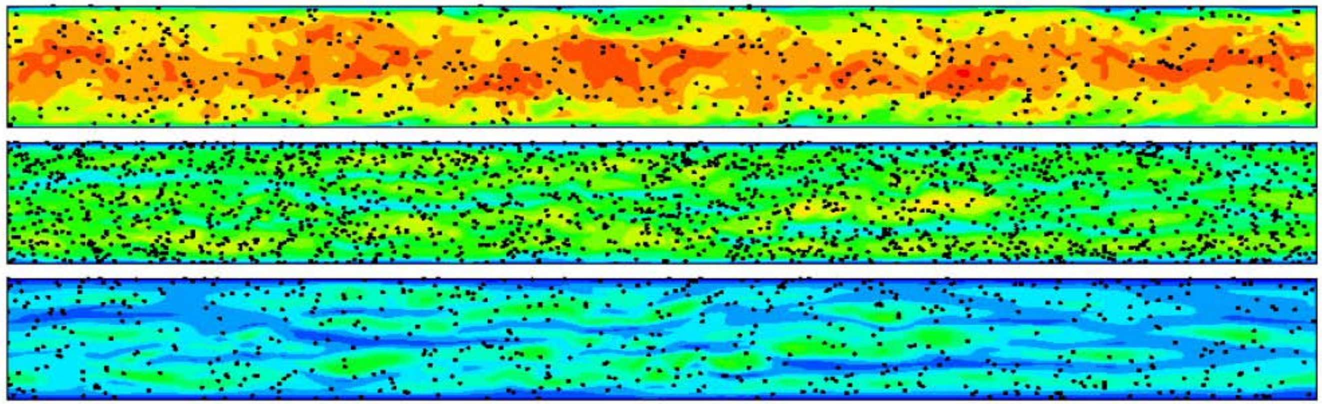
Lecture 7

Nanofluids

Enhancing thermal conductivity of the fluid-dispersion of particles

•Base fluid can be enhanced by suspending micro/larger size solid particles.

- basic concept of dispersing solid particles in fluids to enhance thermal conductivity can be traced back to Maxwell in the 19th Century. (Maxwell 1873). Th solid particles of micrometer, even millimeter magnitudes were blended into the base fluids to make suspensions or slurries. However, large solid particles cause troublesome problems, such as abrasion of the surface, clogging the microchannels, eroding the pipeline and increasing the pressure drop, which substantially limits the practical applications.



Enhancing thermal conductivity of the fluid-dispersion of particles

Since solid materials have much higher thermal conductivities than fluids, it is then a straightforward logic to increase the thermal conductivity of fluids by adding solids. However, if solid particles of micrometer, even millimeter magnitudes are added into the base fluids to make slurries, the increase in thermal conductivity of the slurries is insignificant even at high particle loading. Meanwhile, large particles cause many troublesome problems:

a) **Large particles are easy to settle out from the base fluids, especially in low speed circulation, not only losing the enhancement in thermal conductivity, but forming a sediment layer at the surface, increasing the thermal resistance and reducing the heat transfer capacity of the fluids;**

b) **The large size of the particles or the agglomerates of these particles causes severe**
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clogging problems, especially at low circulation rate of fluids or in microchannels;

c) **Large particles and the agglomerates in fluid flows carry too much momentum and kinetic energy, which may cause damage to the surface;**

d) **The erosion of the pipelines by the coarse and hard particles increases rapidly when the speed the circulation increases; e) Noticeable conductivity enhancement is based on high particle concentration, which leads to apparent increase in viscosity. The pressure drop in fluids (slurries) goes up considerably due to the increase of viscosity.**

Table 1 : Comparison of the Old and New [Sarit K. Das et al. 2008]

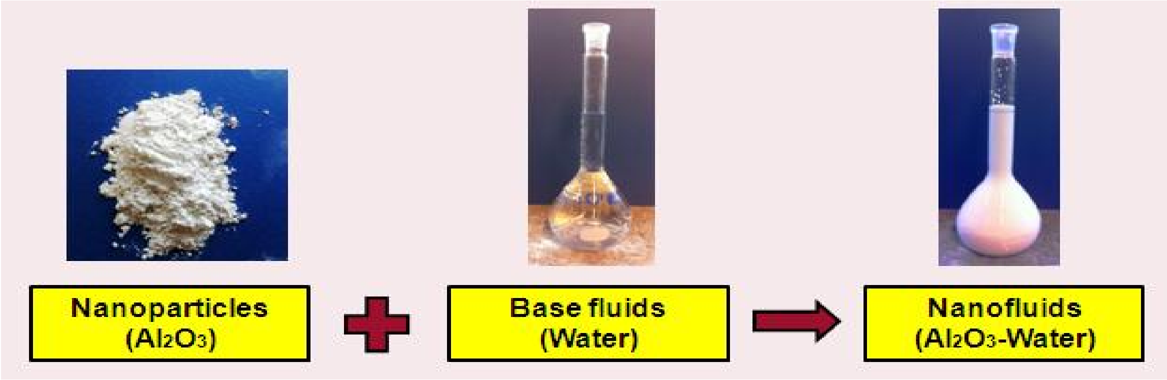
Criteria	Microparticles	Nanoparticles
Stability	Settle	Stable (remain in suspension almost indefinitely)
Surface/volume ratio	1	1000 times larger than that of microparticles
Conductivity	Low	High
Clog in microchannel?	Yes	No
Erosion?	Yes	No
Pumping Power	Large	Small

Nanoparticles stay suspended much longer than micro-particles and, if below a threshold level and/or enhanced with surfactants/stabilizers, remain in suspension almost indefinitely.

- surface area per unit volume of nanoparticles is much larger (million times) than that of microparticles (the number of surface atoms per unit of interior atoms of nanoparticles, is very large).

Nanofluid

" Nanofluid" is the name conceived 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

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

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. Another advantage is that the high mobility of the nanoparticles due to the tininess, which may introduce micro-convection of fluids to further stimulate heat transfer.**

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.**

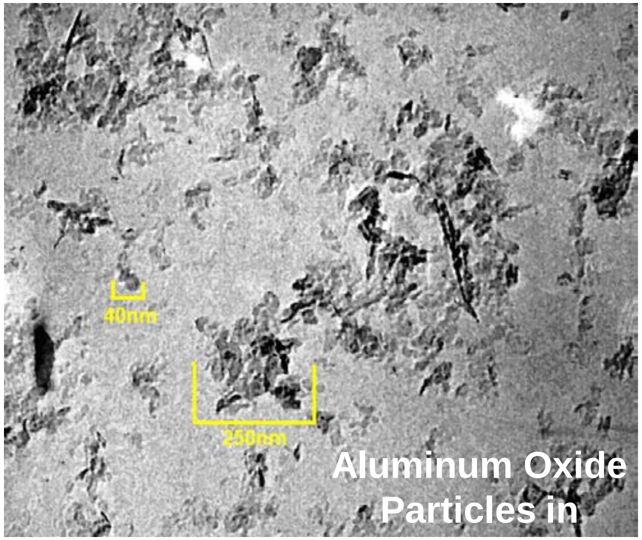
d) **Reduction of erosion. Nanoparticles are very small and do not carry so much momentum as their micro- or macro- counterparts, and thus the momentum and the kinetic energy which they will impart to solid surfaces is small.**

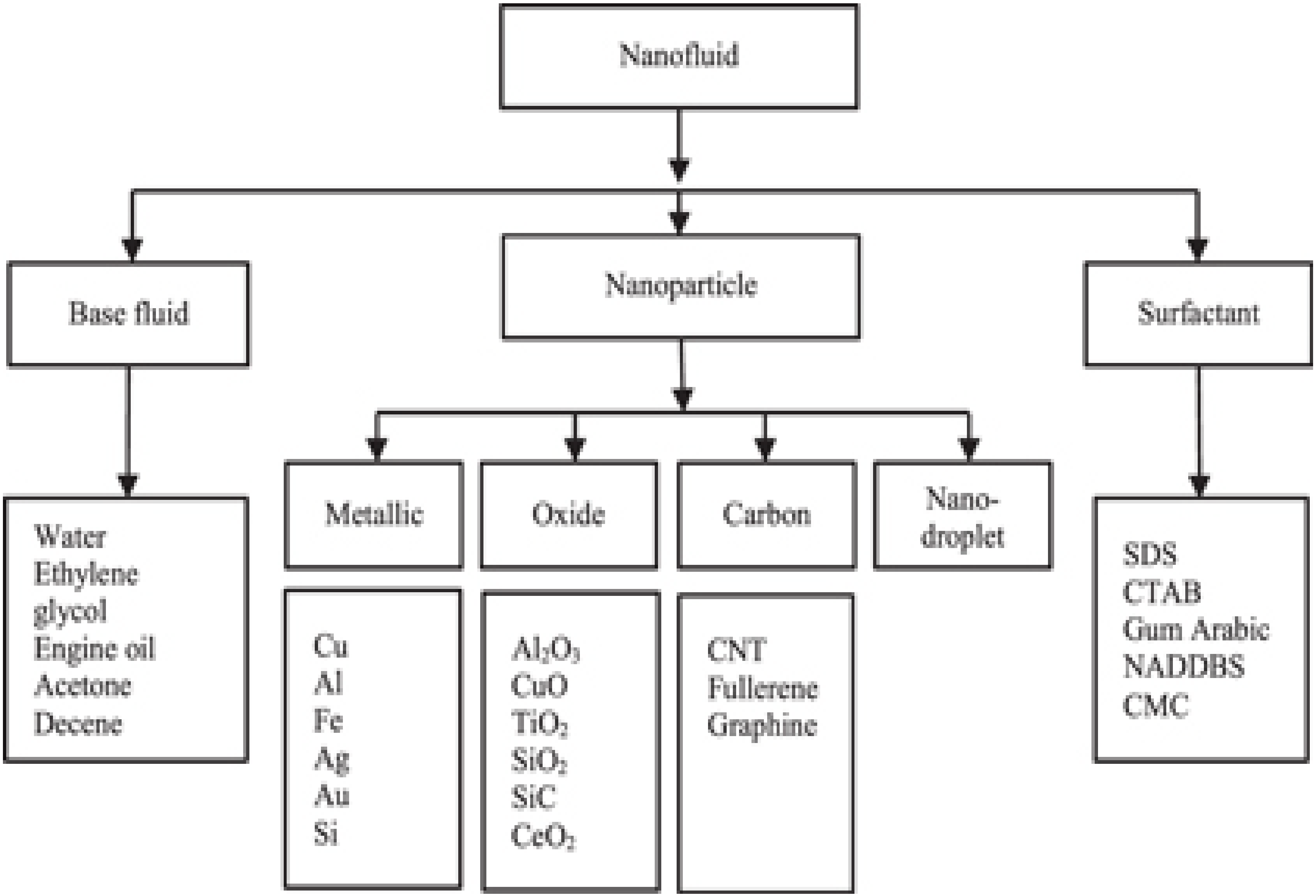
e) **e) Smaller press drop and reduction in pump power. Due to the large specific surface area, nanoparticles have demonstrated high effectiveness to enhance the thermal conductivity of fluids. It is expected that much smaller concentrations of nanoparticles is required to achieve similar enhancements in larger particle suspensions. Less material is needed so that the viscosity increase is smaller, and the pumping power required is also reduced.**

Nanofluids

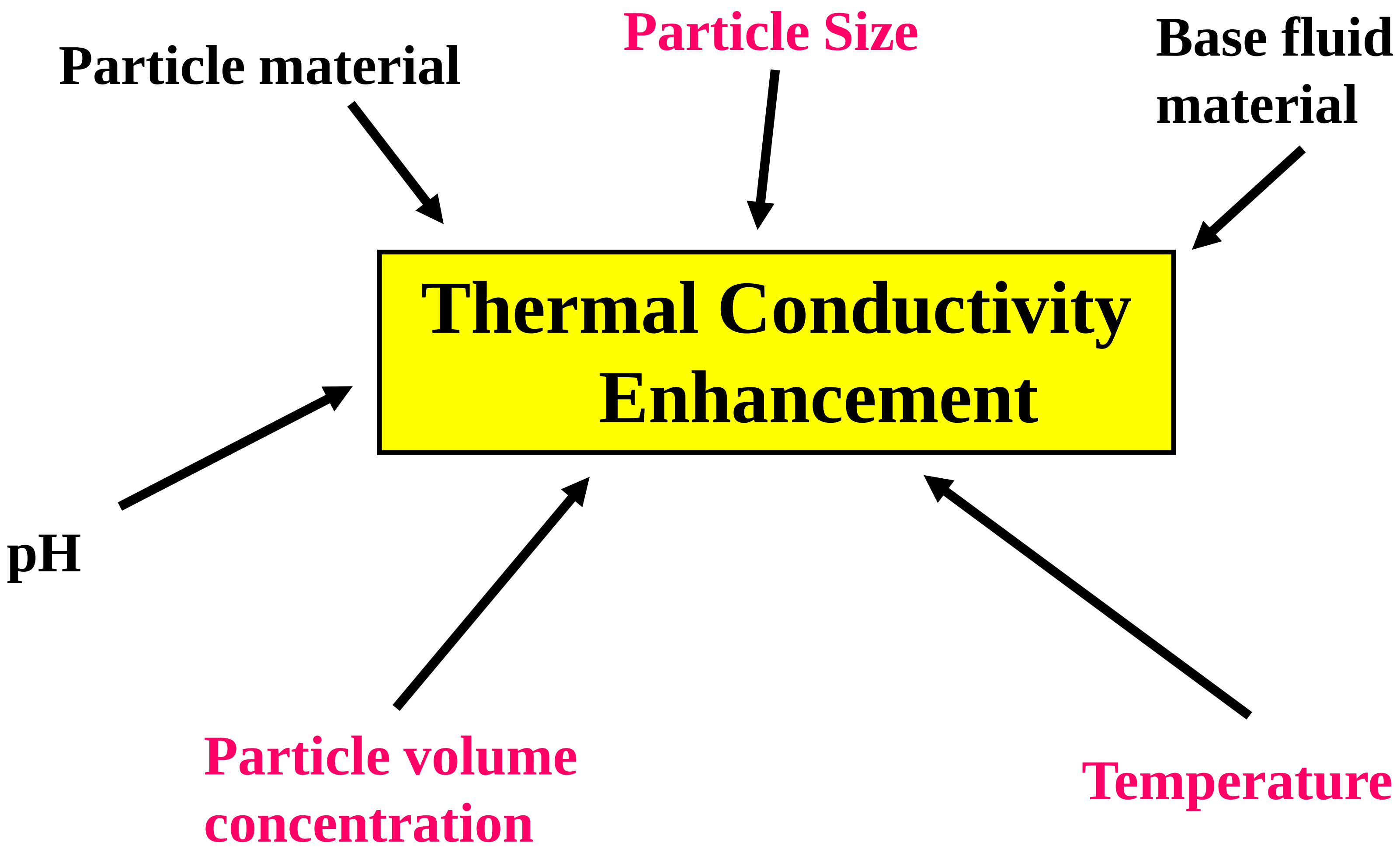
- *Nanofluids are engineered colloids = base fluid (water, organic liquid) + nanoparticles*
- *Nanoparticle size: 1-100 nm*
- *Nanoparticle materials: Al_2O_3, ZrO_2, SiO_2, CuO, Fe_3O_4, Au, Cu, C (diamond, fullerene) etc.*
- *Previous studies suggest significant enhancement of:*
  - *Thermal conductivity (+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 margins. 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
Al2O3
CuO
TiO2
SiO2
SiC
CeO2
CNT
Fullerene
Graphine
SDS
CTAB
Gum Arabic
NADDBS
CMC

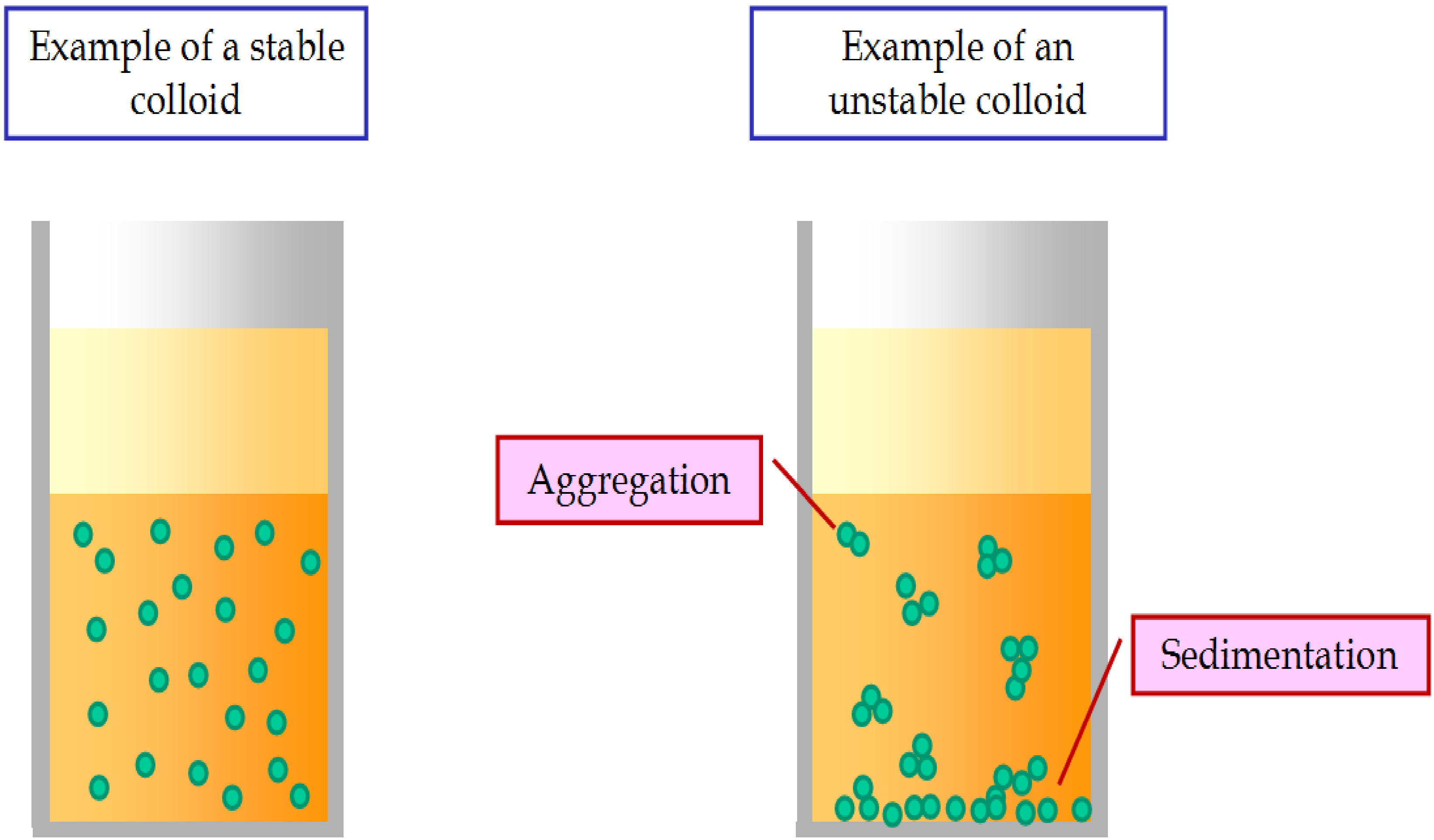
The main factors that affecting thermal conductivity of produced Nanofluid



A nanomaterial can exist in single, fused, aggregated or agglomerated form with spherical, tubular and irregular shapes.

Why nanomaterials have different properties?

Why nanomaterials have superior chemical reactivity?



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

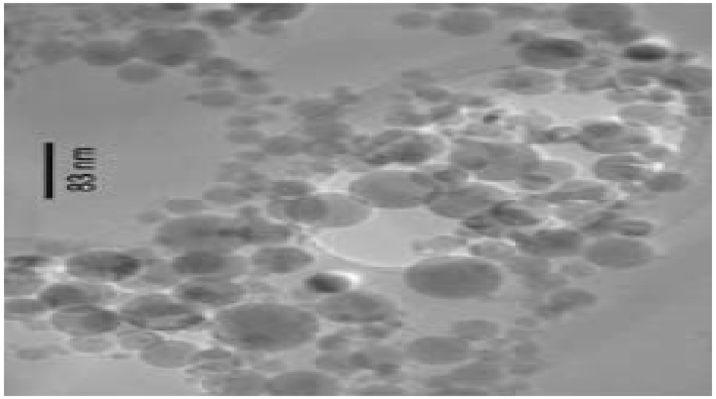
- Only suitable for low vapor pressure fluid

2- The two-step method (widely used)

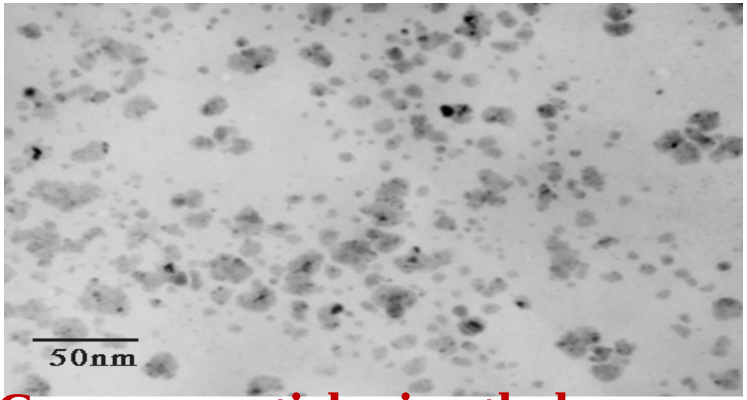
Nanoparticles was first produced and dispersed into the base fluids.

- 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