CHBE 344
Unit Operations I
Fall 2009
Course Syllabus

Course (Calendar) Description
Characterization of particles; comminution, screening and classification; filtration, sedimentation, centrifugal separations and fluidization; thermal operations including evaporation and crystallization.

Lectures/Tutorials
Wednesdays/Fridays 11 am – 12 pm
Fridays of alternating weeks 2 – 4 pm starting the second week

Credits 2

Lecturer
Prof. Naoko Ellis, nellis@chml.ubc.ca; 604.822.1243; CHBE room 227.
Office hours: Most times right after class (Wed/Fri) or by appointment.

Pre-requisites
(a) CHBE 242 or (b) all of CHBE 241, MECH 270; and one of CHBE 251, CIVL 215, MECH 280.

Course Objectives
After taking this course, students should be able to:
- understand and apply the basic methods of characterization of particles and bulk solids;
- evaluate efficiency and energy requirements of non-stagewise unit operations encountered frequently in process engineering;
- practice in using empirical and fundamental tools in the design of equipment and processes;
- understand the concepts and fundamentals of multiphase systems and physical separation processes;
- analyze separation processes with energy and environmental considerations.

Textbook
Course note package at bookstore for CHBE344: includes notes from:
- http://www.engineering.uakron.edu/~chem/fclty/chase/Solids/solids.html
- Towler G and Sinnott R, Chemical Engineering Design, Butterworth-Heinemann, Chapter 10 (2008).
- Allen DT and Shonnard DR, Green Engineering, Prentice Hall PTR, Chapter 9 (2002).

Other useful **References**:
- Richardson JF, Harker JH and Backhurst JR, Coulson and Richardson's Chemical Engineering, 5th ed., vol. 2: Particle Technology and Separation Processes, Butterworth Heinemann, Oxford, 2002.
- McCabe WL, Smith JC and Harriott P, Unit Operations of Chemical Engineering, 7th ed., McGraw Hill, New York, 2004.
- Rhodes M, Introduction to Particle Technology, Wiley, Chichester, 1998.
- E-book: "Chemical Process Equipment – Selection and Design", http://www.knovel.com/web/portal/browse/display?_EXT_KNOVEL_DISPLAY_bookid=401
- E-book: "Perry's Chemical Engineers' Handbook" 8th Edition, http://www.knovel.com/web/portal/browse/display?_EXT_KNOVEL_DISPLAY_bookid=2203

Topics Covered
Introduction (week 1) Chapter 0
introduction and definitions; units and fluid properties

Single Particles (week 1/2) Chapter 1

fundamentals of single particles, terminal settling velocities

Bulk Solids (week 3/4) Chapter 2

bulk solids, characterization of particle size distribution, measurement techniques, flow from hoppers, segregation mechanisms, blending of solids, comminution, agglomeration and granulation, population balances

Packed and Fluidized Beds (week 5/6) Chapter 3

Gas-Solid and Liquid-Solid Contacting: packed beds, fluidized beds, other

Fluid Particle Separation Part I(week 7/8/9) Chapter 4

sedimentation, flocculant settling, flocculants & coagulants, zone settling, gravity separation of oil droplets from water, flotation

Fluid Particle Separation Part II (week 10/11) Chapter 5

centrifugation, cyclones, hydrocyclones, filtration, gas filtration, wet scrubbers, ESP

Evaporation and Crystallization (week 12) Chapter 6

thermal operations: evaporation, crystallization

Green Engineering thinking in Separation Processes (week 13) Chapter 7

pollution prevention strategies, decision analysis for equipment selection

Assessment

8 Assignments (including a mini project)	25%
2 Quizzes during tutorial sessions or marked tutorials	10%
Midterm exam (TBA)	15%
Final exam (TBA)	50%

Course Material

All course material will be available through VISTA.

Academic Honesty

Don't ever compromise your reputation for honesty and professionalism. As stated clearly in the Academic Regulations (http://students.ubc.ca/calendar/index.cfm?tree=3,54,111,0) standards for academic honesty and integrity must be met for all submissions of work for academic credit. This implies that you must submit your own work with other sources of information being appropriately acknowledged. If you copy a write-up from your classmate, you should refer to the work done by your classmate as being the original work. Otherwise, it will be treated as plagiarism.

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1. Nomenclature

2. Solids Processing – Notes by Prof. Chase

   1. Introduction
   2. A Chemical Process Industry Perspective
   3. Properties of Particulate solids
   4. Bulk Properties of Solids
   5. Fluidization
   6. Elutriation
   7. Solid/Liquid Separations
   8. Pretreatment of S/L Mixtures
   9. Segregation Mechanisms
   10. Hopper Design
   11. Grade Efficiency

3. Towler, G., and Sinnott, R., "Chemical Engineering Design", Butterworth-Heinemann (2008)
Chapter 10 – Equipment Selection, Specification, and Design.

4. Allen, DR., and Shoonard, DR., "Green Engineering", Prentice Hall PTR (2002)
Chapter 9 – Unit Operations and Pollution Prevention.

a	surface area	m^2
A	material parameter defined in Equation 4-10	
A	cross sectional area	m^2
A	projected area normal to the flow	m^2
A_j	Projected area	m^2
A_p	projected paddle area of all paddles	m^2
a_s	specific surface area	m^2
a_s	Total surface of particles	m^2
AS	applied shear stress	N
c_0	zero charge concentration in Equation 8-2	
C	concentration	
C_0	initial concentration	
C_D, C_d	drag coefficient	
d	thickness of the double layer	m
D	diameter	m
D_c	circular opening for hoppers	m
D_p	pyramid square opening for hoppers	m
D_{eff}	effective diameter	m
d_P	particle diameter	m
d_p*	dimensionless particle diameter, defined in Equation 3-68	
D_p	Mean particle diameter	m
D_{sph}	defined diameter based on sphericity	m
d_t	vessel diameter	m
e	electronic charge	C
E	external field	
E_T	total separation efficiency	
E_t	recovery by mass	kg
f	friction factor	
F	Cumulative undersize fraction	
F_a	accelerating force	N, $kg.m/s^2$
F_b	buoyancy force	N
f_c	UYS, unconfined yield stress	N
ff	flow factor	
F_g	gravitational force	N
f_k	kinetic frictional force	N
F_k	drag force	N
Fr	Froude number = u^2/gD	
F_r	Froude number = $V_0^2/d_t.g$	
f_L	Frequency distribution based on length	
f_M	Frequency distribution based on mass (equivalent to distribution by volume)	
f_m	Frequency distribution of mass fraction	
F_m	Cumulative mass fraction	
f_N	Frequency distribution based on number	
f_S	Frequency distribution based on surface	
f_s	static frictional force	N
g	gravitational acceleration	m/s^2
G	mean velocity gradient	
G_{si}*	flux rate from an imaginary bed of all particles of size d_{pi}	$kg/m^2.s$
G_s	solids flux	$kg/m^2.s$

G_x	grade efficiency of separation of size x	
h_f	frictional head loss	m
H_f	freeboard height	m
I	ionic strength	
$I_{80/20}$	sharpness of cut, = x_{80}/x_{20}	
JYL	Jeniky Yield Locus	
k	permeability coefficient	
k	Boltzmann's constant	$m^2.kg/s^2.K$
k_1, k_2, k_3	Geometric shape factors	
k	permeability coefficient	
K	Janssen's coefficient defined in Equation 4-22	
K_1, K_2	Wen and Yu constants from Equation 5-12	
KE	characteristic kinetic energy	J
l	length	m
L	length or height of bed	m
L	liquid	
M	empirical constant used in Equation 6-1	
M	mass	kg
M_c	mass of course material	kg
M_f	mass of fine material	kg
MFF	material flow function	
M_x	mass of size x	kg
n	normal force	N
n	bulk concentration of the ν ion	
N	Avogadro's number	
N	Total number of particles	
N	normal force	N
n_j	Number of particles in the jth set	
N_{GA}	Galileo number	
P_0	initial pressure	Pa
P_i	partial pressure f component i in the vapour phase	Pa
P_i*	pure fluid vapour pressure	Pa
P_L	pressure at distance L	Pa, $kg/m.s^2$
P_v	compressive normal stress	Pa
P_w	lateral normal stress acting in the radial direction at the wall	
P_w	lateral normal stress acting in the radial direction at the wall	
Q	volumetric flow rate	m^3/s
R_{ep}	particle Reynold's number	
R_h	Hydraulic radius	m
S	solids	
S	Surface area	m^2
t	time	s
TDH	transport disengagement height	m
u	velocity	m/s
u*	dimensionless velocity	
u_t*	dimensionless terminal velocity, defined in Equation 3-67	
u_t	terminal velocity	m/s
V	volume	m^3

V_p	mean paddle speed	m/s
V_0	approach velocity, or superficial velocity	m/s
V_{0m}, u_{mf}	minimum fluidization velocity	m/s
v^s	solid velocity	m/s
v_r	velocity in the r-direction	m/s
v_θ	velocity in the θ-direction	m/s
x	Particle size	m
x_i	Particle diameter of ith size cut	m
$\overline{x_a}$	Arithmetic mean	m
$\overline{x_c}$	Qubic mean	m
$\overline{x_g}$	Geometric mean (median size where 50% of the particles are grater in size and 50% are smaller in size)	m
$\overline{x_h}$	Harmonic mean	m
x_i	mole fraction in the liquid phase	
x_n	Nth particle size	
$\overline{x_q}$	Quadratic mean	m
ZP	Zeta potential	
z	axial distance	m

β	proportionality constant used in Equation 4-14	
δ_w	wall angle	°
ΔP	pressure drop	Pa
Δx_j	Size increment range that n_j represents	m
ε	Bed porosity, voidage	
ε	dielectric constant of the liquid bulk phase	
ε_c	critical porosity	
ε_{loose}	loose packed porosity	
ε_m	minimum fluidization porosity	
ς	zeta potential	
θ	angle	
θ	coordinate	
λ	packing parameter defined in Equation 4-7	
μ	fluid viscosity	Pa.s
μ	coefficient of friction	
μ^0	bulk viscosity	Pa.s
μ_k'	velocity dependant kinetic friction	
μ_k	kinetic friction	
μ_s	static friction	
ν	valence in Equation 8-2	
ρ, ρ_g	fluid density	kg/m^3
ρ^0	bulk density	kg/m^3
ρ_P	particle density	kg/m^3
σ	Standard deviation	
σ	stress	Pa
σ_g	Geometric standard deviation	
σ_{rr}	stress in the r direction	Pa
σ_{zz}	stress in the z direction	Pa
τ	gradient	
τ_R	shear stress	
φ	coordinate	
Φ	sphericity, defined in Equation 3-63	
χ	Debeye-Huckel function	
φ	angle of wall friction	°
ψ	stream function	
ψ	double layer potential at distance x	
ψ_0	charge potential of the solid	
$\bar{}$	mean	