Extraction of Flavor from Vanilla Beans

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Introduction

- The extraction process impacts quality of vanilla flavor.
- Efficiency of extraction process has impact on cost of vanilla flavor.
- Improvements in quality and efficiency may be achieved through careful examination of extraction process parameters.

Objectives

- To identify the fundamental parameters influencing mass transfer during extraction.
- To describe the extraction process in terms of material balances.
- To evaluate factors influencing convective mass transfer during extraction.
- To discuss the rate-limiting diffusion parameters in the extraction process.

General Definition

- *Mass Transfer* is "the movement of a constituent within a gas, liquid or solid system due to a concentration gradient"
- Many analogies exist between mass transfer and heat transfer.
- Mathematical relationships are very similar, and charts used to solve mass transfer problems may be the same or similar to those used for heat transfer problems.

The diffusion process

- Fick's first law of diffusion –

  $$m_B/A = -D\,\partial c/\partial x$$

  where:

  m_B = mass flux of component B; moles/s

  A = area for diffusion; m^2

  c = concentration of component B; moles/m^3

  x = distance in direction of diffusion, m

  D = mass diffusivity of component B in system; m^2/s

The diffusion process

- When diffusion of a single component occurs in a system, Fick’s Law can be solved for any condition.
- For one-dimensional diffusion of component A, in a system B, the solution is:

$$m_A/A = - D_{AB} (c_{A1} – c_{A2})/(x_1 – x_2)$$

where D_{AB} is mass diffusivity of component A in system B.

Characteristics of molecular diffusion

- Concentrations do not change with time; "Steady-State"
- No convection
- Mass diffusivity (D) is not influenced by concentration
- There are no temperature gradients in the system.

Convective Mass Transfer

- When mass transfer occurs in a system with movement (gas or liquid), the magnitude of mass transfer is enhanced by convection.
- The relationship becomes:

$$m_A = k_m A (c_{A1} - c_{A2})$$

where:

k_m = mass transfer coefficient; m/s

Estimation of Mass Transfer Coefficients

- General form of dimensionless relationships:

  $$N_{Sh} = f\{ N_{Re} , N_{Sc} \}$$

  where:

  N_{Sh} = Sherwood Number

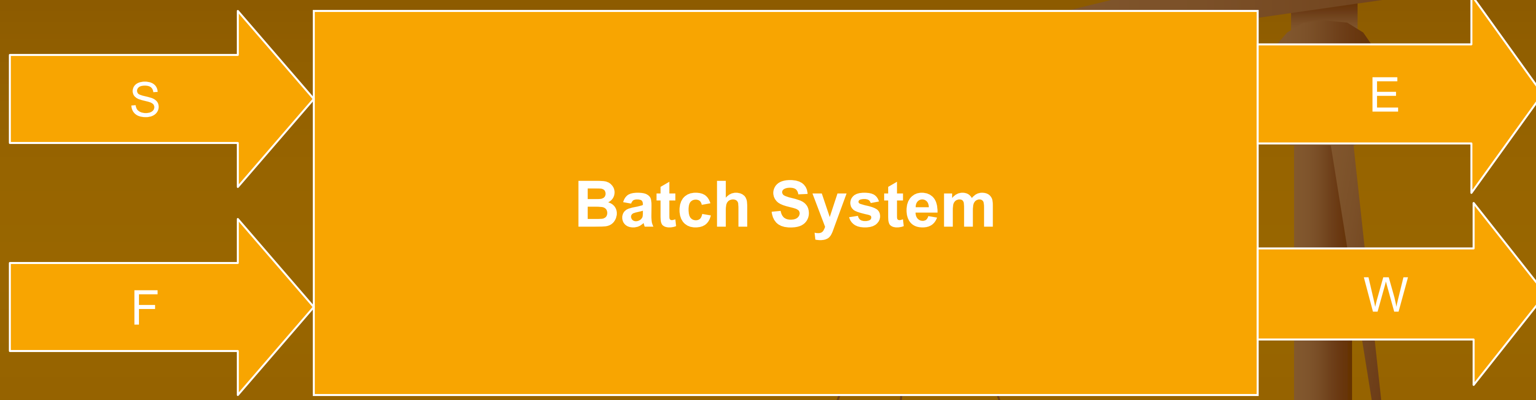
  N_{Re} = Reynolds Number

  N_{Sc} = Schmidt Number

- Note – diffusion relationships for natural convection incorporate contributions of gravity and density.

Material Balance

Extraction Process



S = quantity of Solvent into extraction process

F = quantity of material containing constituent into process

E = quantity of extract leaving the process

W = quantity of waste stream leaving the process

Material Balance Example

- Inputs:

  1. Vanilla bean; 2% flavor, 24% water, 73% solid material.
  2. Solvent; 35% ethyl alcohol, 65% water

- Outputs:

  1. Extract; flavor + alcohol
  2. Waste stream; solid material, water and residual flavor.

Example

- Additional conditions:

  1. Yield = 90%; less than 5% of flavor constituent in feed stream becomes residual in waste stream.
  2. Feed stream = 100 units per 1000 units of solvent.

- Output becomes:

  Extract = 351.925 units

  99.453% alcohol, 0.547% flavor

  Waste stream = 748.075 units

  90.23% water, 9.46% solids, 0.01% flavor

Material Balance

- Questions to be addressed:

1. What general parameters of the process influence yield?
2. How would changes in composition of the vanilla beans influence outputs?
3. Can the residual vanilla flavor in the waste stream be reduced?

Unsteady-State Mass Transfer

- Definition

  "the transfer of a component within a system when concentrations are a function of time"
- Applications include extraction of vanilla flavor from beans.
- Provides concepts needed to predict time required to achieve target yield.

Unsteady-State Diffusion

- Transient-state diffusion –

  $$\partial c/\partial t = D\ \partial^2 c/\partial c^2$$

  where:

  c = concentration of diffusing component; moles/m^3

  D = mass diffusivity of diffusing component in system; m^2/s

- Basic equations can be solved for a given geometry and boundary conditions, in same manner as similar heat transfer equations.

Analytical Solutions

- The following solutions are available, and have been used to create tables and charts for solving problems.

  a. Infinite plate or slab

  b. Infinite cylinder

  c. Sphere

  d. Infinite and semi-infinite systems

  e. Special boundary conditions; internal reactions

Applications

- Solutions are in the following form:

  $c - c_m / c_i - c_m = f\{ N_{Bi}, N_{Fo} \}$

  where:

  c = concentration at defined location and time.

  c_m = concentration outside system

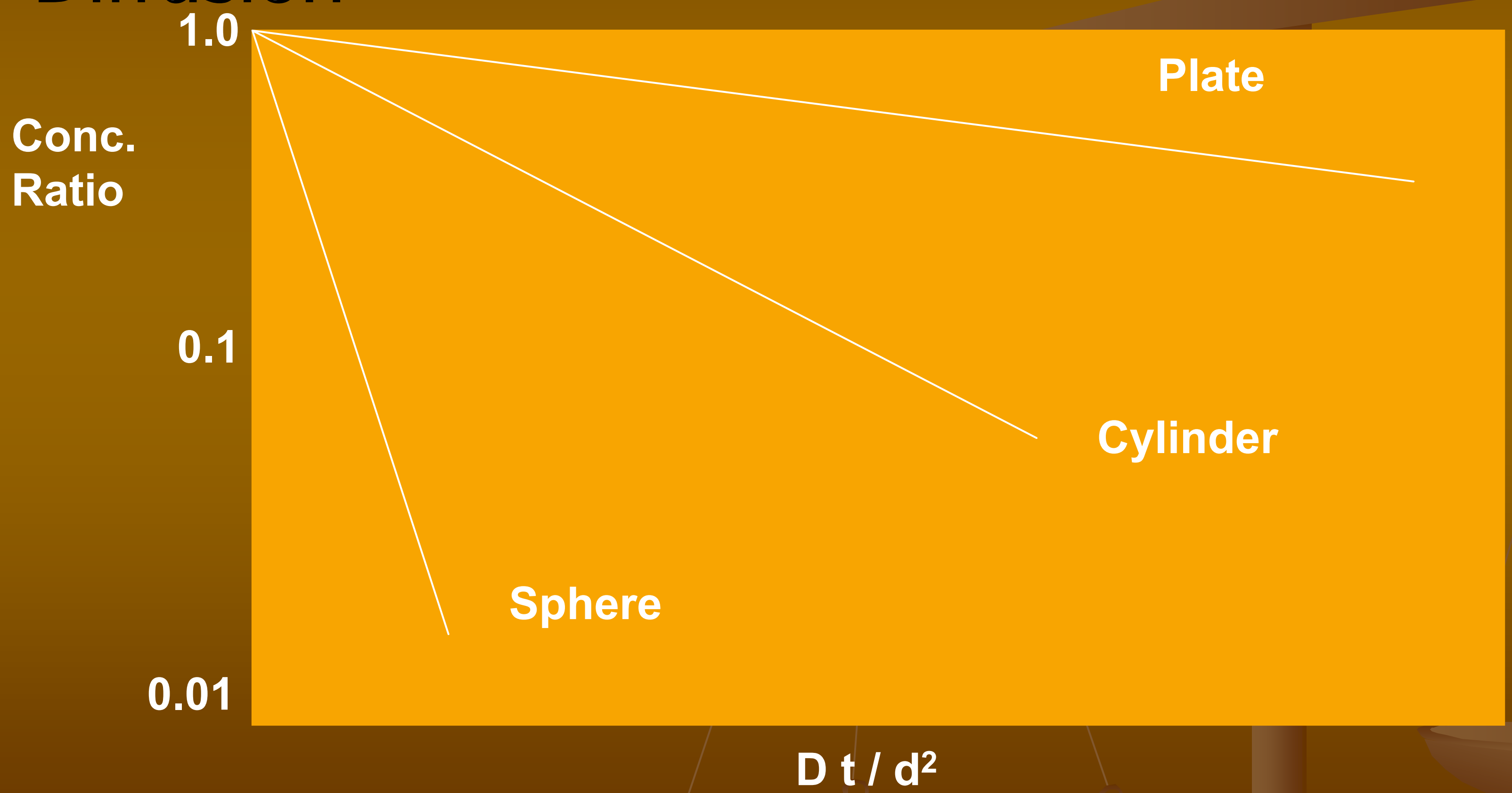
  c_i = initial concentration of system

  $N_{Bi} = k_m \, d / D$

  $N_{Fo} = D \, t / d^2$

Unsteady-State Chart

Diffusion



Example Extraction Time

- Solvent; flavor concentration = 0 (t = 0)

  flavor concentration = 0.00547 (t = ∞)
- Vanilla bean; flavor conc. = 0.02 (t = 0)

  flavor conc. = 0.0001 (t = ∞)
- Parameters:

  Mass diffusivity = 3.5×10^{-11} m^2/s

  Particle dimension = 0.001 m

Flavor Extraction Time

- Using Diffusion Rate Chart –

  Conc. Ratio = 0.0001/0.02 = 0.005

  then: $D\,t\,/\,d^2 = 0.482$

  and: Time = $(0.482)(0.001)^2 / 3.5 \times 10^{-11}$

  = 3.8 hours

Extraction Time

- Questions to be addressed –
  1. Can Mass Diffusivity (D) be increased?
  2. What is influence of particle size on extraction time?
  3. How much does the concentration gradient impact extraction time?
  4. Will convective mass transfer at the particle surface influence extraction time?