ENE 802 Physicochemical Processes in Environmental Engineering

Course learning objectives

At the end of this course, students will be able to:

1. Describe physical and chemical phenomena (Table, column 1) that form the basis for the design of unit processes (Table, column 2) commonly applied for the treatment of environmental media.
2. Explain how the design of each unit process (Table, column 2) leverages the theoretical knowledge of corresponding physical and chemical phenomena (Table, column 1).
3. Design physicochemical treatment processes to meet treatment goals for a given pollution scenario.
4. As a member of a student team and based on the knowledge gained in the course:
    a. Analyze a case study on a failure of a treatment process.
    b. Critically evaluate the implemented remedial approach.
    c. Propose engineering measures necessary to prevent a re-occurrence.
    d. Synthesize the results of the team inquiry in the form of a professionally prepared written report.
5. Critically evaluate research papers on physicochemical unit processes, identify hypotheses and synthesize an overall assessment of the paper in the form of a succinct written review.

Table: Physical and chemical phenomena and corresponding unit processes commonly applied for the treatment of environmental media

Physical/chemical basis	Unit operation/process
Mass transfer across a gas-liquid interface	Aeration, gas stripping, wet scrubbing. Soil vapor extraction.
Colloid stability	Mixing, coagulation and flocculation.
Sorption	Batch and column adsorption processes
Solubility	Softening and precipitation.
Flow in porous media	Granular media filtration. Soil pollution control methods.
Particle dynamics	Gravity settling, flotation, cyclonic separation, centrifugation.
Membrane filtration and osmosis.	Water and air filtration. Osmotic separations for purification and energy generation.
Chemical oxidation and reduction. Photolysis	Redox processes and disinfection. Reactive separations. Advanced oxidation processes.

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Michigan State University
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Topics covered in the course

Module 1: Gas-liquid mass transfer. Gas stripping and aeration

1. Gas-liquid equilibrium. Henry's constant
2. Mass transfer kinetics. Two film theory. Mass transfer coefficients. $K_L a$
3. Packing materials. Specific surface area a (m^2/m^3).
4. Packed tower design: McCabe-Thiell diagram, $(Q_a/Q)_{min}$ and the safety factor.
5. Packed tower design: Eckert correlation
6. Transfer units: NTU, HTU
7. Pilot testing for tower design

Module 2: Adsorption

1. Adsorption kinetics. Rates of adsorption and desorption.
2. Equilibrium. Adsorption isotherms (Freundlich, Langmuir) and related assumptions
3. Carbon dosage. Carbon utilization rate
4. Adsorbent materials. Activated carbon as a universal sorbent.
5. GAC operation: Time to breakthrough and time to exhaustion.
6. Adsorption type: chemisorption vs physisorption
7. Adsorption energies
8. GAC mass transfer zone

Module 3: Particle stability. Coagulation and flocculation

1. Particle properties (size, charge, shape) and measurement methods (Coulter counting, light scattering, microscopies, …)
2. Mixing. Mean velocity gradient $\bar{G}$
3. Particle stability: Electrostatic and van der Waals interactions. DLVO and extended DLVO (XDLVO) theories
4. Collision frequency and attachment efficiency (aka "sticking coefficient")
5. Types/mechanisms of flocculation. β_M, β_μ, β_{DS}
6. Mechanisms of coagulation (Charge neutralization, sweep, etc. and how they depend on initial turbidity and water constituents (pH, NOM, etc.))
7. Coagulant type and dose
8. Electric double layer, Debye length
9. Flocculation kinetics: Smoluchowski equation
10. Jar testing
11. non-DLVO interactions
12. Practical considerations: alkalinity demand, sludge generation

Module 4: Inertial separations

1. Force balance on a suspended particle. Stokes law
2. Drag force and drag coefficient. Particle Reynolds number
3. Overflow rate. Particle removal in rectangular clarifiers
4. Types of settling
5. Centrifugation and hydrocyclonic separation.

Module 5: Flow in porous media. Media filtration

1. Headloss (Carman Kozeny, Rose, Ergun and other equations for clean bed headloss)
2. Yao filtration model. Filtration coefficient, λ
3. Rapid vs slow filtration. Adhesion vs straining.
4. Time to breakthrough vs time to critical headloss
5. Types of filtration plants: Conventional vs direct vs inline/contact filtration
6. Specific deposit. "Filter within filter"
7. Turbidity as metric of filtered water quality. Nephelometric turbidity units.
8. Pilot testing for filter design
9. Filter media
10. Filter ripening
11. Backwash hydraulics

Module 6: Membrane-based separation

1. Pressure driven membrane separations: MF, UF, NF, RO
2. Metrics of membrane performance: permeate flux, rejection, recovery
3. Membrane fouling. Hydraulic and chemical cleaning. Reversible vs irreversible fouling
4. Concentration polarization. Film theory. Polarization factor.
5. Osmotic pressure. van't Hoff's equation
6. Dead-end vs crossflow operation
7. Intrinsic vs observed rejection
8. Other osmotic processes: forward osmosis, pressure retarded osmosis.
9. Membrane configurations: flat sheet, hollow fiber, tubular, spiral wound

Module 7: Disinfection

1. Three strategies: prevention, treatment, secure distribution systems.
2. Common disinfectants: Free chlorine, combined chlorine, O_3, ClO_2, UV,
3. Primary vs secondary disinfection. Residual disinfectant.
4. Disinfection kinetics. Kinetic models
5. CT concept