Particle Characterization: Assignment 2

1. How do cohesive strength and cohesivity depend on particle size?

   Ans: Cohesive strength is directly proportional to the size of the particle and cohesivity is inversely proportional to particle size.

   $F_{cohesion}$ α r

   Cohesivity α 1/r

2. Differentiate between hard & soft particle models of flowability.

   Ans:

Hard particle model	Soft particle model
Cohesiveness Index (n) tends to 1 i.e. free flowing	Cohesiveness Index (n) tends to 2 i.e. highly cohesive
Rapid flows	Cohesive, slower flow
Applies to materials which are less densely packed.	Applies to materials which are more densely packed.
Collisions are binary in nature.	Multi-particle collisions occur.
Contact between particles are instantaneous	Contact between particles are enduring.

3. Identify dominant transport modes by particle size.

   Ans: : Dominant transport modes by particle size are as follows:

Size of particle	Mode of transport
Sub micron range	Brownian diffusion, Electrostatic force
1-10 microns	Convection force, Drag force
>10 microns	Inertial force

4. Write an expression for transient particle mass flux.

   Ans: $J_{flux} = n_o(D_p/\pi t)^{1/2}$

   Where

   D_p = Brownian diffusivity

   n_o = number of particles per unit volume far away from the surface

t = time

5. Define reference particle mass flux in quiescent flow.

   Ans: In quiescent flow, diffusion is the dominant phenomenon.

   $\dot{m}_p{}''_{,ref} = \dot{m}_p{}''_{,ref,diff}$

   $\qquad = D_p\rho(\omega_{p,w} - \omega_{p,\infty})/L$

   Where

   D_p = Brownian diffusivity

   ρ = density of the surrounding fluid

   $\omega_{p,w}$ = mass fraction gradient at the surface

   $\omega_{p,\infty}$ = mass fraction gradient far away from the surface

6. Define reference particle mass flux in convective flow.

   Ans: In convective flow, convection becomes the dominant phenomenon.

   $\dot{m}_p{}''_{,ref} = \dot{m}_p{}''_{,ref,conv}$

   $\qquad = \rho u(\omega_{p,w} - \omega_{p,\infty})$

   Where

   ρu = convective flux

   $\omega_{p,w}$ = mass fraction gradient at the surface

   $\omega_{p,\infty}$ = mass fraction gradient far away from the surface

7. Define dimensionless number for particle mass flux in diffusion-dominated case.

   Ans: For the diffusion dominated case, Nusselt number is defined as below:

   $Nu_{m,p} = j_p{}''/ \dot{m}_p{}''_{,ref,diff}$

8. Define dimensionless number for particle mass flux in convection-dominated case.

   Ans: For the convection dominated case, Stanton number is defined as below:

   $St_{m,p} = j_p{}''/ \dot{m}_p{}''_{,ref,conv}$

9. Define Peclet number for thermophoresis in diffusion & convection-dominated cases.

   Ans: Peclet number for thermophoresis in diffusion dominated cases:

   $$Pe = \frac{-C_{p,t}\, dw}{D_p\, Nu_{mp,o}}$$

Where

-Cp,t = thermophoretic velocity

dw = distance from the surface

Dp = thermophoretic diffusivity

Num,p,o = Nusselt number under zero conditions

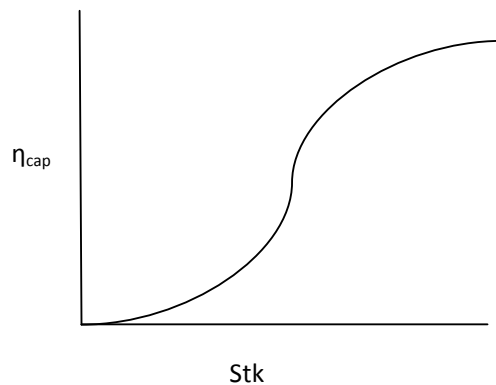Peclet number for thermophoresis in convection-dominated cases:

$$Pe = \frac{-Cp,t}{U\ Stmp,o}$$

Where

Stmp,o = Stanton number under zero conditions

10. Sketch dependence of capture efficiency on surface energy.

Ans : Capture efficiency vs Stokes number

11. Define blowing parameters for heat & mass transfer in droplet burning. How are they related?

Ans:

Blowing parameter for mass transfer:

Bm = ($\omega_{A,\infty}$ - $\omega_{A,w}$)/(1- $\omega_{A,w}$)

Blowing parameter for heat transfer:

Bh = k(T_∞- T_w)/L_A

Bm and Bh are related to each other in the following manner :

Ln(1+Bh) = ln(1+Bm)^{Le}

Where

Le = D/α

D= Fick's diffusivity

α= thermal diffusivity

12. Why do finer droplets burn faster?

    Ans: The time required for burning is directly proportional to the square of the particle size. Therefore, smaller the particle size, lesser the time required for burning.

    $t \propto d_p^2$

13. Name 3 types of filters for particle collection from liquids. Which is most suited to microscopic analysis?

    Ans: The three types of filters used for particle collection are :

    i.   Depth filters
    ii.   Porous membrane filters
    iii. Flat membrane filters

    Flat membrane filters are most suited for microscopic analysis.

14. How can particles in gases be sampled?

    Ans: Particles in gases can be sampled using impactors. Impactors work using the inertial characteristics of the particles to capture them. They contain a series of chambers and the particles are accelerated with progressively greater velocities. The largest particles are captured first and the finer particles are captured downstream. The advantage of impactors over filters is that particles are concentrated in a smaller area compared to filtration.

15. State Bragg's Law and its implications for XRD analysis.

    Ans: Bragg's law :

    $n\lambda = 2d\sin\theta$

    where

    θ = angle between the incident and reflected light

    λ = wavelength of light

    d= distance between two adjacent planes

    When we keep changing θ and plot the intensity of light, we obtain a characteristic spectrum for that crystal. When this is compared with the reference spectra, we can identify which crystalline material it is.

16. What are the 3 modes of operation of an AFM? When do you use each?

    Ans: The three modes of operation of an AFM are as below:

    Contact AFM : Used when high forces of interaction between the surface and probe are preferred. This method generally makes use of a high stiffness cantilever.

    Non-contact AFM : Forces of interaction between the surface and probe are weak. This method makes use of a low stiffness cantilever to get a high signal. The probe is generally set in oscillation and either the frequency or the amplitude is modulated. This method can lead to snapping of probe if the surface is not uniform.

    Intermittent contact AFM : Combination of contact and non-contact modes of operation. In this mode, the stiffness is adjusted in such a way that the probe can go sufficiently close to the particle surface and would not get locked into it.

17. Describe sol-gel method for nano-particle synthesis.

    Ans: Sol-gel method is used to synthesize glass, ceramic and glass-ceramic nanoparticles. This method is a combination of top down and bottom up method of synthesis. A powder of the material is prepared using a bottom-up approach and the powder is ground to nano-dimensions using a top-down approach.

    The sol-gel method can be aqueous or alcohol based. Precursors like alkoxide or metal formates are used. We take a mixture of liquid phase constituents, stir them until a gel is formed. The gel is then dried at 100°C for 24 hours over a water bath and then ground to a powder. This powder is heated gradually at 5°C per minute, calcined in air at 500 to 1200°C for 2 hours. This method can be used to generate materials of high purity. It is particularly suited to the production of nano sized multi-component ceramic powders.

18. Contrast chemical vapour synthesis & chemical vapour deposition.

    Ans: In chemical vapour synthesis, we take vapour phase precursors and bring them into a hot wall reactor under nucleating conditions. Vapour phase nucleation of particles is favoured over film deposition on surfaces. In a CVD reactor we try to design the reactor conditions such that the nucleation only occurs heterogeneously on the target surface on which the film is to be formed. In CVC reactor, the gas itself is kept at conditions such that only homogenous nucleation is promoted. This method can take advantage of the library of precursors available for CVD and make thin films for various applications.

19. How can ultrasound be used in bottom-up & top-down synthesis?

    Ans: Ultra-sound can be used to synthesise nano-particles both by bottom-up approach and top-down approach.

    When we apply an oscillating acoustic field, we start forming bubbles in the liquid which collapse and as they do, they release high amounts of energy. According to the hot spot theory, as bubbles implode temperatures of the order of 5000 to 25000K can be realized for a few nano seconds, which is followed by very rapid cooling. When these high temperatures and high pressures are in effect, chemical reactions can be driven by several orders of magnitude faster than they would proceed otherwise. So, this acoustic cavitation effect can break chemical bonds and can make chemical reactions run very fast and it can intensify the process by which nano particles are synthesized using chemical reactions. The quenching reaction in the presence of cavitation can be used to prepare amorphous substances.

    In the top down approach, we immerse the micron sized particles in high purity water, turn on the acoustic field and start fragmenting the particles. It is a simple, energy efficient process which is also easy to scale-up. The sonication introduces what is known as lattice strain. The crystallinity of the particle is maintained, it does not become an amorphous with extended exposure. The natural adhesiveness or cohesiveness of the particle is greatly increased by the process of sonication. Nano particles synthesised using sono-fragmentation are much more reactive, adhesive and conformable to a process compared to particles produced using other methods.
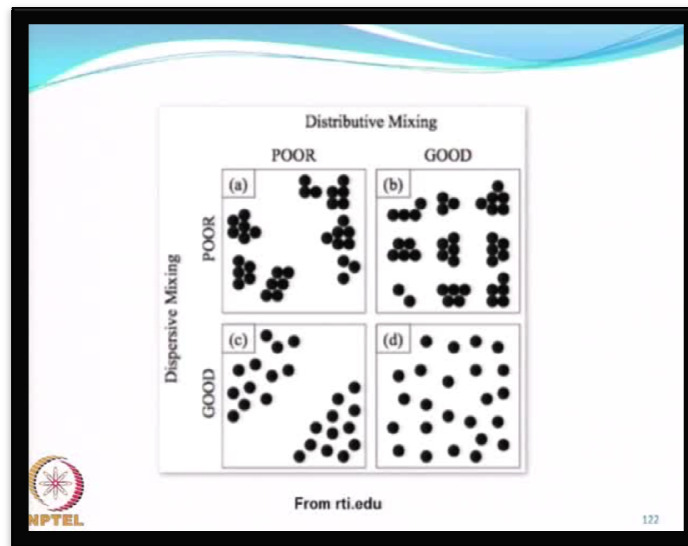
20. Sketch the mechanism of sono-fragmentation

    Ans:
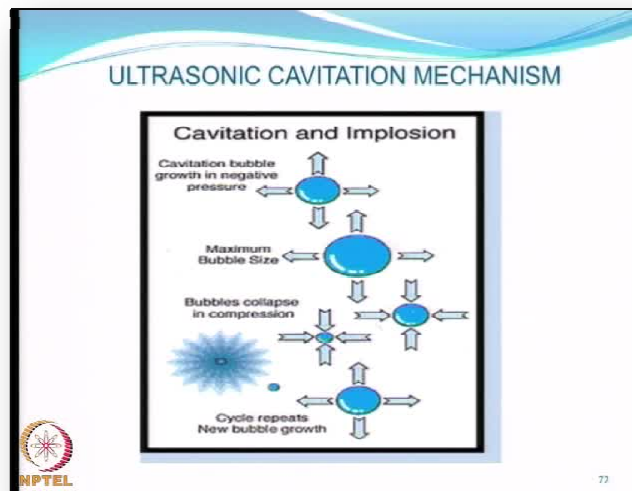
21. Sketch the 4 zones of distributive & dispersive mixing.

    Ans:

22. Identify quantitative metrics for dispersion & distribution.

    Ans: The quantitative metrics for dispersion and distribution are mean particle size and the number of particles in each size range.

23. Describe three density values relevant to nano-particles.

    Ans: The three densities relevant to nano particles are as follows:

    Material density : Material density is defined as the mass of the powder divided by the volume occupied by the solid powder after removing internal voids. It is also known as True density

    Particle density : Particle density is defined as the mass of the powder divide by volume occupied by the particles including the internal closed voids.

    Bulk density : Bulk density is defined as a mass of powder divided by the volume of space below the upper surface of the powder when it is placed in a container.

24. How do melting point, surface tension and specific surface area vary as size shrinks?

    Ans: Melting point of many metals decreases when the size is reduced to nano levels. Therefore it is easier to work with them at almost room temperatures without heating them to very high temperatures.

Surface area increases greatly as size is reduced to nano-dimensions. However, as the surface area increases, the core area of the particle decreases and the exterior area increases. This has several implications on other properties such as melting point.

The contact angle decreases for all metals at 40 nanometers and less. A decrease in contact angle means an increase in wettability and therefore higher surface tension effects.

25. In a suspension of nano-particles, plot how k depends on volume fraction.

Ans:
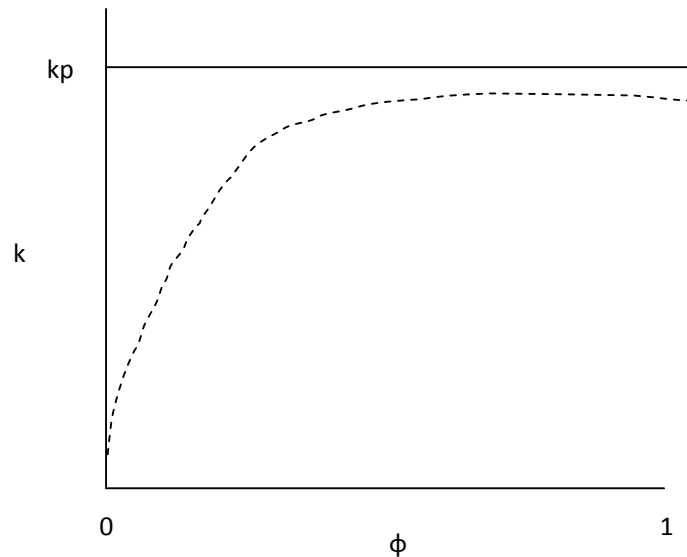
26. Outline possible mechanisms for heat transfer enhancement in nano-fluids.

Ans:

Mechanisms of heat transfer enhancement in nano fluids are :

- Agglomeration of particles
- Formation of bridge between nano particles leads to enhancement of heat transfer as what we are actually measuring would be the conductivity of the solid bridge.
- Brownian diffusion of particles leads to a temperature gradient between the particles and the surrounding fluid. This induces a density gradient and a natural convection flow

27. Define Peclet number and interception parameters for filtration. How do they affect η_s?

Ans:

Peclet number = Vd_f/D_p

Interception parameter = d_p/d_f

Where

V = characteristic velocity

d_f = fiber diameter

d_p = diameter of the particle

D_p = diffusivity of the particle

η_s is proportional to $Pe^{-0.67}$ and scales as $(R^2/1+R)$ where R is the interception parameter.

28. List 3 parameters that affect specific filter surface area, and 3 that affect pressure drop.

    Ans:

    Parameters that affect specific filter surface area :
    - Volume fraction of the fiber which is mass of fiber per unit area of packing over density of the fiber
    - Total depth of the bed
    - Fiber diameter

    Parameters that affect pressure drop :
    - Total depth of the bed
    - Viscosity of fluid
    - Phase velocity which is defined as the flow rate divided by the surface area of the filter
    - Volume fraction of the fiber

29. Describe operation of a cleanroom, including internal & external sources of particles & their controls.

    Ans: A clean room is essentially an isolated environment, in which the level of contaminants in the air is controlled in an active manner. The most popular design for the clean room is what is known as a vertical laminar flow clean room. In a VLF clean room the air enters the room at the top through filters that are located on the ceiling, it is then directed into the room in a unidirectional manner. Air flow is controlled in such a way that all the velocity is vertically down. A false floor is designed with holes so that all the air that is flowing down passes through the holes and is exhausted out.

    Some of the internal sources of particles in a clean room are the clean room facility itself, the equipment used, particles emitted from the process etc. Some external sources of particles are the people using it, chemicals, swab, gloves etc.

The contaminants of a clean room can be eliminated by using filters at the top of the clean room. This prevents external sources of impurities from flowing in. Each equipement is locally fitted with filters to remove any internal sources of contaminants in the clean room.

30. Sketch typical Pareto diagram of particle sources in a cleanroom. How is this used?

Ans:
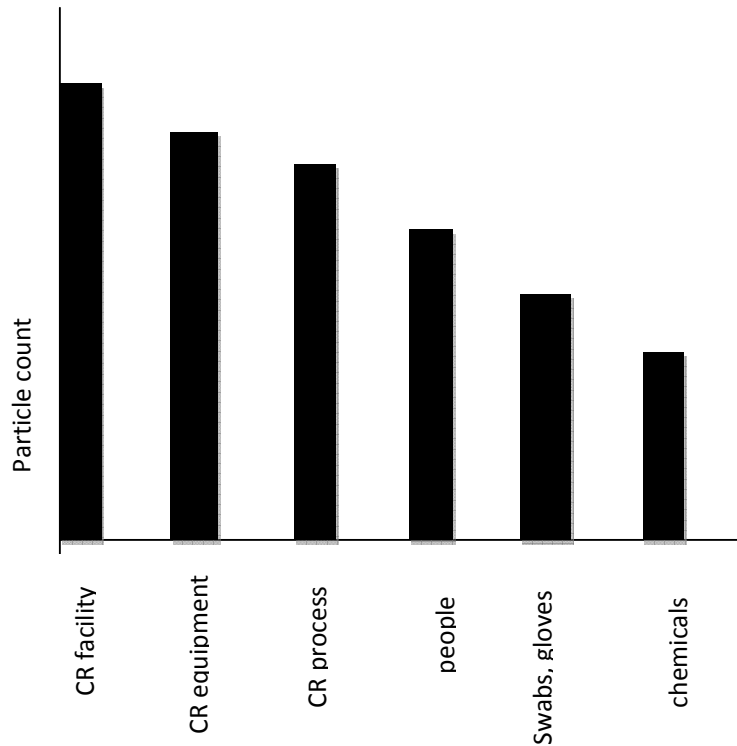
By doing a Pareto analysis, we can identify the main sources of contaminants in a clean room. Once they are identified, they can be eliminated by improving the filtration process, air circulation etc.

31. How is yield related to defect density?

Ans: Defect density is defined as the number of defects on a product per unit length. Higher the defect density, lower the yield. Therefore, yield is inversely proportional to defect density.

32. Plot probability of failure versus particle size with & without chemical effects.

Ans:
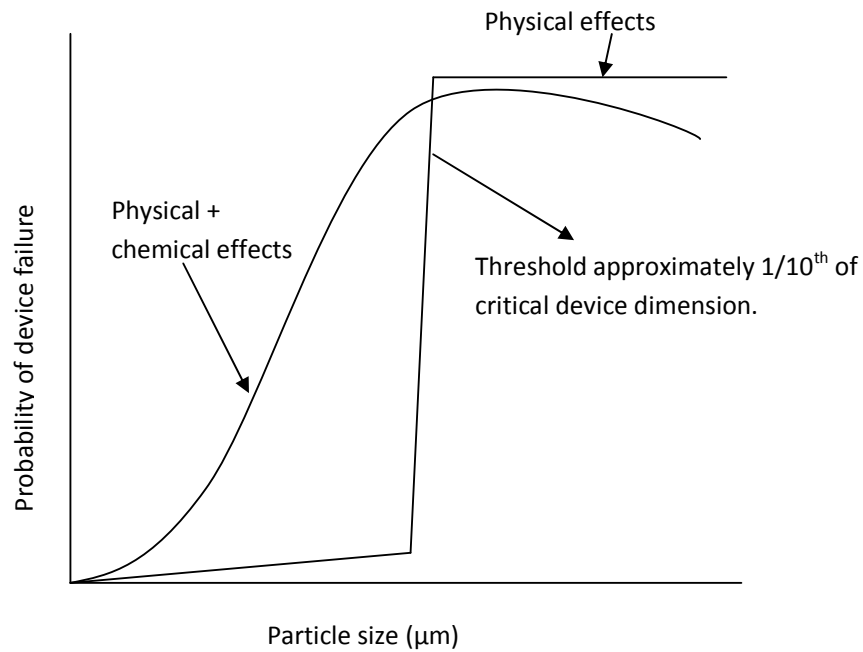
33. Identify key non-dimensional parameters influencing fluid aerosolization.

Ans: $SMD / d_o = A \, (Re)^B \, (We)^C \, (\rho_L/\rho_G)^D (\mu_L/\mu_G)^E \, (X/d_o)^F$

Where :

SMD = Sauter mean diameter = $S_{32} = \sum nidi^3 / \sum nidi^2$

d_o = spray orifice diameter

Re = Reynolds number = $d_o V \mu_L / \rho_L$

We = Weber number = $\rho_G V^2 d_o / \sigma_L$

ρ_L, ρ_G = density of liquid, gas

μ_L, μ_G = viscosity of liquid, gas

V = exit velocity of liquid from nozzle

34. Draw a decision chart involving SMD and ignition safety of a heat-transfer fluid.

Ans:

High combustion efficiency Low Hazard potential High Sauter mean diameter	High combustion efficiency High Hazard potential Low Sauter mean diameter
Low combustion efficiency Low Hazard potential High Sauter mean diameter	Low combustion efficiency High Hazard potential Low Sauter mean diameter

(vertical axis label: Combustion efficiency)

Hazard potential

35. What role do atmospheric particles play in "acid rain"?

Ans: Sulphur from automobile exhausts and factory emissions are in the form of SO_2 and SO_3. Sulphur dioxide and Sulphur trioxide react with water to form sulphuric acid and come down on earth as acid rain. Particles play a major role and act as a catalyst by providing the surface on which SO_2 and H_2O particles react to form H_2SO_4.

36. Contrast physisorption & chemisorption as mechanisms in atmospheric sulfate formation.

Ans: There are two mechanisms by which sulphate formation can happen : physisorption and chemisorption.

Physisorption occurs when we have particles and H_2SO_4 molecules are formed in the atmosphere and these molecules attach themselves to the surface of the particles.

In chemisorption, we have H_2O, SO_2 and SO_3 molecules coming together on the surface to form H_2SO_4 liquid on the surface and this is a chemisorption process because the reaction to convert the vapour species to the condensed phase happens on the surface.

37. In a dilute slurry, how does particle concentration affect removal rate?

    Ans: In a dilute slurry, the ratio of inter-particle distance (σ) over particle size(dp) must be much greater than one. This is achieved by either increasing inter-particle distance or reducing particle size. However, increasing inter-particle distance would lead to extremely dilute slurries and as the concentration decreases, associated polishing rate or removal rate also decreases.

38. How do particles affect film deposition in a plasma reactor?

    Ans: When the surface is bombarded with ions or plasma to form vapour the key is to maintain homogenous kinetics in such a way that particles do not form in the gas phase. When we use plasma to make these vapours, particles tend to charge differently from molecules. In a plasma reactor where charge is being generated, the particles will be charged differently from the vapour molecules. Therefore their transport characteristics will be very different and needs to be avoided in the design of reactors.

39. How do particles affect solar power generation?

    Ans: One of the key components in a solar device is the collector. You need a surface to collect the solar energy and this is usually polished glass. One of the limiting factors to the efficiency of the solar device is to maintain the purity of the solar collector because the formation of dust layers on the collector surfaces results in deterioration of efficiency. Therefore, particle properties play a significant role in solar energy devices.

40. How do particles affect aerospace components?

    Ans: There is a parameter in the aerospace industry called the obscuration ratio. Obscuration ratio is defined as the percent of surface covered by particles. Once obscuration ratio exceeds one percent, the surface is considered too contaminated to be used any further. Particle counters and other devices are used to track the number of particles on the surface and the surface is removed offline once the contamination exceeds a certain specified value. Therefore, particle characterization is of immense use in aerospace industry.