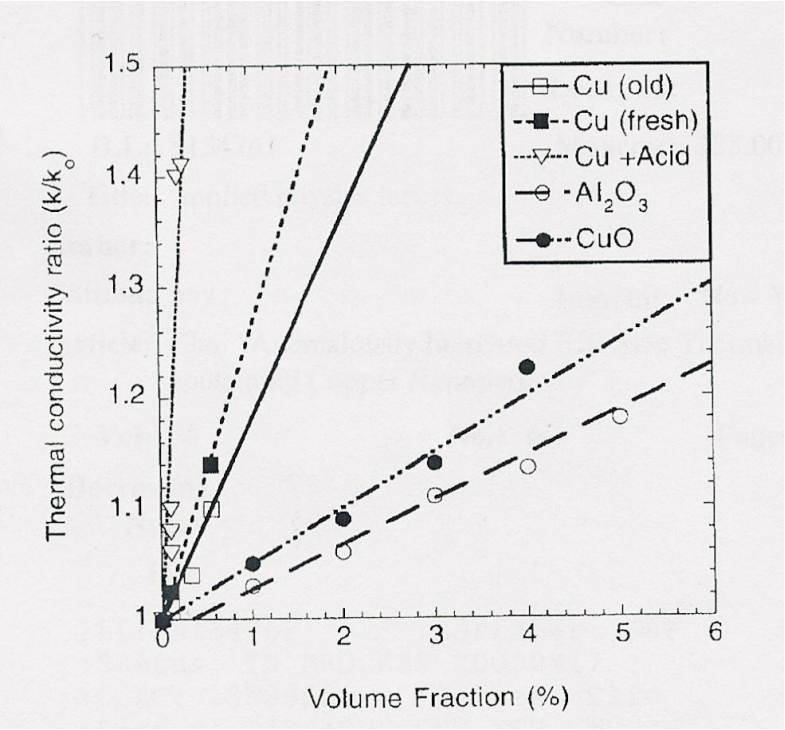


Source: Boutin, C., 2001

Advantages of Nanofluid

Dramatic Increase in thermal conductivity of base liquid

Material	Thermal conductivity (W/mK)	Material	Thermal Conductivity (W/mK)
Nonmetallic Liquid		Metallic Solids	
Water	0.613	Silver	429
Engine Oil	0.145	Copper	401
Ethylene Glycol	0.253	Aluminum	237



Source: Eastman, 2001

Hamilton & Crosser's Equation for Thermal Conductivity of Nanofluid

$$k_{nf} = k_f \left[\frac{k_p + (n-1)k_f - (n-1)\phi(k_f - k_p)}{k_p + (n-1)k_f + \phi(k_f - k_p)} \right]$$

Source: Hamilton & Crosser, 1962

Theory of Nanofluid

Nusselt Number $$Nu_{nf} = c_1(1.0 + c_2\phi^{m_1} Pe_d^{m_2})\,\mathrm{Re}_{nf}^{m_3}\,\mathrm{Pr}_{nf}^{0.4}$$

Particle Peclet Number $$Pe_d = \frac{u_m d_p}{\alpha_{nf}}$$

Laminar Flow $$Nu_{nf} = 0.4328(1.0 + 11.285\phi^{0.754} Pe_d^{0.218})\,\mathrm{Re}_{nf}^{0.333}\,\mathrm{Pr}_{nf}^{0.4}$$

Turbulent Flow $$Nu_{nf} = 0.0059(1.0 + 7.6286\phi^{0.6886} Pe_d^{0.001})\,\mathrm{Re}_{nf}^{0.9238}\,\mathrm{Pr}_{nf}^{0.4}$$

Heat Transfer Coefficient $$h_{nf} = (Nu_{nf} k_{nf}) / D$$

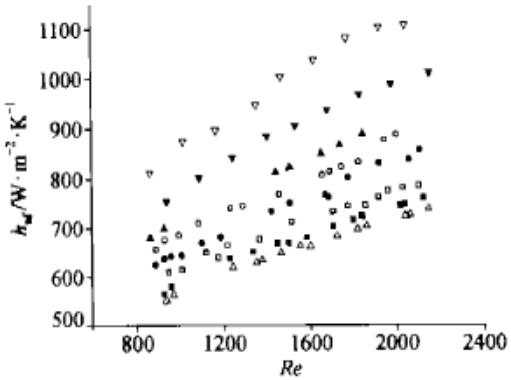


Fig. 3. The convective heat transfer coefficient of nanofluids for the laminar flow. △, Water (experimental values); ■, 0.3 vol%; □, 0.5 vol%; ●, 0.8 vol%; ○, 1.0 vol%; ▲, 1.2 vol%; ▼, 1.5 vol%; ▽, 2.0 vol%.

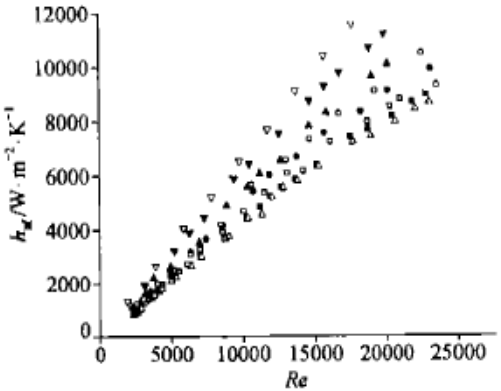
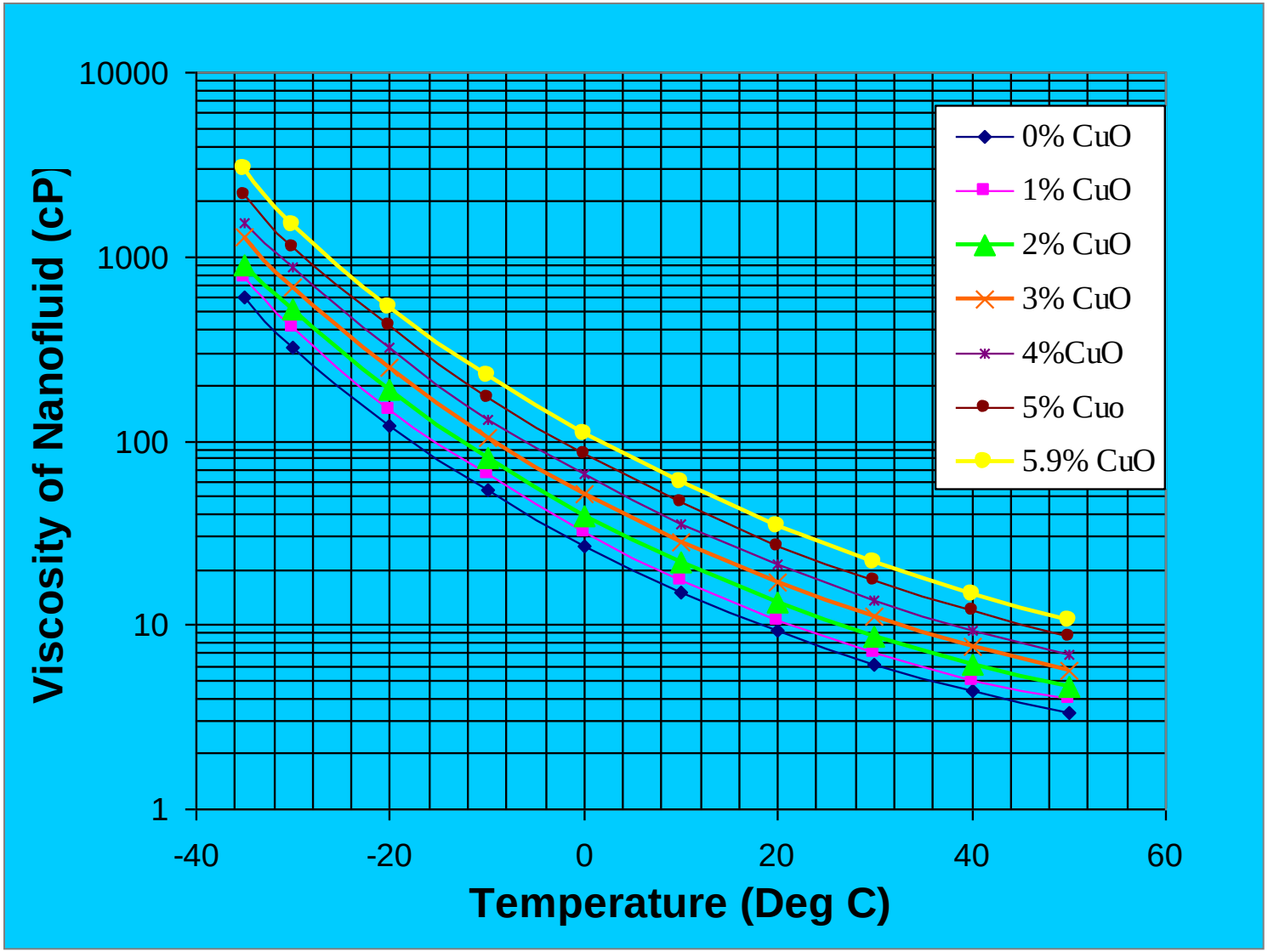


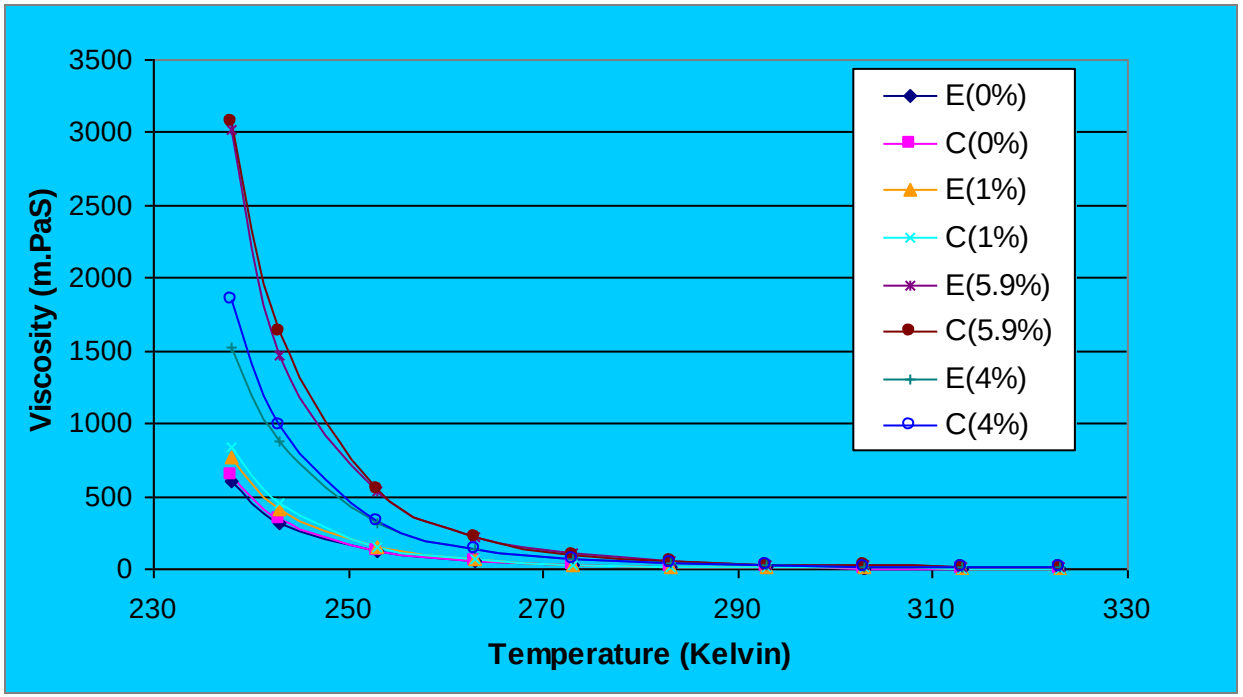
Fig. 4. The convective heat transfer coefficient of nanofluids for the turbulent flow. △, Water (experimental values); ■, 0.3 vol%; □, 0.5 vol%; ●, 0.8 vol%; ○, 1.0 vol%;, 1.2 vol%; ▼, 1.5 vol%; ▽, 2.0 vol%.

Source: Li and Xuan, 2002

Viscosity Vs Temperature



Viscosity of Nanofluid (CuO-PG/Water)

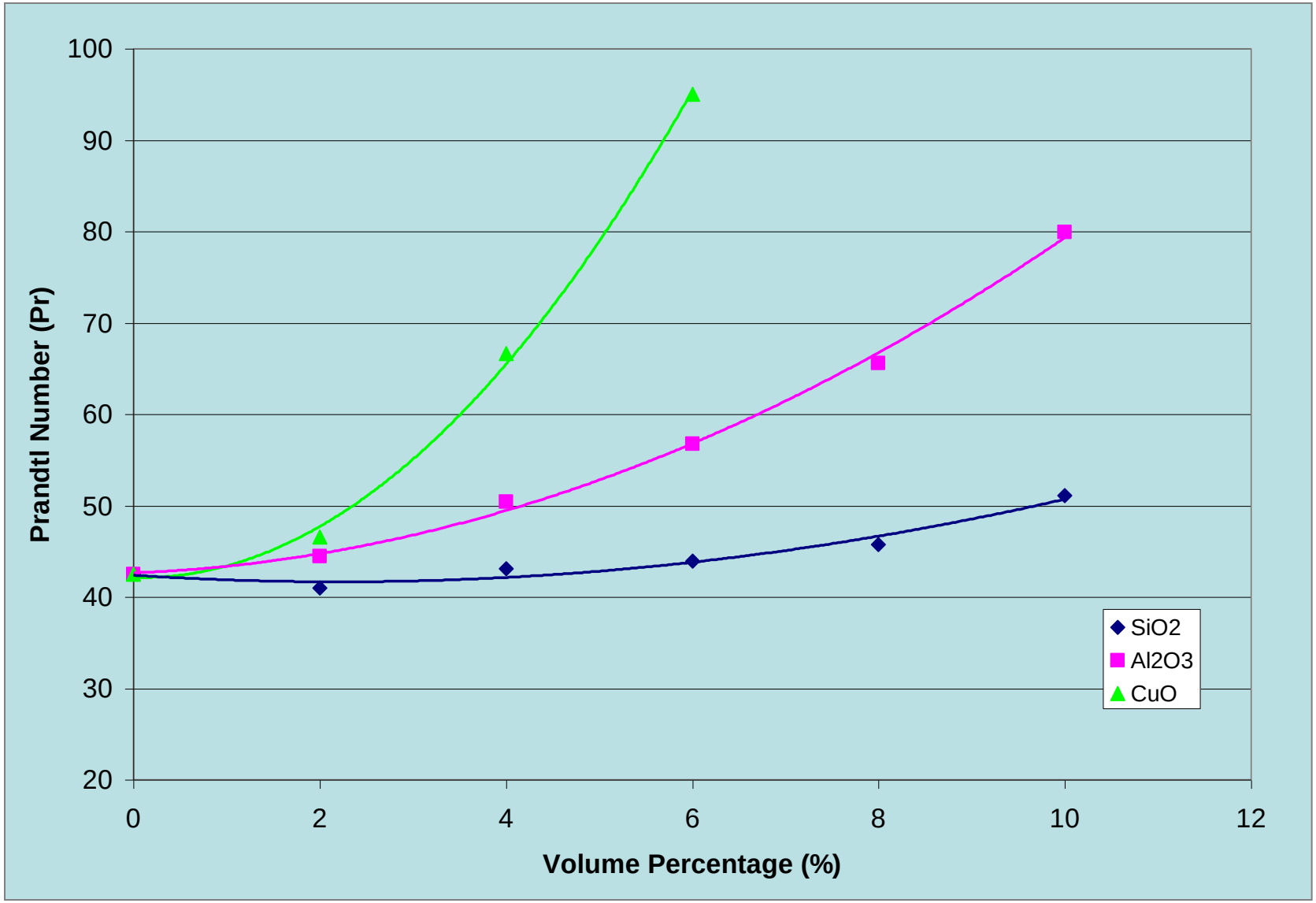


$$\mu_s = Ae^{B\phi} \qquad \ln(A) = 736.9e^{-0.0199T}$$ with $R^2 = 0.99$

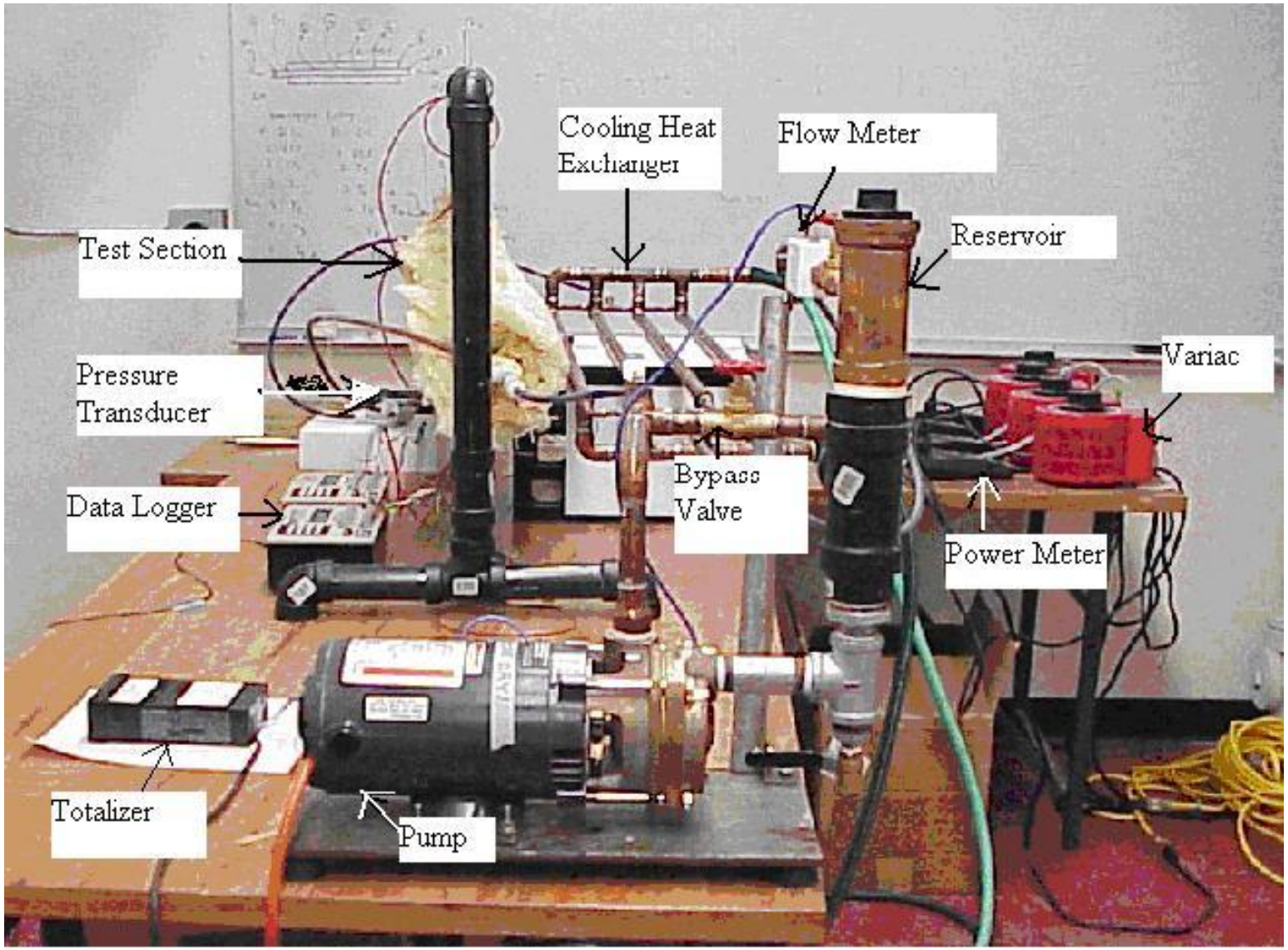
$$B = 44.794 - 0.0765T$$ with $R^2 = 0.98$

T is temperature in Kelvin and ϕ ranging from 0 to 0.06

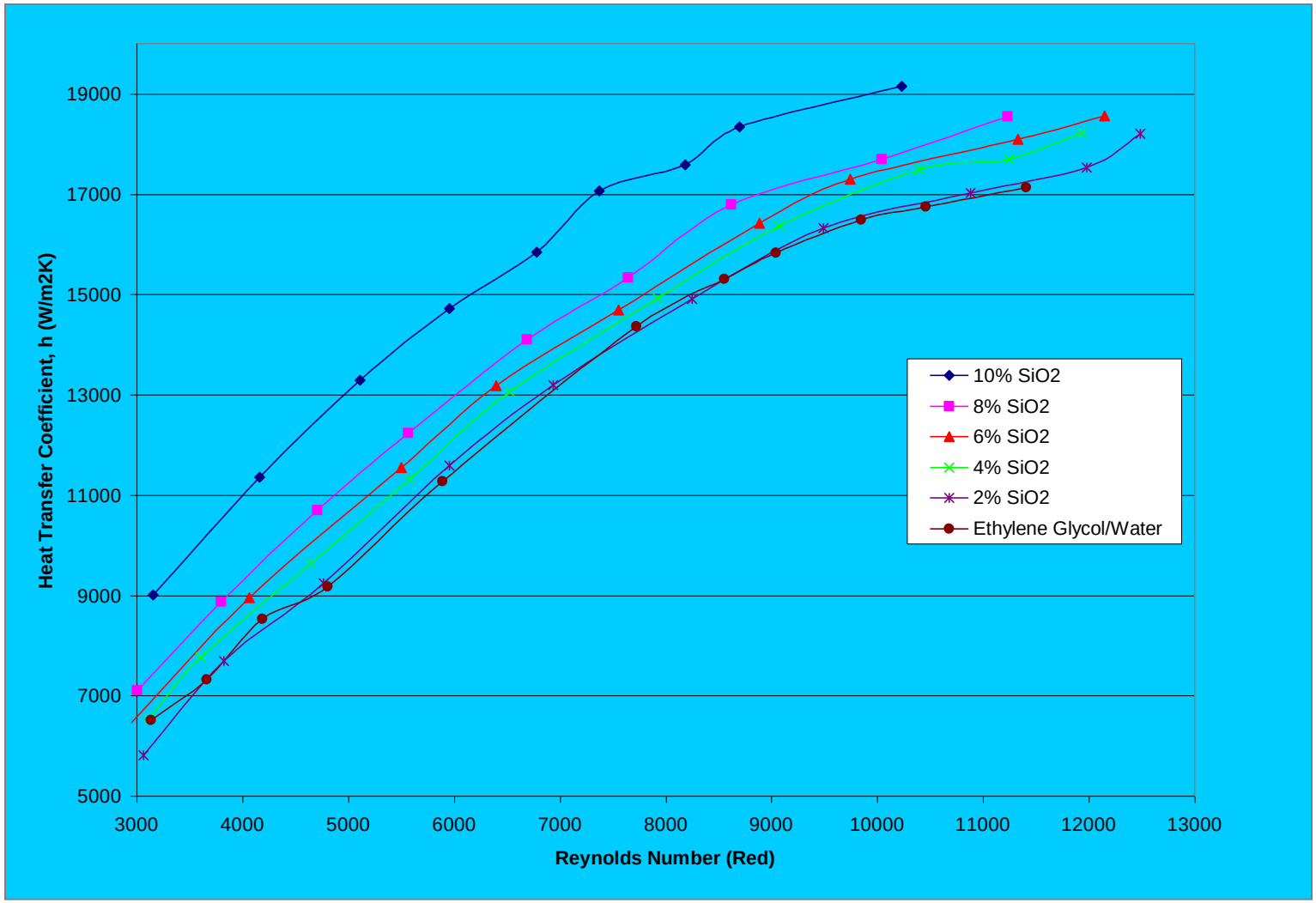
Prandtl Number Vs Particle Loading



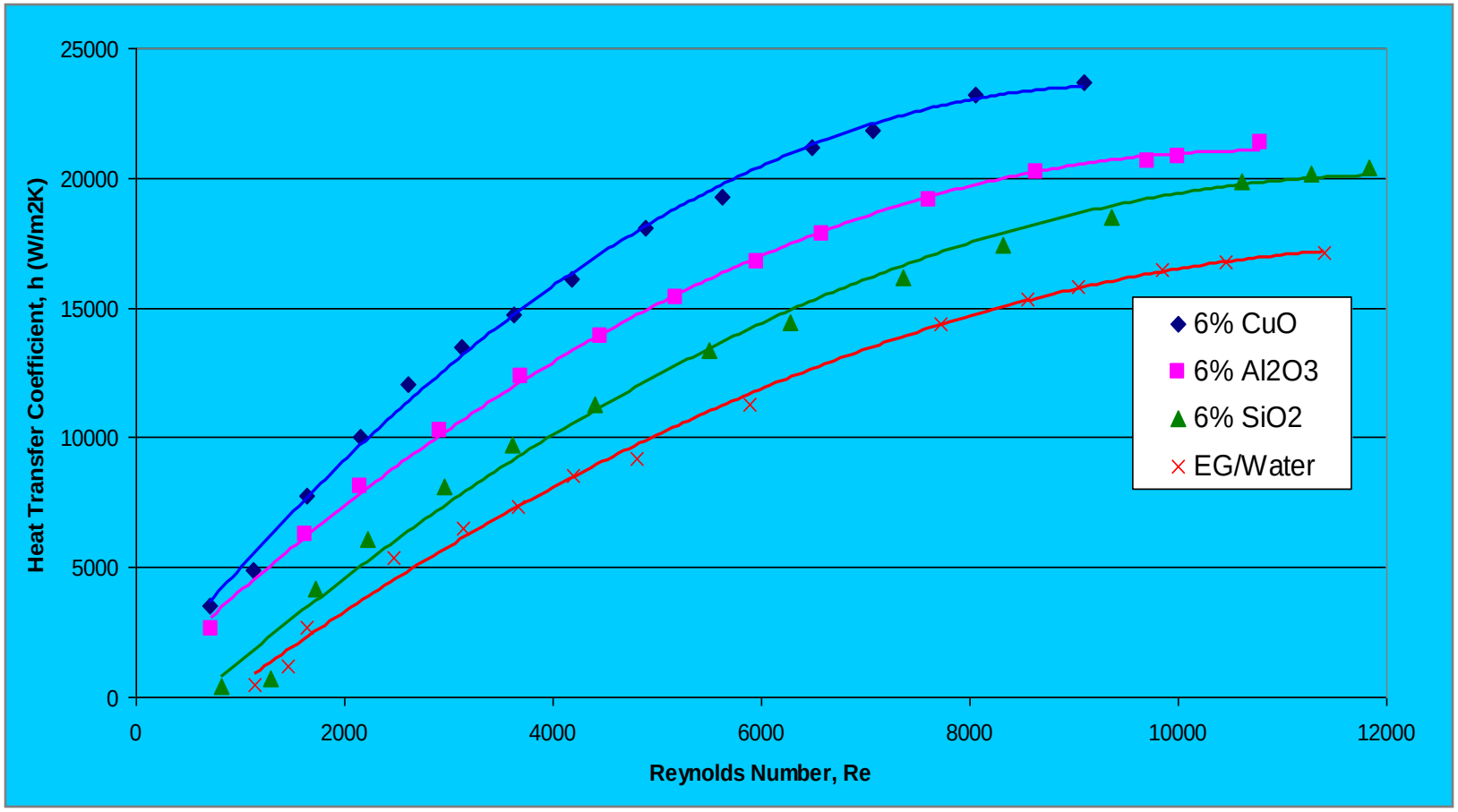
Experimental Setup



Heat Transfer Coefficient Vs Reynolds Number



Heat Transfer Enhancement



Performance Comparison of Nanofluids

Type of Fluid Parameters	60/40 EG/Water	6% Copper Oxide	6% Aluminum Oxide	6% Silicon Dioxide
Heat Transfer Coefficient (W/m2K)	14,400	14,400	14,400	14,400
Reynolds Number (Re)	8,000	3,600	4,500	6,290
Pressure Loss (kPa)	346	430	340	322
Viscosity (mPa.s)	1.1	2.27	1.41	1.17
Density (kg/m3)	1038	1366	1192	1116
Specific Heat (J/kg.K)	3120	2339	2718	2821
Velocity (m/s)	2.12	1.5	1.33	1.65
Volumetric Flow Rate (10E+5 m3/s)	2.66	1.89	1.67	2.07
Reduction in Volumetric Flow Rate (%)	……	28.95	37.22	22.18
Power (W)	11.5	10.16	7.1	8.33
Power Advantage (W)	……	1.34	4.4	3.17
Power Advantage (%)	……	11.65	38.26	27.57
Mass Flow Rate (kg/s)	0.028	0.0258	0.0199	0.023
Reduction in Mass Flow Rate (%)	…….	6.495	27.904	16.333

Nanofluids in Heat Exchangers

Heat transfer rate from a heating coil circulating nanofluid to air

$$\dot{Q} = U_o A_o \Delta t_m$$

Rate of heat transfer from the nanofluid to the pipe

$$\dot{Q} = h_i A_{P,i} (t_f - t_{P,i})$$

Rate of heat transfer through the pipe wall

$$\dot{Q} = \frac{k_P A_{P,m} (t_{P,i} - t_{P,o})}{x_P}$$

Rate of heat transfer from the pipe and fin to the air

$$\dot{Q} = h_{c,o} (A_{P,o} + \eta A_F)(t_{P,o} - t)$$

Overall heat transfer coefficient

$$U_o = \frac{1}{\frac{A_o}{A_{P,i} h_i} + \frac{A_o x_P}{A_{P,m} k_P} + \frac{1-\eta}{h_{c,o}(A_{P,o}/A_F + \eta)} + \frac{1}{h_{c,o}}}$$

Typical Data for Heat Exchanger:

$A_{P,i}$ = 0.03536 m^2 $A_{P,m}$ = 0.0375 m^2 A_o = 0.09845 m^2 η = 0.75

$A_{P,o}$ = 0.03658 m^2 A_F = 0.948 m^2 $h_{c,o}$ = 57 W/m^{2}K

Reduction in Surface Area with Nanofluids

Component	60:40 EG/Water	6% Copper Oxide	6% Aluminum Oxide	6% Silicon Oxide
Reynolds Number	4000	4000	4000	4000
Inside heat transfer coefficient, h_i	3407	10,000	8,000	4,900
Inside Surface Resistance x 10E3 $R_i = A_o / A_{p,i} h_i$	8.17	2.78	3.475	5.67
Pipe Wall Resistance x 10E5 $R_p = A_o x_p / A_{p,m} k_p$	4.8	4.8	4.8	4.8
Fin Resistance x 10E3 $R_F = \frac{1}{h_{c,o}} \left(\frac{1-\eta}{\eta + A_{p,o} / A_F} \right)$	6.16	6.16	6.16	6.16
Outside Surface Resistance x 10E3 $R_o = 1/h_{t,o}$	17.5	17.5	17.5	17.5
Total Resistance x 10E3 $R_t = R_i + R_p + R_F + R_o$	31.88	26.48	27.175	29.37
Overall Heat Transfer Coefficient $U_o = 1 / R_t$	31.37	37.76	36.8	34.04
% Reduction in Area	……	**20.37**	**17.3**	**8.5**

Conclusions

- The CuO nanofluid showed the highest heat transfer coefficient followed by the Al_2O_3 nanofluid, then the SiO_2 nanofluid and the lowest was the base fluid.

- Use of nanofluids can reduce the volumetric flow rate, mass flow rate and the pumping power for the same heat transfer rate.

- Use of nanofluids in heat exchangers can reduce their size and the required pumping power on the basis of equal heat transfer.

- Use of nanofluids will reduce size, material volume, weight and power consumption in heat transfer systems and is therefore attractive for applications in space exploration.

- Reduction of material volume and power will reduce environmental pollution.

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Thank You

Questions ???