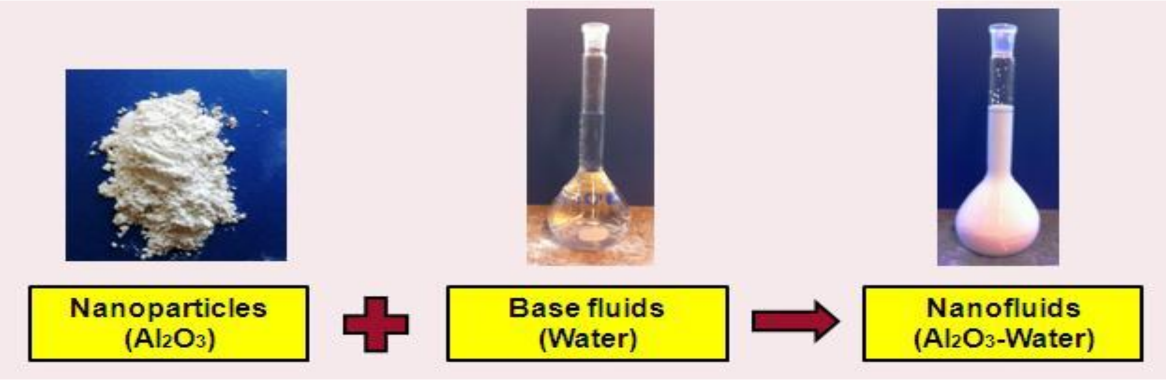
Nanofluids

Nanofluid

" Nanofluids" is the name imaginary to describe a fluid in which nanometer-sized particles are suspended.



Thermal conductivities of various solids and liquids

	Material	Thermal conductivity (W/m K)
Metallic solids	copper	401
	aluminum	237
Nonmetallic solids	silicon	148
	alumina (Al_2O_3)	40
Metallic liquids	sodium (644 K)	72.3
Nonmetallic liquids	water	0.613
	ethylene glycol (EG)	0.253
	engine oil (EO)	0.145

$$k_{nanoparticles} > k_{base\ fluids}$$

Advantages of Nanofluids

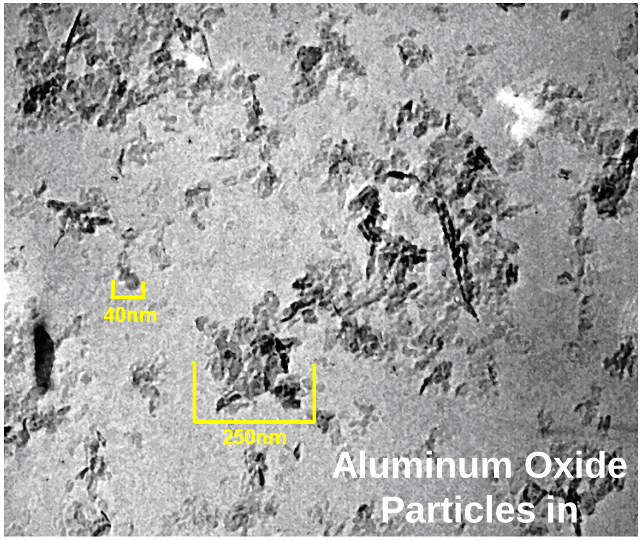
Well-dispersed and stable nanofluids are formed and exhibit several beneficial features:

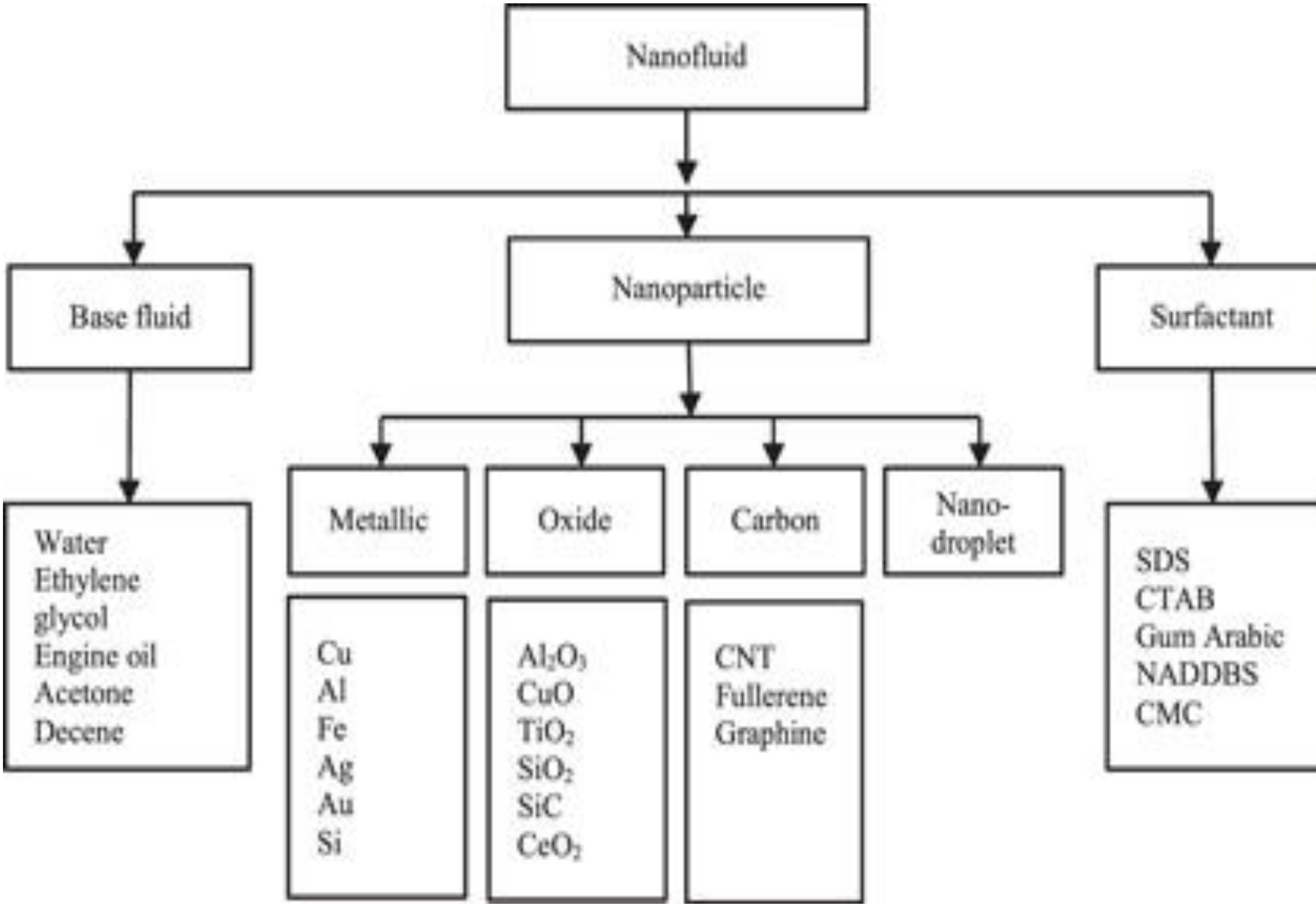
a) **Greatly improved heat conduction. Nanofluids demonstrate higher thermal conductivities than the base fluid due to several factors. The large surface area of nanoparticles per unit volume allows for more heat transfer between solids particles and base fluids.**
b) **High stability of nanofluids. Because the nanoparticles are small, the particles are stably staying in the liquid phases for months or even years without sedimentation.**
c) **Elimination of clogging. Nanoparticles are only composed of hundreds or thousands of atoms, about 1 ~ 100 nm in diameter and are well-dispersed in nanofluids, so that they will not causing any clogging problem.**
d) **Reduction of erosion. Nanoparticles are very small and do not carry so much momentum as their micro- or macro- counterparts, and thus the momentum and the kinetic energy which they will impart to solid surfaces is small.**
e) **e) Smaller pressure drop and reduction in pump power. Due to the large specific surface area, nanoparticles have demonstrated high effectiveness to enhance the thermal conductivity of fluids. It is expected that much smaller concentrations of nanoparticles is required to achieve similar enhancements in larger particle suspensions. Less material is needed so that the viscosity increase is smaller, and the pumping power required is also reduced.**

Nanofluids

- ***Nanofluids are engineered colloids = base fluid (water, organic liquid) + nanoparticles***
- ***Nanoparticle size: 1-100 nm***
- ***Nanoparticle materials: Al_2O_3, ZrO_2, SiO_2, CuO, Fe_3O_4, Au, Cu, C (diamond, fullerene) etc.***
- ***Previous studies suggest significant enhancement of:***
  - ***Thermal conductivity (+40%)***
  - ***Single-phase convective heat transfer (+40%)***
  - ***Critical Heat Flux (+100%)***

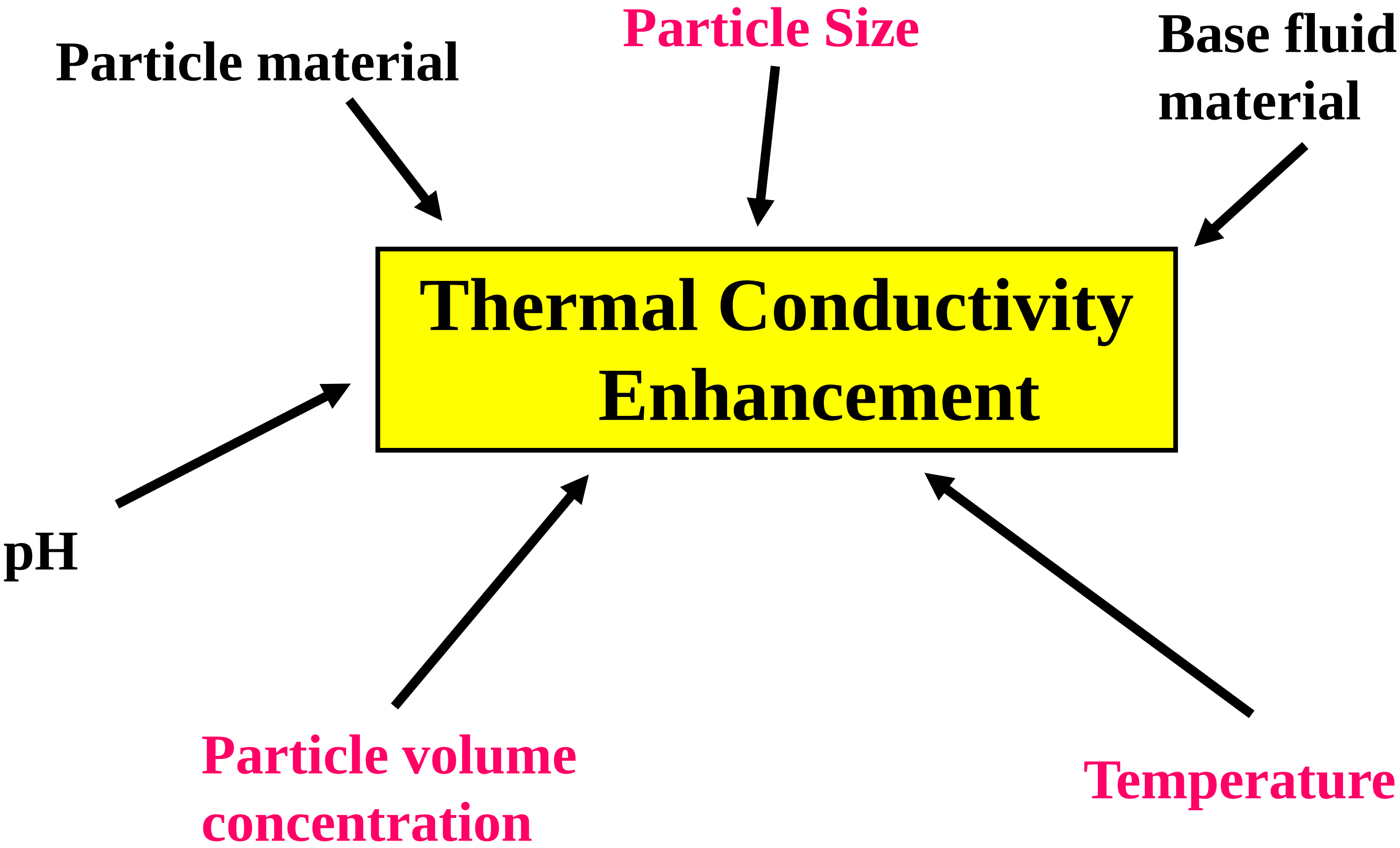
The improved thermal transport properties of nanofluids would improve the efficiency of heat exchanging, reduce the size of the systems, save pump power, reduce operational cost and provide much greater safety limits. Better properties of nanofluids may be obtained if higher-quality and more monodispersed nanoparticles can be synthesized.

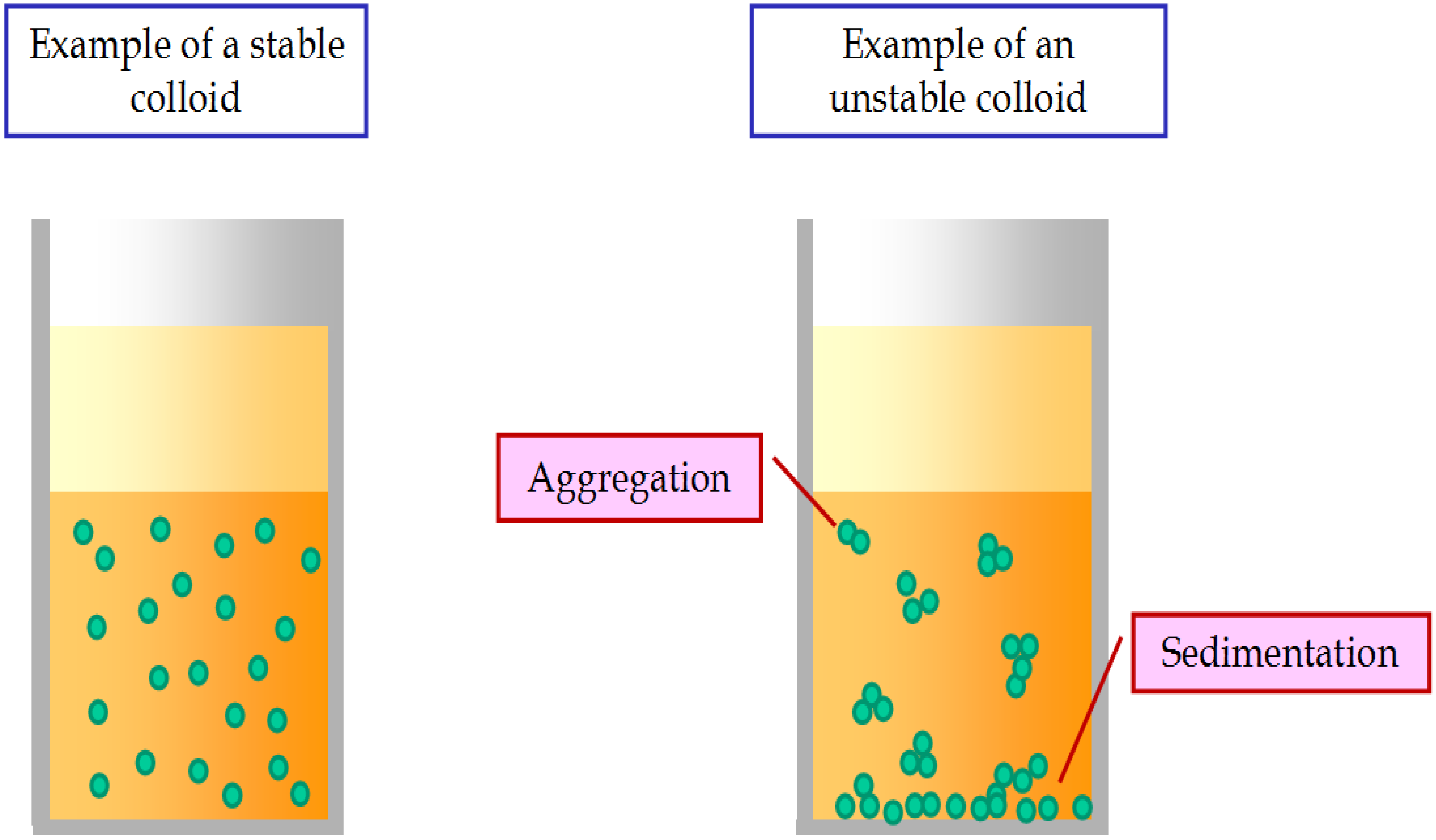




Nanofluid
Base fluid
Nanoparticle
Surfactant
Water
Ethylene glycol
Engine oil
Acetone
Decene
Metallic
Oxide
Carbon
Nano-droplet
Cu
Al
Fe
Ag
Au
Si
Al_2O_3
CuO
TiO_2
SiO_2
SiC
CeO_2
CNT
Fullerene
Graphine
SDS
CTAB
Gum Arabic
NADDBS
CMC

The main factors that affecting thermal conductivity of produced Nanofluids




Example of a stable colloid
Example of an unstable colloid
Aggregation
Sedimentation

Preparation of Nanofluids

- **Two techniques are used to prepare nanofluids:**

1 - The single step method

The single step simultaneously makes and disperses the nanoparticles directly into a base fluid; best for metallic nanofluids.

- Nanoparticles agglomeration is minimized

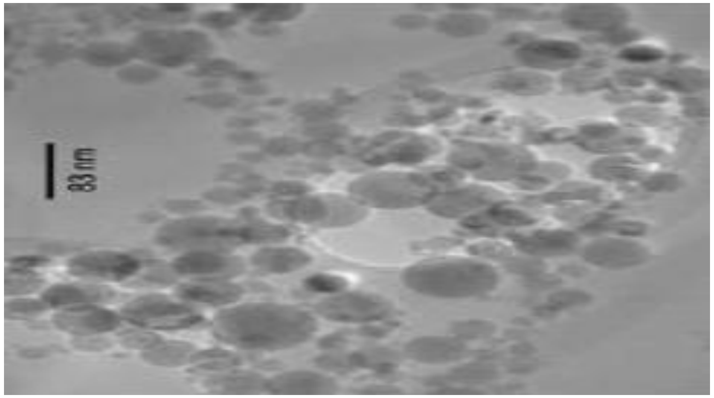
- Only suitable for low vapor pressure fluid

2- The two-step method (widely used)

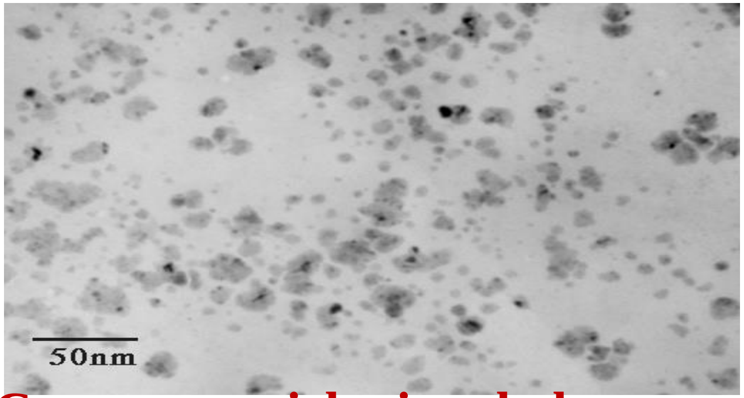
Nanoparticles was first produced and dispersed into the base fluids.

- Good for oxides nanoparticles

- Not suitable for metallic nanoparticles

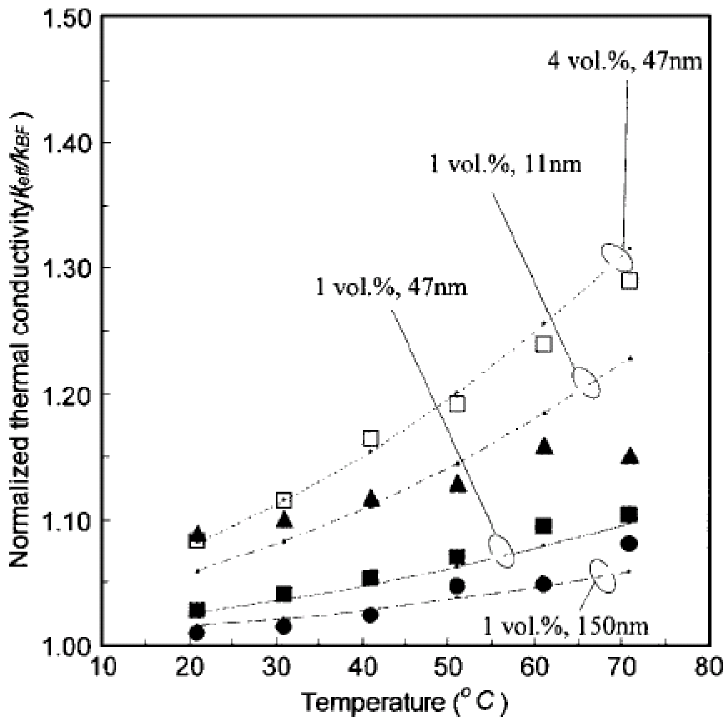


ZrO_2 in water that produced with Two Step method

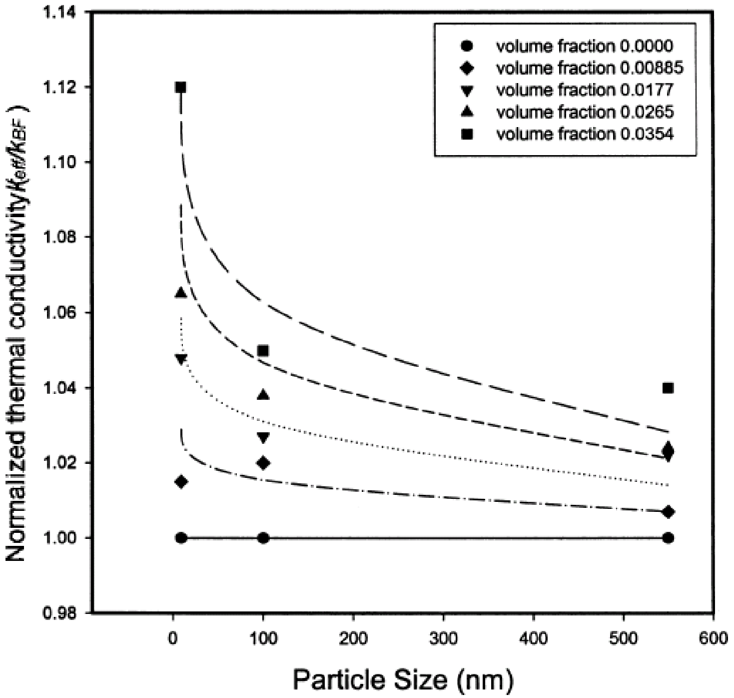


Cu nanoparticles in ethylene glycol produced with One Step method

Effect of Particle Size



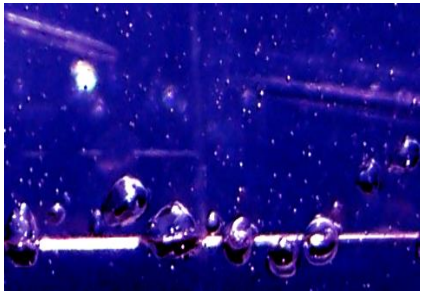
Effect of particle size for Al_2O_3 in water
[Chon C.H. et. al. (2006)]



Effect of particle size for Al_2O_3 in ethylene glycol
[H.U. Kang et. Al. (2006)]

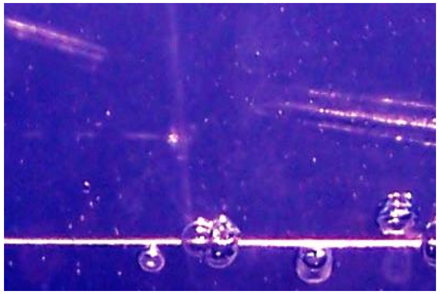
- Smaller particles, higher thermal conductivity
- Effective surface area increase as particle size decrease

Nanofluid Critical Heat Flux (CHF)

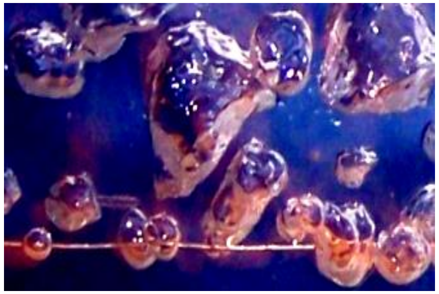


DI water (0.5 MW/m²)

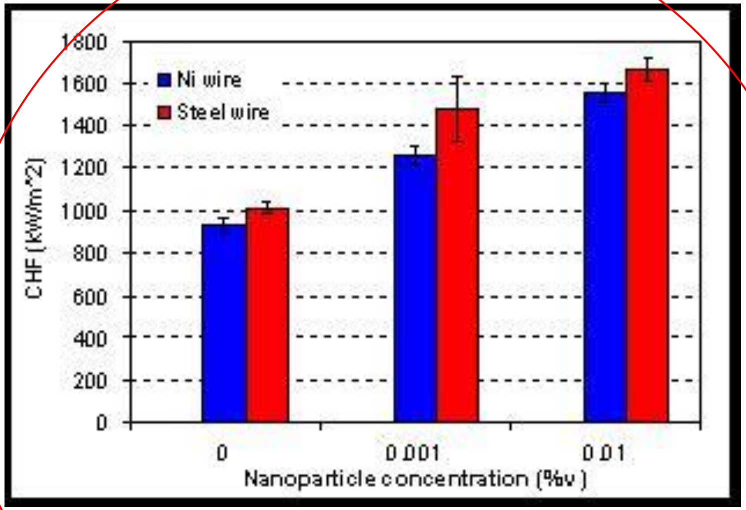
DI water (1 MW/m²)



Nanofluid (0.5 MW/m²)



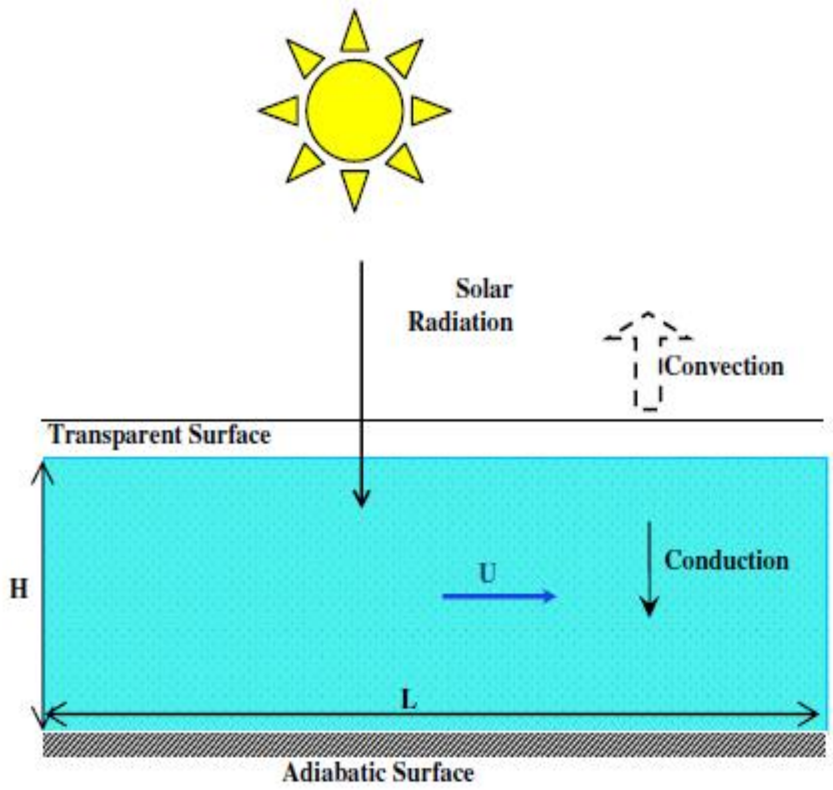
Nanofluid (1 MW/m²)



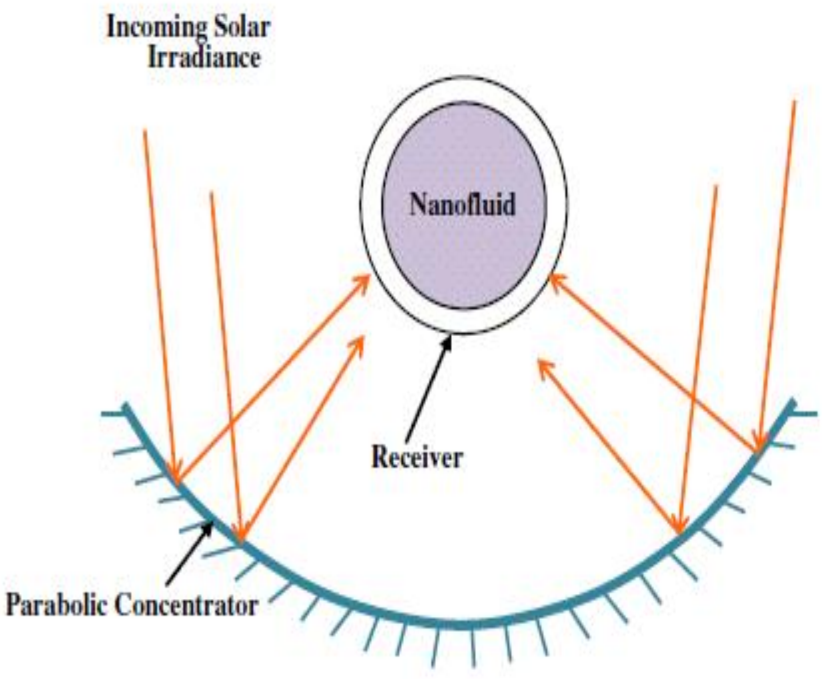
Water-based nanofluid with ZrO_2 particles

Very significant CHF enhancement observed at low nanoparticle concentrations

Applications of Nanofluids in Solar Energy



Schematic of the nanofluid-based direct absorption solar collector



Schematic of nanofluid-based concentrated parabolic solar collector

Nuclear Applications of Nanofluids

1) ***PWR main coolant.*** **Coolant chemistry and particle deposition are big concerns**

2) ***Safety systems.*** **Requires also post-CHF enhancement (not proven yet)**

3) ***In-vessel retention for high-power density reactors.*** **Very promising**