FDE 211
MATERIAL & ENERGY BALANCES

Instructor: Dr. Ilgin Paker Yikici
Fall 2015
Meet & Greet

- Hello! My name is...
- I am from...
Class Overview

- Units & Conversions
- Process & Process Variables
- Process Units & Flow Charts
- Material Balance
- Single & Multiunit Process Calculations
- Energy & Energy Balances
- Simultaneous Material & Energy Balances
Material & Energy Balances in Food Engineering

Ali Esin, 2008

Middle East Technical University Publications
Syllabus

- 2 Midterms & Final
- 5 Homework Assignments
- In class activities---- Bonus points!

- Please bring a notebook & pen/pencil to class!
Contact

- Dr. Ilgin Paker Yikici
- Office @ Food Engineering Department
- ilginyikici@gmail.com
- By appointment please!
Why Material & Energy Balances in Food Engineering?

Food engineering is concerned with processes that cause substances to undergo required changes in their chemical or physical composition, structure, energy content, or physical state.
Food engineering is the profession in which a knowledge of mathematics, chemistry, biology and other natural sciences gained by study, experience, and practice is applied to develop economic ways of using materials and energy for the benefit of mankind.

The profession encompasses the spectrum from products, to the processes and equipment for making them, and to their applications.
Turn low-value materials into high-value products are involved in product design and development

Design processes to manufacture products

Are involved in process scale-up, development, and optimization

Perform economic analysis of the production process

Operate and control the processes to ensure that product quality satisfies the required specification

Are involved in the management of the processes and in product sales and technical service.
Food Engineering

for our healthful lives

Food Engineering

Measurement and Evaluation of Physical Properties of Food

Development of New Food Processing Technologies

Development of Effective Utilization Methods for Food Waste

Effective Utilization of Resources

Utilization and Production Technologies

Basic and Applied Researches

Eco-Technology

AgroBio-Resources

Recycle
Food Engineering Principle

“Given the amount and the properties of the raw materials, calculate the amount of the products and determine their properties or vice versa.”
Material & Energy Balances
Week 1

- Unit Conversions
  - Express the same quantity in different ways
- Significant figures
- Dimensional homogeneity
  - units on both sides of the equal sign must be the same
- Processes and Process Variables
Learning Objectives

- Have a working knowledge of units and conversion between units
- Identify an invalid equation based on dimensional arguments
- Calculate process stream flow rates in a variety of units
- Calculate stream compositions in a variety of units
- Calculate pressure through the application of the manometer equation
- Be aware of the importance of material and energy balances
Dimensions, Units, and Unit Conversion

- Define dimensions and units
- Perform unit operations
- Identify units commonly used in engineering and scientific calculations
Definitions

- **Dimension**: Indicates a measurement used to designate a physical quantity or a characteristic variable under consideration

  Examples: Mass, length, time, force

- **Unit**: A dimension to designate the magnitude or size according to a reference scale

  Examples: Meter for length, Kilogram for mass, seconds for time, Newton for force
Definitions

- **Unit System**: The general heading used to indicate which standard scale of measure is adopted as units of dimensions

  Examples: British system, American system, International system

- **Base units**: Dimensionally independent units and can designate only one dimension

  Examples: Unit of length, unit of time, unit of mass
Definitions

Derived units: Combinations of the units of various dimensions which may have a special name or a defined as a group.

Example: In SI, Pascal or kg\(\times m^{-1}\times s^{-1}\)
# Systems of Units

### International System of Units

- **SI**: Meter [m], Second [s], Kilogram [kg], Newton [N]
- **CGS**: Centimeter [cm], Second [s], Gram [g], dyne
- **AES**: Foot [ft], Second [s], Pound mass [lbm], Pound force [lbf]

### Conversion Factors
- 1.0 N = Force that will accelerate a mass of 1.0 kg by 1.0 m/s²
- 1.0 dyne = Force that will accelerate a mass of 1.0 g by 1.0 cm/s²
- 1.0 lb = Force that will accelerate a mass of 1.0 lbm by 32.174 ft/s²

### Metric Prefixes

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Symbol</th>
<th>Factor</th>
<th>Unit</th>
<th>Prefix</th>
<th>Symbol</th>
<th>Factor</th>
<th>Unit</th>
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<tbody>
<tr>
<td>10⁶</td>
<td>M</td>
<td>10⁶</td>
<td>Mega</td>
<td>K</td>
<td>k</td>
<td>10³</td>
<td>Kilo</td>
</tr>
<tr>
<td>10⁵</td>
<td>G</td>
<td>10⁵</td>
<td>Giga</td>
<td>M</td>
<td>m</td>
<td>10⁴</td>
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<td>10⁴</td>
<td>T</td>
<td>10⁴</td>
<td>Tera</td>
<td>G</td>
<td>g</td>
<td>10³</td>
<td>Giga</td>
</tr>
<tr>
<td>10³</td>
<td>P</td>
<td>10³</td>
<td>Peta</td>
<td>M</td>
<td>m</td>
<td>10²</td>
<td>Mega</td>
</tr>
<tr>
<td>10²</td>
<td>E</td>
<td>10²</td>
<td>Exa</td>
<td>P</td>
<td>p</td>
<td>10¹</td>
<td>Peta</td>
</tr>
</tbody>
</table>

### Acceleration of Gravity
- **g** = 9.8066 m/s² (sea level, 45° latitude)
- **g** = 32.174 ft/s²

### Gas Constant

- **R** = 10.731 psia-ft³/lbmol = 0.7302 atm-ft³/lbmol
- **R** = 0.082056 atm-L/mole-K = 8.3143 Pa·m³/mole-K
- **R** = 0.08314 L-bar/mole-K = 1.987 Btu/lb mol = 8314.3 J/kg mol-K
- **R** = 8.3143 J/mole-K = 62.36 L-mmHg/mole-K = 1.987 cal/mol-K

### Density of Water at 4°C
- **ρ** (H₂O, 4°C) = 1.0 g/cm³ = 1.0 kg/L = 10³ kg/m³
- **ρ** (H₂O, 4°C) = 8.34 lbm/gal = 62.43 lbm/ft³

### Specific Gravity of Water
- ** Specific gravity of water = 1.0 **

### Specific Gravity of Hg
- ** Specific gravity of Hg = 13.6 **
# Quantities, Units, Symbols in SI

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit (Base Unit)</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>Meter</td>
<td>m</td>
</tr>
<tr>
<td></td>
<td>Centimeter</td>
<td>cm</td>
</tr>
<tr>
<td>Mass</td>
<td>Kilogram</td>
<td>kg</td>
</tr>
<tr>
<td></td>
<td>Gram</td>
<td>g</td>
</tr>
<tr>
<td>Time</td>
<td>Second</td>
<td>s</td>
</tr>
<tr>
<td></td>
<td>Day</td>
<td>day</td>
</tr>
<tr>
<td>Temperature</td>
<td>Celsius</td>
<td>°C</td>
</tr>
<tr>
<td></td>
<td>Kelvin</td>
<td>K</td>
</tr>
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</table>

Quantities, Units, Symbols in SI

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit</th>
<th>Symbol</th>
<th>In Terms of Base Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>Liter</td>
<td>L</td>
<td>0.001 m³</td>
</tr>
<tr>
<td>Force</td>
<td>Newton</td>
<td>N</td>
<td>1 (kg·m)/s²</td>
</tr>
<tr>
<td>Energy</td>
<td>Joule</td>
<td>J</td>
<td>1 N·m = 1 kg·m²/s²</td>
</tr>
<tr>
<td>Pressure</td>
<td>Pascal</td>
<td>Pa</td>
<td>N/m²</td>
</tr>
<tr>
<td>Density</td>
<td></td>
<td></td>
<td>g/cm³</td>
</tr>
<tr>
<td>Molecular weight</td>
<td></td>
<td></td>
<td>g/mol</td>
</tr>
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</table>

## Units Associated with Systems of Units

<table>
<thead>
<tr>
<th>System</th>
<th>Mass ($m$)</th>
<th>Length ($l$)</th>
<th>Time ($t$)</th>
<th>Temperature ($T$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SI</td>
<td>Kilogram (kg)</td>
<td>Meter (m)</td>
<td>Second (s)</td>
<td>Kelvin (K)</td>
</tr>
<tr>
<td>AES</td>
<td>Pound mass (lb_m)</td>
<td>Foot (ft)</td>
<td>Second (s)</td>
<td>Degree Fahrenheit (°F)</td>
</tr>
<tr>
<td>CGS</td>
<td>Gram (g)</td>
<td>Centimeter (cm)</td>
<td>Second (s)</td>
<td>Kelvin (K)</td>
</tr>
<tr>
<td>FPS*</td>
<td>Pound mass (lb_m)</td>
<td>Foot (ft)</td>
<td>Second (s)</td>
<td>Degree Fahrenheit (°F)</td>
</tr>
<tr>
<td>British</td>
<td>Slug</td>
<td>Foot (ft)</td>
<td>Second (s)</td>
<td>Degree Celsius (°C)</td>
</tr>
</tbody>
</table>

* Imperial system units are sometimes referred to as FPS.
## Summary SI

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit</th>
<th>Symbol</th>
<th>Formula</th>
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<tbody>
<tr>
<td>Length</td>
<td>Meter</td>
<td>m</td>
<td>-</td>
</tr>
<tr>
<td>Mass</td>
<td>Kilogram</td>
<td>Kg</td>
<td>-</td>
</tr>
<tr>
<td>Time</td>
<td>Second</td>
<td>Sec or s</td>
<td>-</td>
</tr>
<tr>
<td>Temperature</td>
<td>Kelvin</td>
<td>K</td>
<td>-</td>
</tr>
<tr>
<td>Force</td>
<td>Newton</td>
<td>N</td>
<td>Kg*m/s²</td>
</tr>
<tr>
<td>Pressure</td>
<td>Pascal</td>
<td>Pa</td>
<td>N/m²</td>
</tr>
<tr>
<td>Frequency</td>
<td>Hertz</td>
<td>Hz</td>
<td>1/s</td>
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<tr>
<td>Energy</td>
<td>Joule</td>
<td>J</td>
<td>N*m</td>
</tr>
<tr>
<td>Power</td>
<td>Watt</td>
<td>W</td>
<td>J/s</td>
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## Summary

<table>
<thead>
<tr>
<th>System</th>
<th>Use</th>
<th>Length</th>
<th>Mass</th>
<th>Time</th>
<th>Temperature</th>
<th>Force</th>
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<tr>
<td>SI</td>
<td>Universal</td>
<td>Meter</td>
<td>Kilogram</td>
<td>Sec</td>
<td>K</td>
<td>Newton</td>
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<tr>
<td>British</td>
<td>Scientific</td>
<td>foot</td>
<td>Pound (lb)</td>
<td>sec</td>
<td>F</td>
<td>Pound force</td>
</tr>
</tbody>
</table>
Conversions: Mass

1 lb = 0.453593 kg = 453.593 g = 16 oz

1 kg = 1000 g = 2.20462 lb = 0.001 t
Conversions: Length

1 ft = 12 in.
1 ft = 0.3048 m = 30.48 cm
1 in. = 2.54 cm
1 mile = 5280 ft
1 m = 39.37 in. = 3.2808 ft = 1.0936 yd = 0.0006214 mi
Conversions: Volume

$1 \text{ ft}^3 = 7.481 \text{ gal} = 1728 \text{ in.}^3 = 28.317 \text{ L} = 28,317 \text{ cm}^3$

$1 \text{ gal} = 231 \text{ in.}^3$

$1 \text{ in.}^3 = 16.387 \text{ cm}^3$

$1 \text{ cc} = 1 \text{ cm}^3 = 1 \text{ mL}$

$1000 \text{ mL} = 1 \text{ L}$

$1000 \text{ L} = 1 \text{ m}^3 = 35.3145 \text{ ft}^3 = 264.17 \text{ gal} = 1056.68 \text{ qt}$

$8 \text{ fl oz} = 1 \text{ cup}$

$4 \text{ cup} = 1 \text{ quart}$

$4 \text{ quart} = 1 \text{ gal} = 128 \text{ fl oz}$
Conversions: Density

Density = \frac{\text{Mass}}{\text{Volume}}

1 \text{ g/cm}^3 = 1 \text{ kg/L} = 1000 \text{ kg/m}^3 = 62.428 \text{ lb/ft}^3 = 8.345 \text{ lb/gal}
Conversions: Pressure

1 bar = 105 Pa = 100 kPa = 105 N/m²

Pascal (Pa) is defined as 1 N/m² = 1 kg/m-s²

1 atm = 1.01325 bar = 14.696 lbf/in.² = 760 mmHg at 0°C (torr) = 29.92 in Hg at 0°C

1 psi = 1 lbf/in.²

psia (absolute) = psig (gauge) + 14.696
Conversions: Energy

$1 \text{ J} = 1 \text{ N}^\ast \text{m} = 1 \text{ kg}^\ast \text{m}^2/\text{s}^2$
Conversions: Temperature

K (absolute temperature)
C (relative temperature)

\[ T (K) = T (^\circ C) + 273.15 \]

Freezing point at water= 0 °C
Boiling point of water= 100 °C
Absolute zero= -273.15 °C = 0 K
Conversions: Temperature

- $1 \, \text{K} = 1.8 \, (^\circ \text{R})$
- $T \, (^\circ \text{F}) = T \, (^\circ \text{R}) - 459.67$
- $T \, (^\circ \text{F}) = 1.8 \, T\, (^\circ \text{C}) + 32$
How to convert

1. Determine old & new units
2. Determine the relationship between old & new units
3. Write an equality
4. Determine conversion factor

Multiply old units with conversion factor
Cancel out old units
Example

- Convert 5 inches to cm

1. Old unit: inch  New unit: cm
2. 1 in = 2.54 cm
3. \[
\frac{1 \text{ in}}{2.54 \text{ cm}} = \frac{2.54 \text{ cm}}{1 \text{ in}} = 1
\]
4. \[
5 \text{ in} \times \frac{2.54 \text{ cm}}{1 \text{ in}} = 12.7 \text{ cm}
\]
Example

- Convert 15 ft\(^2\) to m\(^2\)

1. Old = ft\(^2\)  New = m\(^2\)

2. 1 ft = 0.3048 m \rightarrow 1 ft^2 = 0.0929 m^2

3. \[\frac{1 \text{ ft}^2}{0.0929 \text{ m}^2} = \frac{0.0929 \text{ m}^2}{1 \text{ ft}^2} = 1\]

4. \[15 \text{ ft}^2 \times \frac{0.0929 \text{ m}^2}{1 \text{ ft}^2} = 1.3935 \text{ m}^2 \approx 1.4 \text{ m}^2\]
Example

- Convert 50 mph to m/s

1. Old = mph or mi/h  New= m/s
2. 1 mi = 1.609 km = 1609 m
   1 h = 3600 s
3. \[
   \frac{1\text{mi}}{1\text{h}} \times \frac{1609\text{ m}}{1\text{mi}} \times \frac{1\text{h}}{3600\text{s}} = 0.45\text{ m/s}
   \]
4. 50 \times 0.45 = 22.35 \text{ m/s}
On a warm day, outside temperature reads 82 °F. What does this correlate to in °C?

\[
T (°F) = 1.8 \times T(°C) + 32
\]

a. 20  
b. 25  
c. 28  
d. 33
In Class Problems

- Convert 30 mg/s to its equivalent in kg/h
- Convert 30 lb/s to its equivalent in kg/min
- Convert a volume of 5 ft$^3$ to its equivalent in m$^3$
Conversion of 30 mg/s to kg/h

$$30 \text{ mg/s} \times 1 \text{ g/1000mg} \times 1 \text{ kg/1000g} \times 3600\text{s/h} = 0.11 \text{ kg/h}$$
Convert 30 lb/s to kg/min

\[
30 \text{ lb/s} \times 1 \text{ kg/2.205 lb} \times 60 \text{ s/min} = 816.3 \text{ kg/min}
\]
Convert 5 ft\(^3\) to m\(^3\)

\[5 \text{ ft}^3 \times (1 \text{ m}/3.28 \text{ ft})^3 = 0.14 \text{ m}^3\]
Significant Figures

The significant figures of a number are the digits from the first nonzero digit on the left to either the last digit (zero or nonzero) on the right, if there is a decimal point, or the last nonzero digit of the number, if there is no decimal point.
Significant figures with decimal point

Count from nonzero on the left to the last digit on the right:

- 0.0012: \( (1.2 \times 10^{-3}) \)
  - 2 significant figures

- 0.001200 \( (1.200 \times 10^{-3}) \)
  - 4 significant figures
Count from nonzero on the left to the last nonzero on the right:

40500 \( (4.05 \times 10^4) \)

3 significant figures

182300 \( (18.23 \times 10^4) \)

4 significant figures
Dimensional Homogeneity

The dimensions on both sides of the “equals” sign in an equation must be the same
Equations must be dimensionally homogeneous.

Consequently, the units of each term in the equation must be the same (via conversion) as the units of other terms it is added to or subtracted from.

It is also good practice to identify an invalid equation based on dimensional arguments.
Which of the following equations are dimensionally homogeneous?

1. \( X (m) = x_0 (m) + 0.30 (m/ft) \times (ft/s) t(s) + 0.5a (m/s^2) t (s^2) \)

2. \( P (kg/ms^2) = 101,325 (Pa/atm) \times 1 ((kg/ms^2)/Pa) \times P_0 (atm) + P_1 (kg/m^3) \times (m/s) \)
Dimensional Homogeneity

\[ x(t) = x_0 + 0.30 \text{(m/ft)} \times (\text{ft/s}) t + 0.5a \text{(m/s}^2\text{)} t^2 \]
Maintaining Dimensional Consistency

\[ C = -0.03 \, e^{-2.00 \, t} \]

Where, \( C \) has the units kg/L, \( t \) has the units seconds

- What are the units associated with 0.03 and 2.00?

**Solution:** Unit of 0.03 is the same as the unit of \( C \) (kg/L). Because the argument of an exponential function must be dimensionless, the figure 2.00 must have a unit \( s^{-1} \).
Dimensionless Quantities

- help predict similar flow patterns in different fluid flow situations
- An example of dimensionless quantities is the Reynolds number (Re):

\[ Re = \frac{\rho \upsilon D}{\mu} \]

\( \rho = \) the fluid density

\( \upsilon = \) the fluid velocity

\( D = \) the pipe diameter

\( \mu = \) the fluid viscosity
Dimensionless Quantities

\[ Re = \frac{\rho u D}{\mu} \]
\[ \rho = \text{kg/m}^3 \]
\[ u = \text{m/s} \]
\[ D = \text{m} \]
\[ \mu = \text{kg/m}*\text{s} \]

so

\[ Re = \frac{((\text{kg/m}^3) \times (\text{m/s}) \times \text{m})}{\text{kg/m}*\text{s}} \]
Next Class!

- Processes & Process Variables!