DES487 Lecture Summary

Topic in Computer Information System: General Food Science
SIIT DE Y3T3/2021 – By Paphana Yiwsiw (@waterthatfrozen)

Contents

Lecture 1 –Introduction to Food Preservation

Dimension

- A physical entity is defined qualitatively by a dimension, quantitative magnitude of a dimension is expressed by a unit.
- SI unit system is based on 7 dimensionally independent: Length (m), Mass (kg), Time (s), Electric current (A), Temperature (K), Amount of substance (mol), and Luminous intensity (cd).
- Derived units are combinations of base units by multiplication and division.
- Supplementary units are used along with base and derived unit such as plane angle (radian) and solid angle (Sr).

System

- A system is prescribed in space or finite quantity of matter enclosed by a boundary, either real or imaginary. Everything outside the boundary becomes the surroundings.
- Real boundary of a system can be the wall of a tank etc., and it can be imaginary surface that can enclose the system. The boundary can also be movable or immovable.
- Open system can be transfer mass, heat, and work freely. But Closed system doesn't exchange mass with its surrounding (mass is constant), it may exchange heat and work which can result in change of energy, volume, and other properties of the system.
- Equilibrium state is when all properties of a system will have the fixed values which we can calculate and obtain the complete description of the system. If it changes, the state of the system will change.

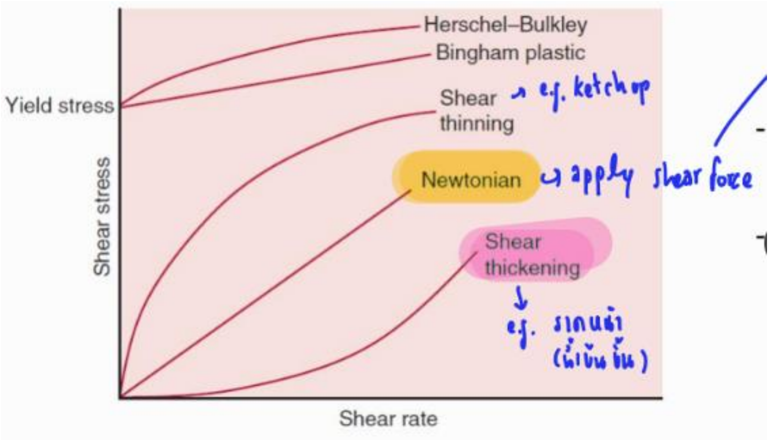
Variables

- Density: there are 3 types of density, solid density (calculate with no space), bulk density (calculate with space), particle density (inside the particle).
    - Porosity = 1 – (Bulk density / Solid density)
    - Interparticle porosity = 1 – (Bulk density / Particle density)
- Concentration: $X_A = n_A / (n_A + n_B)$; n → mol
- Moisture Content (MC)
    - wb: wet base, db: dry base
    - MC_{wb} = mass of water / (mass of water + mass of dry solid)
    - MC_{db} = mass of water / mass of dry solid
    - $MC_{wb} = MC_{db} / (MC_{db} + 1)$; $MC_{db} = MC_{wb} / (1 - MC_{wb})$
- Sweetness (Brix%)
    - (Sucrose or Sugar amount (in kg) / Solution amount (in kg)) x 100

Liquid Transport System

- Fluids in food processing plants are transported mostly in pipes or ducts (closed conduits)
- Pumps may be classified as centrifugal (increase liquid pressure/for low viscosity liquid food ex. milk and juice) or positive displacement (pressure to push liquid/for viscous liquid ex. honey)

Properties of Liquids



- Fluid flow takes place when force is applied on a fluid, defined as stress (force per unit area)
    - Shear stress is when the force acts parallel upon the surface
- Viscosity: Physical property that describes the resistance of the material to shear-induced flow
    - Shear stress unit: Pa (Pascal)
    - Shear rate: poise (dyne*s/cm^2) → 1 poise = 0.1 Pa s → 1 cP (centi-poise) = 1 mPa s
    - Kinematic viscosity = dynamic viscosity / density

Food Preservation

Food Processing and Process Control

- It involves many unit operations to carry out the food processing.
- It can operate in a batch mode (need intervention from human) or continuous mode (higher efficiency). Some operations require human intervention such as inspection etc.
- Example of the process in canning tomatoes are as follows: Unloading → Washing → Lye-Bath Peeling → Peel removal → Filling → Sealing → Retorting → Distribution
- Criteria to be addressed in food manufacturing are: production capacity, quality and hygiene, flexibility, optimal use of labour, economic, environmental regulations, safe working environment, and special constrain by processing equipment.

Processing Variables and Performance Indicators

- Operators are often concerned with a variety of different process variables. They must ensure that it must reach the desired value for the specified amount of each variable. It can result in either under-processed or over-processed and quality drop if it does not satisfy.
- There are 3 types of variables:
    - Controlled variables are variables that can be controlled in the system, such as pressure, density, density, moisture content, color, etc.
    - Uncontrolled variables cannot be controlled as the process is carried out.
    - Manipulated variables are dependent variables that can be changed to bring the desired outcome. It can be either human operator or a control mechanism. Such as the temperature change due to the change of the steam flow rate.
- Disturbances in the variables are caused by some changes outside the system boundary which can resulted in the undesired changes in output.
- Robustness is the system tolerance to the changes in process parameters. It can make the system unstable if there is small change in process parameter when robustness decreased.
- Performance tells how effective the control system is.
- There is a trade-off among robustness and performance.

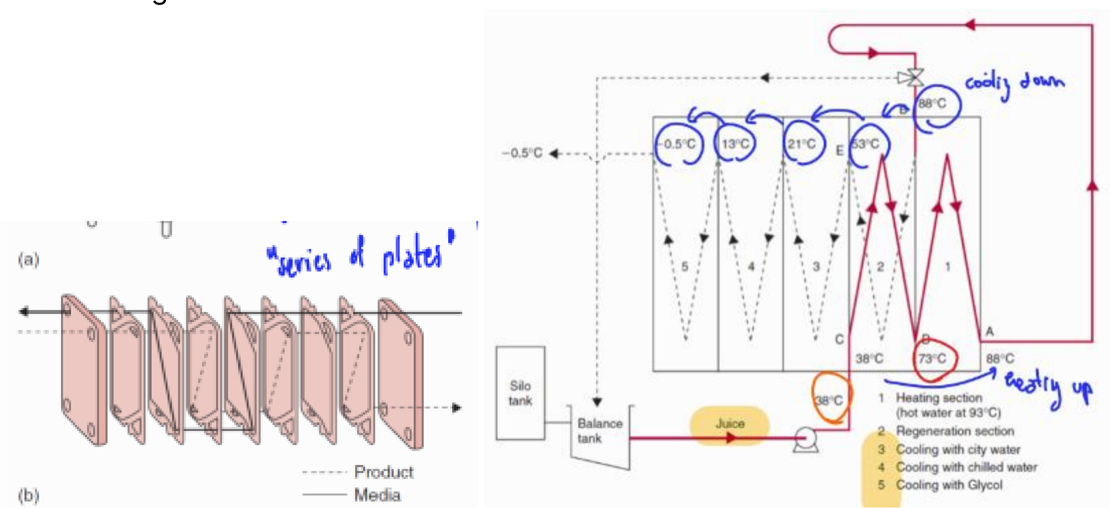
Input and Output Signals to Control Processes

- Output signals sends command to tell components of an equipment such as valves and motors to act in a certain way.
- Input signals provide feedback after processing components is acted, measure process variables, and monitor equipment and detect process completion.

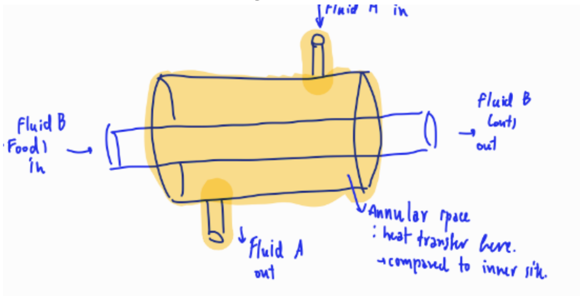
Design of a Control System

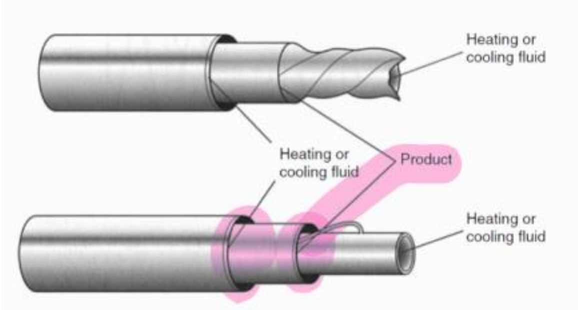
- Control Strategy
  - Equipment may set to be digital control (on/off) or analog signal (ranged).
  - Monitoring to check for critical aspects of the process and major fault that might occurs.
  - You need to know what you need to control.
- Feed<u>back</u> Control System
  - “Change then adjust”
  - Determine and continuously update the value position as the load condition changes.
- Feed<u>forward</u> Control System
  - “Before it happens”
  - It anticipated the change in the system and act prior to any changes in the system
  - Like evaluate then adjust to prevent it. Like predict to prevent.
- On-Off Control
  - The control can be either max or no flow. Valve signal is on or off.
- Transmission lines are used to carry signals from sensor to controller and controller to control element. It can be electric or pneumatic or liquid.
- Final control element implements an action according to the signal it received. The most common one is the pneumatic valve.

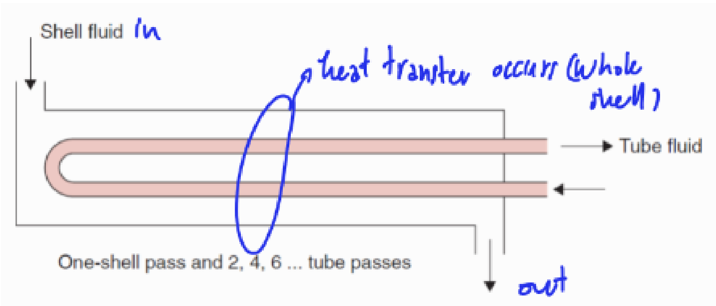
Systems for Heating and Cooling Food Products

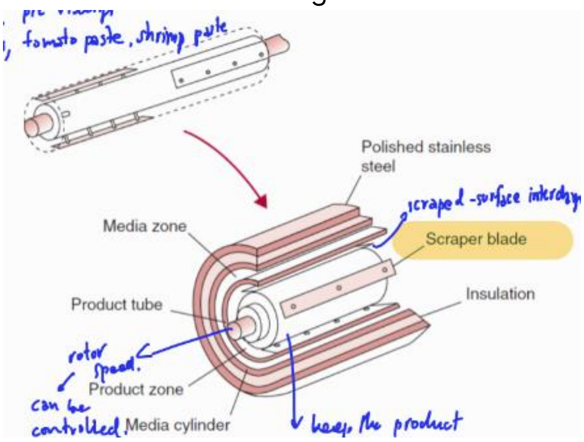
- Plate Heat Exchanger
  - 

  - “Energy Conservation” used to cool or heat up
  - The gaskets help to direct or cooling and product stream flow. It can be either parallel or counter flow to each other.
  - It is suitable for low-viscosity (< 5 Pa s) liquid food. If solids are present, particles should be less than 0.3 cm.
  - A liquid food is heated to pasteurization. The cold stream is heated to a temperature where it requires little additional energy.
  - %regeneration = (T preheat – T start) / (T holding – T start) x 100

- Tubular Heat Exchanger
  - Most simple
  - Double-pipe heat exchanger consists of concentric pipe inside another pipe.
    - 

    - Two fluid flow in the annular space and in the inner pipe.
    - It can be either parallel flow or counter flow.
  - Triple-tube heat exchanger
    - 

    - product flows in the inner annular space, heating or cooling medium flow in the inner tube and outer annular space.
  - Shell-and-tube heat exchanger
    - 

    - One of the fluid flows inside while other is pumped over the tube.
    - Heat exchange occurs at the shell allow for the crossflow pattern
  - Scraped-surface heat exchanger
    - 

    - Suitable for soup, citrus concentrate, pie fillings, peanut butter etc.
    - Heat transfer to a fluid is affected by hydraulic drag and heat resistance.
    - Its application is heating, pasteurizing, sterilizing etc.

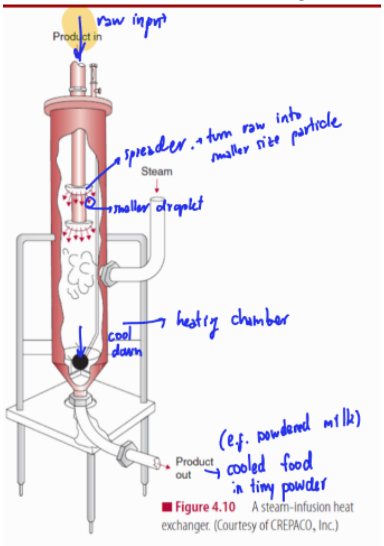
- Steam-Infusion Heat Exchanger
    - 

Figure 4.10 A steam-infusion heat exchanger. (Courtesy of CREPACO, Inc.)
    - Provide a direct contact between steam and product.
    - The viscosity of the liquid determines the size of the spreaders.
    - High rates of heat transfer are achieved when steam contact tiny food droplet.

- A wide variety of food products is processed using heat exchangers.
- Thermal properties such as specific heat, thermal conductivity and diffusivity of food can play important role in heat transfer rate calculations.
- Mode of heat transfer: Conduction, Convention, Radiation.
- Steady-state (surrounding = system/no gradient of change) and unsteady-state (gradient of change exist)

Pathogenic Microorganism

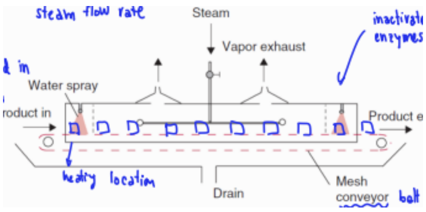
- Bacteria: 0.5 – 10 microns / Microbial spoilage type / cause food poisoning.
- Yeast: baker yeast → leavening agent. / Active dried yeast work better with bread.
- Mold/Fungi: air/everywhere, refers population as colony.
- Virus: ex. Hepatitis A, Rotavirus
- Parasite: need host to survive, biological hazard, cause of food-borne disease.

Lactic Acid

- Probiotic, good for digestive system
- Prevent/reduce the growth of pathogenic bacteria
- Solid state fermentation → produce antioxidant, helps with aging.

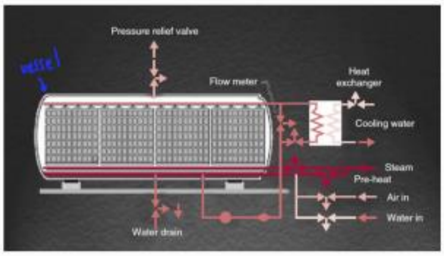
Processing Systems

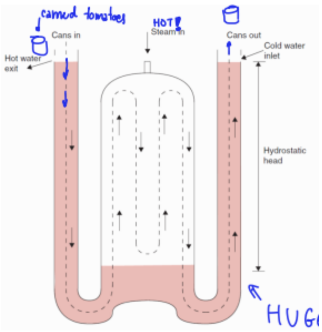
Pasteurization and Blanching Systems

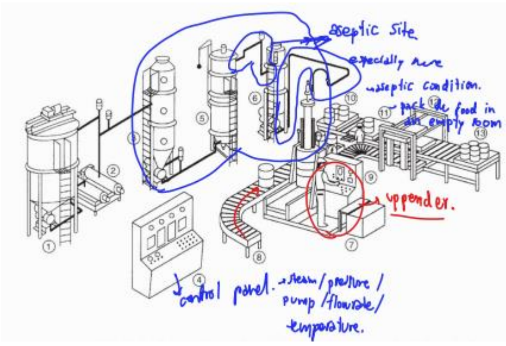
- Traditional thermal processing
- Designed to eliminate pathogenic microorganism and other causing deterioration to extend the shelf-life and food safety.
- Blanching is thermal process to inactivate enzymes. Achieve a similar to pasteurization but with application to solid food.
    - 

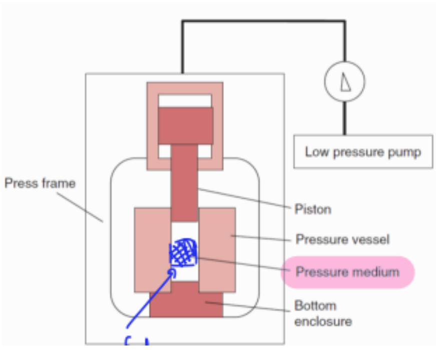
- HTST; continuous high-temperature-short-time components includes heat exchanger, holding tube, pump and control flow, and flow diversion valve (FDV).

Commercial Sterilization System

- Objectives: extend shelf-life significantly and steady (food didn't change due to time)
- Temperature used exceed boiling point of water (over 100/ can be kept in fridge > 2 yrs for milk).
- System can be
    - Batch system: still retort, product in vessel after placed in container.
        - 

    - Continuous retort system: canned food, vessel is filled with product container then sealing of vessel.
        - 

        - Pouch processing system designed for metal canned food products. Unique crate within the vessel to suspend the product pouches in the steam environment.
    - Aseptic system: Process is accomplished before product is placed in container or package. The system requires independent sterilization of the container.
        - 

    - Ultra-High Pressure System
        - 

        - Placing product in the vessel, fill the space with medium, pressure increased by pumps or piston to reduce the volume surroundings.

- Pulsed Electric Field System
- Alternative Preservation Systems: UV light, pulsed light, ultrasound etc.

Microbial Survivor Curves

- Death rate curve
- First-order curve
- The decimal reduction **D** defined as the time that microorganism reduced by 90%.

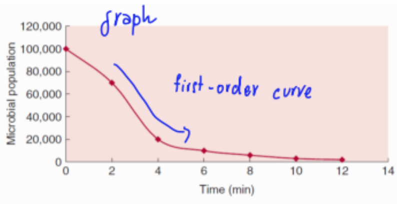


Figure 5.8 A survivor curve for a microbial population.

A general model for description of the microbial curve

First order

$$\frac{dN}{dt} = -kN$$

concentration, microbial population; order of the reaction; time; rate constant

$$\frac{dN}{dt} = -kN$$

$$A \xrightarrow{k_1} B$$

$$r = -\frac{d[A]}{dt} = k_1[A]$$

rate, concentration

time: $t = 0$; $[A] = a_0$

$t = t$; $[A] = a$

survivor curve:

$$\log N_0 - \log N = \frac{t}{D}$$

$$\boxed{D = \frac{t}{\log N_0 - \log N}}$$

initial, final

$$\frac{N}{N_0} = 10^{-t/D}$$

$$\frac{N}{N_0} = e^{-kt}$$

$$\boxed{k = \frac{2.303}{D}}$$

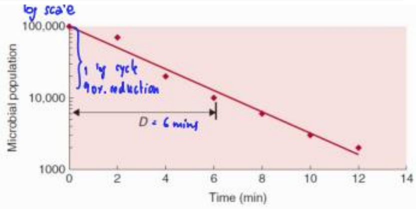


Figure 5.9 Microbial survivor curve on semilogarithmic coordinates.

Time (min)	Number of survivors
0	10^6
4	1.1×10^5
8	1.2×10^4
12	1.2×10^3

Determine the D value of the microorganism.

first-order

$$\log N_0 - \log N = \frac{t}{D}$$

non-first order

$$\log N_0 - \log N = \left(\frac{t}{D'}\right)^n$$

$$D = \frac{12 \text{ mins}}{\log(10^6) - \log(1.2\times10^3)} = \frac{12 \text{ mins}}{6 - 3.079} = \frac{12}{2.921} \approx \underline{4.108 \text{ mins.}}$$

- Non first-order

The following survivor curve data were obtained during an ultra-high pressure process of a food product at 300 MPa:

Example 5.2

Time (s)	Microbial Numbers
0	1000
1	100
2	31
3	20
4	30
5	10
6	6
7	6
8	5
16	2
24	1

Determine the parameters needed to describe the survivor curve.

$$\log \frac{N_0}{N} = \left(\frac{t}{D'}\right)^n$$

$$\underbrace{\log\left(\log \frac{N_0}{N}\right)}_{y} = \underbrace{n}_{m}\left[\underbrace{\log(t)}_{x} - \underbrace{\log D'}_{c}\right]$$

$$= \underbrace{n}_{m} \underbrace{\log(t)}_{x} - \underbrace{n \log D'}_{c}$$

The following survivor curve data were obtained during an ultra-high pressure process of a food product at 300 MPa:

Example 5.2

Time (s)	Microbial Numbers
0	1000
1	100
2	31
3	20
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6	6
7	6
8	5
16	2
24	1

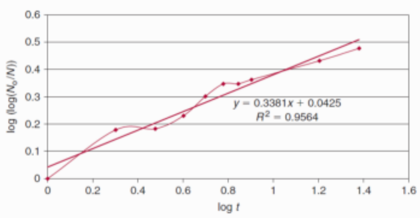
Determine the parameters needed to describe the survivor curve.

slope = 0.3381

intercept = 0.0425

$$D' = 10^{\left(\frac{0.0425}{0.3381}\right)} = \underline{0.74 \text{ s}}$$

$$n = 0.34$$



(intercept/slope)

- Thermal Death Time; **F**
  - Total time required to accomplish a stated reduction in a population of cells or spores, described in multiple of D values , typically F = 12D.
- Spoilage Probability
  - Used in estimation of the number of spoiled containers within processed product batch.
  - r; number of containers exposed to the preservation process, N_0 is the initial microorganism population in each container

$F = 50$ mins

Example 5.5 Estimate the spoilage probability of a 50-minute process at 113°C when $D_{113} = 4$ minutes and the initial microbial population is 10^4 per container.

$\underbrace{D_{113} = 4 \text{ minutes}}_{4D}$ $\quad$ $\underbrace{10^4 \text{ per container}}_{N_0}$

$$\frac{1}{r} = \frac{N_0}{10^{F/D}}$$

$$\frac{1}{r} = \frac{10^4}{10^{50/4}}$$

$$\frac{1}{r} = \frac{10^4}{10^{12.5}} \Rightarrow r = \frac{10^{12.5}}{10^4} = 10^{8.5} \Rightarrow \underline{3.16 \times 10^8}$$

- Spoilage of 1 container in 3.16×10^8 can be expected (1 in 3.16×10^8)

or

- approximately 3 containers from 10^9 processed is contaminated.

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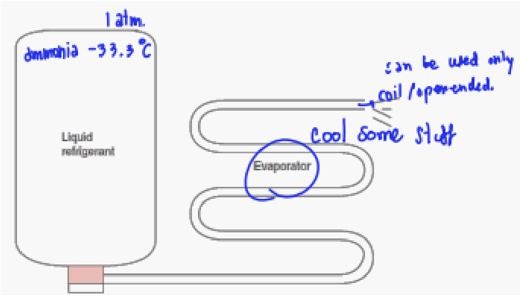
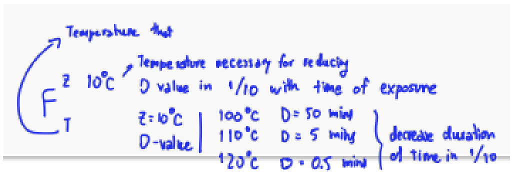
Lecture 2 –Refrigeration System

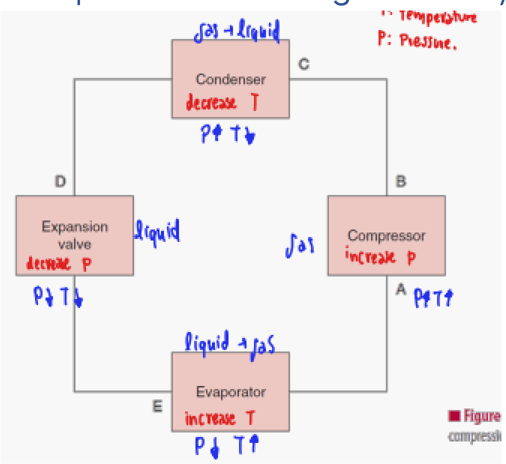
Simple Refrigeration System

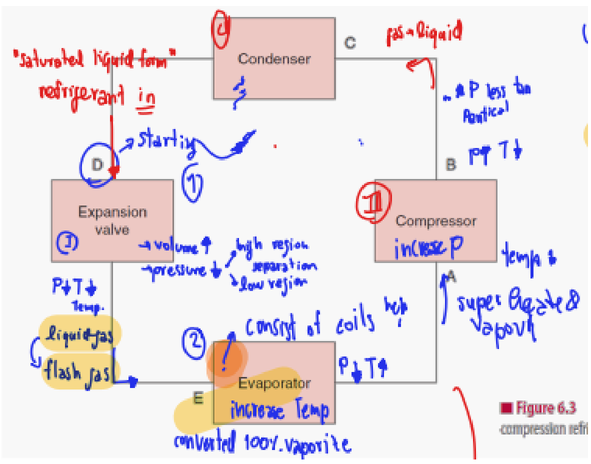
- Preserve food by remove heat from food.
- A very simple system utilizes a refrigerant. Drawbacks → Expensive, must be reuse.
  - 

Selection of Refrigerant

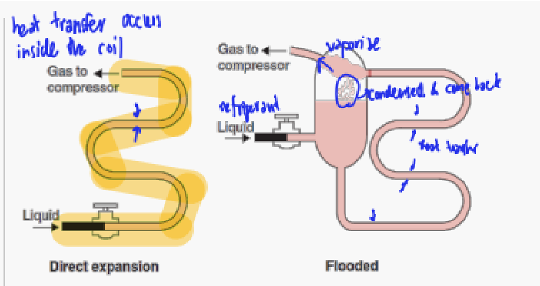
- Characteristics
  - Latent heat of vaporization: High
  - Condensing pressure: High (but not excessively high)
  - Freezing temperature: below evaporator temperature
  - Critical temperature: above highest ambient temperature
  - Toxicity, Flammability, and Corrosiveness: non-toxic non-flammable, non-corrosive.
  - Chemical stability: chemically stable
  - Leak detection: easily to detect by adding color or scent.
  - Cost: low-cost
  - Environmental Impact: no damage to environment
- The performance characteristics (active range of temperature); the lower, the better.
  - Common refrigerant:
    - R-717: high latent heat of vaporization, toxic at 0.5% vol concentration, ice cream
    - R-12: better circulation
    - R-22: slightly better than R-12, active temp at -40 to -87 c
    - R-134a
  - 

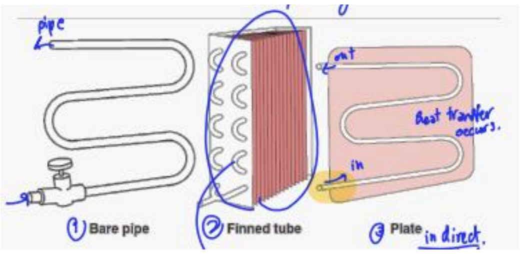
Components of Refrigeration System





Evaporator

- 2 categories:
    - Direct-expansion: allow refrigerant to vaporize inside the evaporator coils
        - There is no recirculation of the refrigerant within the evaporator. The liquid changes to gas as conveyed through the continuous tube.
        - Or flooded types: allows recirculation, enter surge chambers that boils the coil and extracts heat from surrounding.
        - 

    - Indirect-expansion: use carrier medium, cooled by refrigerant vaporizing in the coil.
- 3 Types:
    - 

    - Bare-pipe evaporators: easy to defrost and clean
    - Finned-tube evaporators: fin added, surface area increase, heat transfer rate increase.
    - Plate evaporators: indirect contact between the product and refrigerant.

Compressor

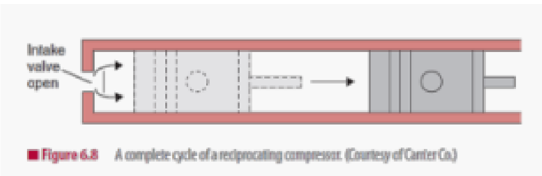
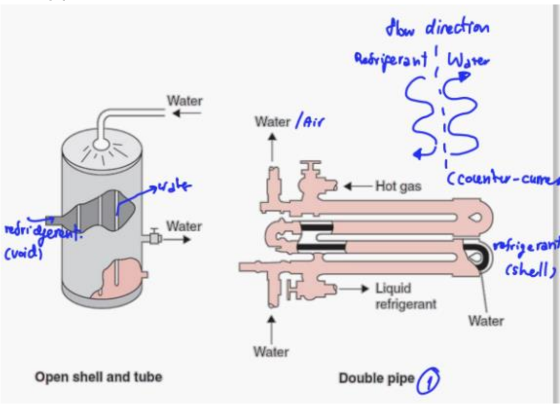
- The most important part, decrease the volume.
- Refrigerant enters compressor in vapor state at low P and low T.
- Compressor raises P and T of refrigerant. Heat can be discharged by the refrigerant in the condenser.
- Compressor raises temperature of the refrigerant above ambient temperature surrounding the condenser, so it promotes the heat flow from refrigerant to the ambient.
- 3 common types:
    - Reciprocating: piston travels back and forth.
    - Centrifugal: impeller with several blades turn in high speed.
    - Rotary: vane that rotates inside a cylinder.
- Parameters
    - The important one that influence the performance is the compressor capacity.
    - Factors includes: piston displacement, clearance between the piston head and the end of cylinder, and size of suction and discharging valves. Other factors from operating conditions that affects compressor capacity are revolution per minute, type of refrigerant, suction pressure, and discharge pressure.
    - 

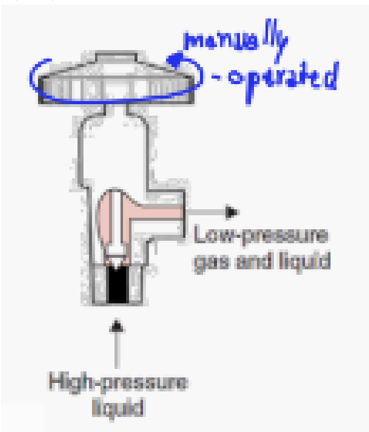
Figure 6.8 A complete cycle of a reciprocating compressor. (Courtesy of Carter Co.)

Condenser

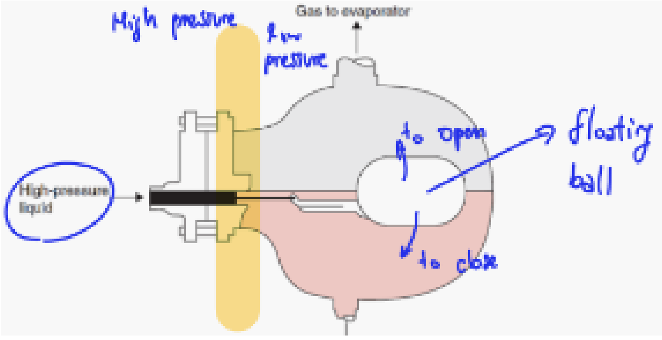
- "to transfer heat from refrigerant to another medium"
- Refrigerant in gas state condenses to liquid inside the condenser
- 3 major types of condensers: water-cooled, air-cooled, evaporative.
- In evaporative condenser, air and water are used.
- Common types of water-cooled condensers are:
    - 

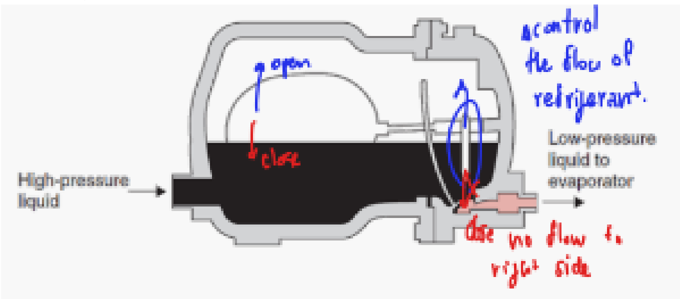
    - Double-pipe
        - Water pumped into inner pipe, refrigerant flows in outer pipe.
        - Counter-current flow used to obtain high heat transfer efficiency.
    - Shell-and-tube
        - Water pumped through the pipe, refrigerant flows in the shell.
        - Fin is optional but it allows for better heat transfer.
        - Low cost and easy to maintain.
    - Shell-and-coil
        - Most compact structure and low in cost.
        - Welded shell contains a coil of finned water tubing.

Expansion valve

- Typical valve direction: Counter-clockwise → OPEN / Clockwise → CLOSE
- In contrast with compressor, "to control the flow of refrigerant"
- It is essentially a metering device to control the flow of liquid refrigerant to an evaporator.
- It can be either manually or automatically by sensing pressure.
- Common types of metering devices are:
    - Manually operated
        - 

        - Allows desired amount flow from HIGH pressure liquid side to LOW pressure gas/liquid side. Refrigerant cools as pass through the valve. The heat is absorbed to convert liquid to vapor.

- Automatic low-pressure float valve
    - 

    - Used in flooded evaporator. Float ball is located on the LOW pressure side. As more liquid is boiled away, the float ball DROP and OPEN the orifice to allow more liquid from the HIGH pressure side, orifice close as the float rise.
- Automatic high-side float
    - 

    - Float is immersed in HIGH pressure liquid, as the heated gas condensed, liquid refrigerant level rises, float rises, open the orifice, allow refrigerant to flow to evaporators.
- Automatic expansion valve
- Thermostatic expansion valve

Lecture 3 – Freezing Systems

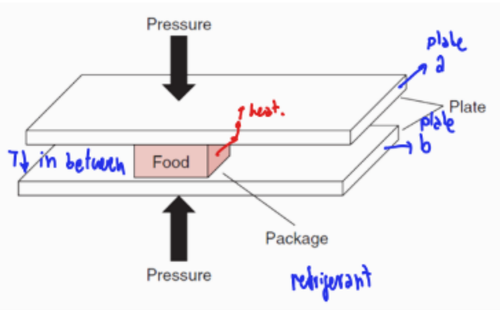
Freezing Systems

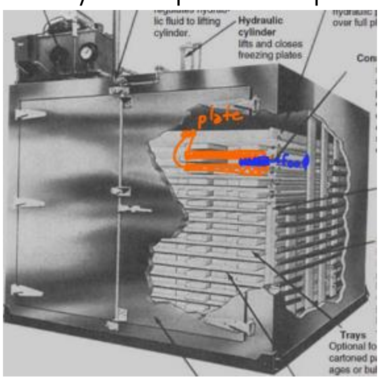
- Preservation of a food by freezing occurs by several mechanisms.
- At below 0 °C, there is significant reduction in microorganism growth rates and in the deterioration due to microbial activity.
- The formation of ice crystal within the product changes the water availability to take part in the reactions. As temperature reduced and more water solidified, less water to support the reaction.
  - Ice crystal formation is in phases, it can change the texture in food when defrost.
  - If it drops below freezing point immediately, crystal is small. It will be large if it spans over a long period of time.

Indirect Contact System

- The product and refrigerant are separated by a barrier.
- Systems use nonpermeable barrier between product and refrigerant.
- Indirect freezing systems include any system without direct contact, including those where package material become the barrier.

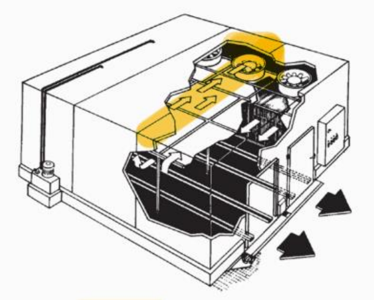
Plate Freezers

- 

- The product is frozen while held between two refrigerated plates.
- The barrier will include both the plate and packaging material in most cases.
- The heat transfer through the barrier can be improved by using pressure to perform heat transfer across the barrier.
- In some cases, plate systems may use single plates and accomplish freezing with heat transfer across a single package. But this would be less efficient. → For ไอติมผัด
- Costly to acquire and operate. It can be operated as batch system.
- 

- The plate-freezing in continuous mode operates by placing product between two refrigerated plates. The movement of plates occurs as the plates move upward or across within the compartment. In continuous plate-freezing system, the freezing time is total time required for the product to move from entrance to exit.

Air-blast Freezers

- 
- Air-blast freezers can be a simple design as the case of refrigerated room.
- The product is placed in the room, the low-temp air is allowed to circulate around the product for freezing time duration.
- Most air-blast freezers are continuous, the product placed on the conveyor belt that move through a stream of high-velocity air. Length and speed establish freezing time.
- Can be used for various product size and shape.

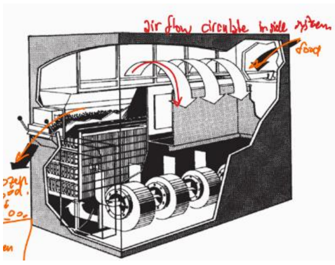
Freezers for Liquid Foods

- The residence time in the freezing compartment is sufficient to decrease the product temperature by several degree below the temperature of initial ice-crystal formation.
- 60% and 80% of latent heat has been removed from the product, and product is in the form of frozen slurry.

Direct Contact Systems

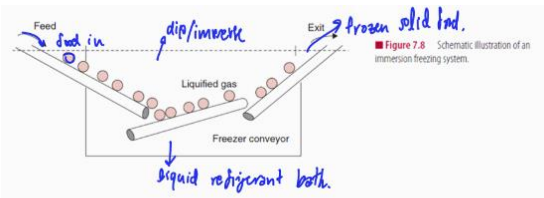
- These systems will operate more efficiently since there are no barriers to heat transfer between the refrigerant and the product.
- In all cases, the systems are designed to achieve rapid freezing, IQF: Individual quick freezing will apply (Rapid Freezing).

Air Blast

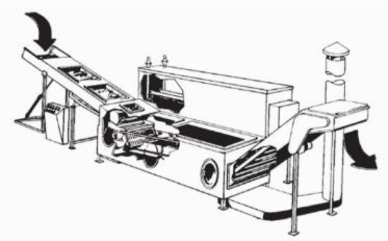
- 

- Suitable for small solid food → using the fluidized bed.
- The use of low-temperature air at high speed in direct contact with small product is one of IQF.
- Product is moved through high-speed air region.

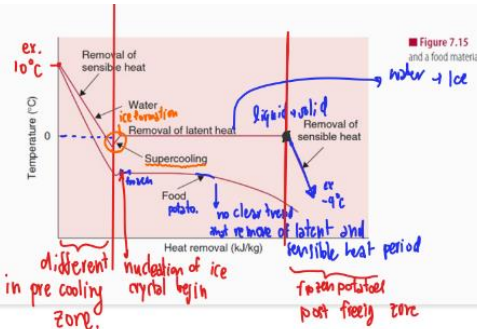
Immersion

- 

- Immerse food product in refrigerant, the product surface is reduced to a very low temperature.
- The freezing process is accomplished very rapidly or under IQF conditions.
- The freezing time is shorter than air-blast or fluidized-bed system.
- The most common refrigerants for this purpose are N and CO_2

- 
- For a commercial immersion IQF system, freezing compartment is filled with refrigerant vapor. Product is exposed to liquid refrigerant spray which absorbs thermal energy. The cost of the refrigerant is the disadvantages.

Freezing Time

- 3 periods while food undergoing freezing: pre-freezing/precooling, phase change, and postfreezing.
- 

- Properties to consider: density, thermal conductivity, enthalpy.
- The temperature which initial nucleation occurs is lower than that of water. After a brief period of supercooling, latent heat is gradually removed. The deviation in temperature result in the concentration effect during freezing of foods.
- Typically, fruits and veggies are frozen to a temperature of -18 °C, and foods with higher fat are to lower temperature of -25 °C.
    - Freezing remove both sensible and latent heat
    - Freezing pure water show sharp transitions between different freezing periods, where food transition is more gradual.
    - Endpoint temperature; frozen food may still have some water present as liquid.

Plank's Equation

- Consider an infinite slab of thickness a. Initial temperature of the slab is T_F. Initial freezing point is 0 °C. The temperature of slab after freezing medium at T_a.
    - Latent heat of fusion for the food material

      $$L_f = m_m L$$

      (moisture content x latent heat fusion of water 333.3 kJ/kg K)
    - Freezing time

      $$t_F = \frac{\rho_f L_f}{T_F - T_a}\left(\frac{P'a}{h} + \frac{R'a^2}{k_f}\right)$$

        - ρ_f is the density of the frozen material,
        - L_f is the change in the latent heat of the food (kJ/kg),
        - T_F is the freezing temperature (°C),
        - T_a is the freezing air temperature (°C),
        - h_c is the convective heat transfer coefficient = 50 W/[m² °C],
        - a is the thickness/diameter of the object (m),

- k is the thermal conductivity of the frozen material (W/[m °C]),
- The constants P' and R' are used to account for the influence of product shape.
    - Infinite plate: P' = 1/2, R' = 1/8
    - Infinite cylinder: P' = 1/4, R' = 1/16
    - Infinite sphere: P' = 1/6, R' = 1/24

Example 7.1

A spherical food product is being frozen in an air-blast freezer. The initial product temperature is 10°C and the cold air −40°C. The product has a 7 cm diameter with density of 1000 kg/m³, the initial freezing temperature is −1.25°C, the thermal conductivity of the frozen product is 1.2 W/(m K), and the latent heat of fusion is 250 kJ/kg. Compute the freezing time.

T_f T_a slab L_f ρ_f k_f

Given

Initial product temperature $T_i = 10°C$
Air temperature $T_\infty = -40°C$
Initial freezing temperature $T_F = -1.25°C$
Product diameter $a = 7\,cm = 0.07\,m$
Product density $\rho_f = 1000\,kg/m^3$
Thermal conductivity of frozen product $k = 1.2\,W/(m\,K)$
Latent heat $H_L = 250\,kJ/kg$
Shape constants for spheres:

$$P' = \frac{1}{6}$$
$$R' = \frac{1}{24}$$

Convective heat-transfer coefficient $h_c = 50\,W/(m^2\,K)$ → h

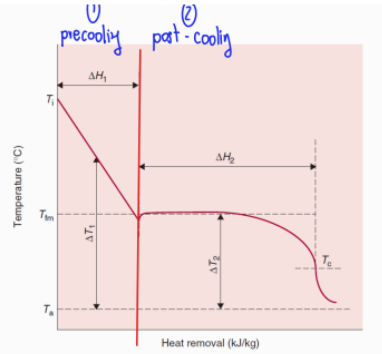
$$t_f = \frac{\rho_f L_f}{T_F - T_a}\left(\frac{P'a}{h} + \frac{R'a^2}{k_f}\right)$$

$$= \frac{\left(1000\,\frac{kg}{m^3}\right)\left(250\,\frac{kJ}{kg}\right)}{(-1.25°C - (-40°C))}\left(\frac{\left(\frac{1}{6}\right)(0.07\,m)}{50\,\frac{W}{m^2 K}} + \frac{\left(\frac{1}{24}\right)(0.07\,m^2)}{1.2\,\frac{W}{m K}}\right)$$

$$= \frac{2905}{1116} = 2.6\,\frac{kJ}{W} \Rightarrow \begin{array}{|l} 1\,W = 1\,J/s \\ 1000\,J = 1\,kJ \end{array}$$

$$\Rightarrow t_f = 2.6 \times 10^3\,s \Rightarrow \underline{0.72\ hours}$$

Pham's Method

- Predict food freezing and thawing time (time to undo/unfreeze).
- Use for finite-size objects of irregular shapes.
- Assumptions in this method are environment conditions are constant, initial temperature T_i is constant, final temperature T_c is fixed, convective heat transfer at surface of an object is described by newton's law of cooling.
- 

- Final center / freezing medium

$$T_{fm} = 1.8 + 0.263T_c + 0.105T_a$$

    - T_{fm} is a mean freezing temperature
        - used to separate the diagram into two parts
            - precooling period with some phase change
            - post-cooling period with comprising largely the phase change
    - T_c is final center temperature
    - T_a is freezing medium temperature.
- Freezing time →

change of entropy

$$\boxed{t = \frac{d_c}{E_f h}\left[\frac{\Delta H_1}{\Delta T_1} + \frac{\Delta H_2}{\Delta T_2}\right]\left(1 + \frac{N_{Bi}}{2}\right)}$$

change of temperature

E_f : shape of solid food constant
infinite slab : $E_f = 1$
infinite cylinder : $E_f = 2$
sphere : $E_f = 3$

- d_c is a characteristic dimension, either shortest distance to the center or radius (m)
- h is the convective heat transfer coefficient (W/[m²·K])
- E_f is the shape factor of an equivalent heat transfer dimension.

ΔH_1 is the change in volumetric enthalpy (J/m³) for the precooling period, obtained as :

$$\Delta H_1 = \rho_u c_u (T_i - T_{fm}) \quad ; \text{ initial to mean freezing}$$

where c_u is the specific heat for the unfrozen material (J/[kg·K]), T_i is the initial temperature of the material.

ΔH_2 is the change in volumetric enthalpy (J/m³) for the phase change and post-cooling period obtained from the following expression :

$$\Delta H_2 = \rho_f [L_f + c_f (T_{fm} - T_c)] \quad ; \text{ mean freezing to final}$$

where c_f is the specific heat for the frozen material (J/[kg K]), L_f is the latent heat of fusion of food (J/kg), and ρ_f is the density of frozen material.

$\hookrightarrow L_f = m_m L$
$= (\text{moisture}) \times (\text{latent of water})$
$= \text{moisture} \times 333.3 \text{ kJ/kg·K}$

The temperature gradients ΔT_1 and ΔT_2 are obtained from following equations :

$$\Delta T_1 = \left(\frac{\overset{\text{initial}}{T_i} + \overset{\text{mean freeze}}{T_{fm}}}{2} \right) - \overset{\text{freezing medium}}{T_a} \quad ; \text{ change of temperature in precooling}$$

$$\Delta T_2 = T_{fm} - T_a \quad ; \text{ change of temperature in postcooling}$$

Pham's procedure involves first calculating various factors to obtain freezing time. Note that, depending upon the factor E_f, the equation is useful in determining freezing time for an infinite slab, infinite cylinder, or a sphere shape.

Example 7.2

* Pham's method.

Recalculate the freezing time in Example 7.1, using Pham's method with the following additional information. Final center temperature is −18°C (°C), density of unfrozen product (ρ_u) is 1000 kg/m³, density of frozen product (ρ_f) is 950 kg/m³, moisture content of the product is 75%, specific heat of unfrozen product (c_u) is 3.6 kJ/(kgK), and specific heat of frozen product (c_f) is 1.8 kJ/(kgK).

Initial product temperature T_i = 10°C
Air temperature T_∞ = −40°C
Initial freezing temperature T_F = −1.25°C
Product diameter a = 7 cm = 0.07 m
Product density ρ_f = 1000 kg/m³
Thermal conductivity of frozen product k = 1.2 W/(m K)
Latent heat H_L = 250 kJ/kg
Shape constants for spheres:
$P' = \frac{1}{6}$
$R' = \frac{1}{24}$
Convective heat-transfer coefficient h_c = 50 W/(m² K)

Given
Initial product temperature = 10°C
Air temperature = −40°C
Product diameter = 0.07 m
Product density, unfrozen = 1000 kg/m³
Product density, frozen = 950 kg/m³
Thermal conductivity of frozen product = 1.2 W/(m K)
Product specific heat, unfrozen = 3.6 kJ/(kg K)
Product specific heat, frozen = 1.8 kJ/(kg K)
Final center temperature = −18°C
Moisture content = 0.75

① find T_{fm} :

$$T_{fm} = 1.8 + 0.263 T_c + 0.105 T_a$$
$$= 1.8 + 0.263(-18) + 0.105(-40) = -7.134\,°C$$

② $\Delta H_1 = \rho_u c_u (T_i - T_{fm})$
$= (1000)(3600)(10 - (-7.134)) = 61{,}682{,}400 \text{ J/m}^3$

$\Delta H_2 = \rho_f [L_f + c_f (T_{fm} - T_c)]$
$= (950)[(0.75)(333.3 \times 1000) + (1.8)(1000)(-7.134 - (-18))]$
$= 256{,}057{,}110 \text{ J/m}^3$

$\Delta T_1 = 41.43\,°C$

$\Delta T_2 = 32.87\,°C$

Example 7.2

Recalculate the freezing time in Example 7.1, using Pham's method with the following additional information. Final center temperature is −18°C, density of unfrozen product is 1000 kg/m³, density of frozen product is 950 kg/m³, moisture content of the product is 75%, specific heat of unfrozen product is 3.6 kJ/(kgK), and specific heat of frozen product is 1.8 kJ/(kgK).

Given
Initial product temperature = 10°C
Air temperature = −40°C
Product diameter = 0.07 m → radius = 0.035 m
Product density, unfrozen = 1000 kg/m³
Product density, frozen = 950 kg/m³
Thermal conductivity of frozen product = 1.2 W/(m K)
Product specific heat, unfrozen = 3.6 kJ/(kg K)
Product specific heat, frozen = 1.8 kJ/(kg K)
Final center temperature = −18°C
Moisture content = 0.75

③ $$t = \frac{d_c}{E_f h} \left[\frac{\Delta H_1}{\Delta T_1} + \frac{\Delta H_2}{\Delta T_2} \right] \left[1 + \frac{\overset{1.46}{N_{Bi}}}{2} \right]$$

$$= \frac{(0.035 \text{ m})}{(3)(50 \frac{W}{m^2 K})} \left[\frac{61{,}682{,}400}{41.43} + \frac{256{,}057{,}110}{32.87} \right] \left[1 + \frac{1.46}{2} \right]$$

$= 3{,}745.06 \text{ s}$

$= \underline{1.04 \text{ hours.}}$

Prediction of Freezing Time of Finite-Shaped Objects

$$\beta_1 = \frac{\text{second shortest dimension of object}}{\text{shortest dimension}}$$

$\beta_1 = \frac{\text{otherside}}{\text{shortest}}$

$$\beta_2 = \frac{\text{longest dimension of object}}{\text{shortest dimension}}$$

$\beta_2 : \frac{\text{longest}}{\text{shortest}}$

-

- Prediction of Freezing Time of Finite-Shaped Objects

The equivalent dimension E_f is obtained as follows :

$$E_f = G_1 + G_2E_1 + G_3E_2$$

where values of G_1, G_2, and G_3 are obtained from Table 7.1, and E_1 and E_2 are obtained from the following equations :

$$E_1 = \frac{X_1}{\beta_1} + [1 - X_1]\frac{0.73}{\beta_1^{2.5}}$$

and

$$E_2 = \frac{X_2}{\beta_2} + [1 - X_2]\frac{0.73}{\beta_2^{2.5}}$$

Table 7.1 G Values for Different Shapes

	G_1	G_2	G_3
Finite cylinder, height < diameter	1	2	0
Finite cylinder, height > diameter	2	0	1
Rectangular rod	1	1	0
Rectangular brick	1	1	1

where factors X_1 and X_2 are obtained from

$$\boxed{X_1 = \frac{2.32\beta_1^{-1.77}}{(2N_{Bi})^{1.34} + 2.32\beta_1^{-1.77}}}$$

and

$$\boxed{X_2 = \frac{2.32\beta_2^{-1.77}}{(2N_{Bi})^{1.34} + 2.32\beta_2^{-1.77}}}$$

will be given

-

Example 7.3

Lean beef in the shape of a large slab with 1 m length, 0.6 m width and 0.25 m thickness is to be frozen in an air-blast freezer with a Biot Number of 2.5. Calculate the shape factor from the given dimensions.

↳ E_f

Given

Length = 1 m
Width = 0.6 m
Thickness = 0.25 m
N_{Bi} = 2.5

① $\beta_1 = \frac{0.6}{0.25} = 2.4$, $\beta_2 = \frac{1}{0.25} = 4$

0.6, 1, 0.25

② $X_1 = \frac{2.32\beta_1^{-1.77}}{(2N_{Bi})^{1.34} + 2.32\beta_1^{-1.77}} = \frac{2.32(2.4)^{-1.77}}{(2(2.5))^{1.34} + 2.32(2.4)^{-1.77}} = 0.0539$

$X_2 = \frac{2.32(4)^{-1.77}}{(2(2.5))^{1.34} + 2.32(4)^{-1.77}} = 0.0226$

③ $E_1 = \frac{X_1}{\beta_1} + (1 - X_1)\frac{0.73}{\beta_1^{2.5}} = \frac{0.0539}{2.4} + [1 - 0.0539]\frac{0.73}{2.4^{2.5}} = 0.0999$

$E_2 = \frac{0.0226}{4} + [1 - 0.0226]\frac{0.73}{4^{2.5}} = 0.0279$

-

Example 7.3

Lean beef in the shape of a large slab with 1 m length, 0.6 m width and 0.25 m thickness is to be frozen in an air-blast freezer with a Biot Number of 2.5. Calculate the shape factor from the given dimensions.

Given

Length = 1 m
Width = 0.6 m
Thickness = 0.25 m
N_{Bi} = 2.5

then,

④ $E_f = G_1 + E_1G_2 + E_2G_3$

$= 1 + 1(0.0999) + 1(0.0279)$

$= \underline{1.1278}$

E_f is in range of 1 to 2.

- Plank's
- Pham's dev. from Plank's
  - focused more on enthalpy & temperature.

-

Quality Changes in Foods during Frozen Storage

- Each type of food needs different type of storage.
- Usually, we will keep food no more than half a year. Usually a month.
- The efficiency of food freezing is influenced by freezing process, quality by storage conditions.
- Quality loss reduced at lower temperatures, using lowest storage temperature feasible in terms of extending storage life without using refrigeration energy inefficiently.
- Practical storage life (PSL) is the period of frozen storage after freezing during which the product retains its characteristics properties and remains suitable for consumption or other intended process. Commercial food chain typical temperature is -18 °C.
- High-quality life (HQL) is the time elapsed from freezing of an initially high-quality product and the moment when sensory assessment gives initial high quality different in statistically significant ($p < 0.01$) established. Temperature used for control experiments is -35°C

Lecture 4 – Drying and Dehydration

Drying Process

- The removal of moisture from food product is one of the oldest preservation methods.
- By reducing the water content to very low level, microbial deterioration opportunities are eliminated, other deterioration reaction reduced significantly.
- Dehydration reduces product mass and volume by significant amount, some result in more convenient consumer use,
- Unique challenges of dehydration is structural configuration of fruits and vegetables products, it mush be accomplished in least detrimental to product quality.

Water Activity

- "Make change to the surface"
- One of the important things is the equilibrium condition. Water activity is important in analysis of dry food storage stability.
- There is a sigmoid isotherm → difference between adsorption and desorption.
- Higher temperature result in lower equilibrium, large moisture gradient for moisture movement.

Example 12.1 A dry food product has been exposed to a 30% relative-humidity environment at 15°C for 5 h without a weight change. The moisture content has been measured and is at 7.5% (wet basis). The product is moved to a 50% relative-humidity environment, and a weight increase of 0.1 kg/kg product occurs before equilibrium is achieved.

in equilibrium state

in 0.075 kg H_2O/kg product

moves to new environment.

a. Determine the water activity of the product in the first and second environments.

b. Compute the moisture contents of the product on a dry basis in both environments.

water molecule is already escape.

water activity
(30%) 1st env. : 0.3
(50%) 2nd env. : 0.5

Given

Equilibrium relative humidity = 30% in first environment

Product moisture content = 7.5% wet basis in first environment

For 30% relative-humidity environment, moisture content will be 0.075 kg H_2O/kg product.

Basis water activity of product are determined by dividing equilibrium relative humidity by 100; the water activities are 0.3 in first environment, and 0.5 in the second environment.

-

DEHYDRATION 8

% MC ⇒ moisture content
↳ wet-basis : kg H_2O/kg product
↳ dry basis : kg H_2O/kg solid.

more humid, more weight increase

- **Drying Processes**

Example 12.1 A dry food product has been exposed to a 30% relative-humidity environment at 15°C for 5 h without a weight change. The moisture content has been measured and is at 7.5% (wet basis). The product is moved to a 50% relative-humidity environment, and a weight increase of 0.1 kg/kg product occurs before equilibrium is achieved.

Given
Equilibrium relative humidity = 30% in first environment
Product moisture content = 7.5% wet basis in first environment
For 30% relative-humidity environment, moisture content will be 0.075 kg H_2O/kg product.

b) The dry basis moisture of the product at equilibrium in 30% RH (relative humidity) is

$$7.5\%\ \text{wet basis} = \frac{7.5\ \text{kg}\ H_2O}{100\ \text{kg product}} = \frac{0.075\ \text{kg}\ H_2O}{\text{kg product}}$$

100 kg product → (dried food + water)

So, (1 − 0.075) = 0.925 dry food.

$$\Rightarrow \frac{0.075\ \text{kg}\ H_2O/\text{kg product}}{0.925\ \text{kg solid}/\text{kg product}} = 0.08108\ \frac{\text{kg water}}{\text{kg solid}}$$

⇒ 8.11% moisture content (dry basis)

Based on weight gain at 50% RH

$$\frac{0.075\ \text{kg}\ H_2O}{\text{kg product}} + \frac{0.1\ \text{kg}\ H_2O}{\text{kg product}} = \frac{0.175\ \text{kg}\ H_2O}{\text{kg product}}$$

= 17.5 % MC (wet basis)

dry basis

$$\Rightarrow \frac{0.175}{1-0.175} = \frac{0.175\ \text{kg}\ H_2O/\text{kg product}}{0.825\ \text{kg solid}/\text{kg product}} = 0.2121\ \frac{\text{kg}\ H_2O}{\text{kg solid}}$$

21.21% MC (dry basis)

-

Moisture Diffusion

- Moisture removal will occur due to diffusion of liquid water (liquid → vapor phase)
- The rate of moisture diffusion can be expressed by molecular diffusion.

Drying-Rate Curves

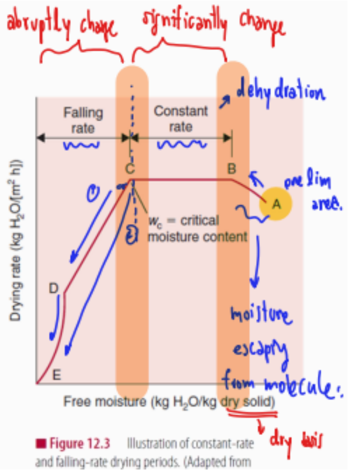
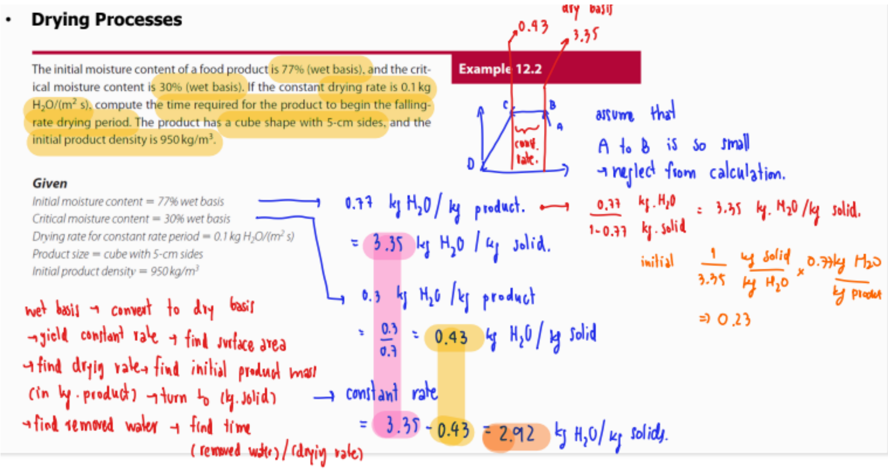
- 

Figure 12.3 Illustration of constant-rate and falling-rate drying periods. (Adapted from

- There are 2 periods: constant-rate (significantly change) and falling-rate (abruptly change)'
- Initial removal AB show slight temperature increase, followed by significant reduction in moisture at constant rate BC, then falling-rate drying CE reduce moisture to critical moisture content abruptly.
- **Heat and Mass Transfer**
  - There are no longer in steady state, temperature gradient occurs between product surface and water surface.
  - Vapor transported from water to product surface, cause moisture-vapor diffusion.
  - Limited by thermal conductivity of product structure, mass transfer is proportional to molecular diffusion.
  - 

    • **Drying Processes**

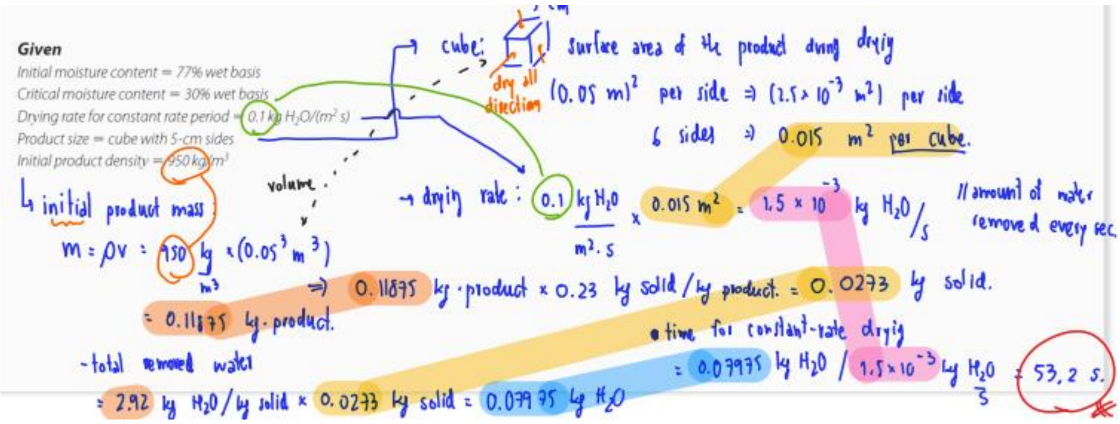
    Example 12.2

    The initial moisture content of a food product is 77% (wet basis), and the critical moisture content is 30% (wet basis). If the constant drying rate is 0.1 kg $H_2O/(m^2$ s), compute the time required for the product to begin the falling-rate drying period. The product has a cube shape with 5-cm sides, and the initial product density is 950 kg/m³.

    Given
    Initial moisture content = 77% wet basis
    Critical moisture content = 30% wet basis
    Drying rate for constant rate period = 0.1 kg $H_2O/(m^2$ s)
    Product size = cube with 5-cm sides
    Initial product density = 950 kg/m³

    0.43 dry basis 3.35
    C B A D const. rate
    assume that A to B is so small → neglect from calculation.

    0.77 kg H_2O / kg product. = 3.35 kg H_2O / kg solid.
    $\frac{0.77}{1-0.77}$ kg. H_2O / kg. solid = 3.35 kg. H_2O / kg solid.
    initial $\frac{1}{3.35}$ kg solid / kg H_2O × 0.77 kg H_2O / kg product ⇒ 0.23
    0.3 kg H_2O / kg product = $\frac{0.3}{0.7}$ = 0.43 kg H_2O / kg solid
    → constant rate = 3.35 - 0.43 = 2.92 kg H_2O/ kg solid.

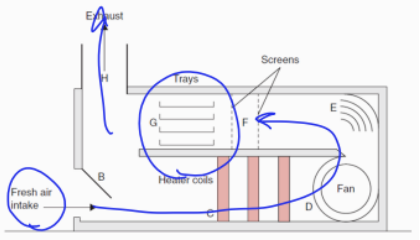
    wet basis → convert to dry basis
    → yield constant rate → find surface area
    → find drying rate → find initial product mass (in kg. product) → turn to (kg. solid)
    → find removed water → find time (removed water) / (drying rate)
  - 

    Given
    Initial moisture content = 77% wet basis
    Critical moisture content = 30% wet basis
    Drying rate for constant rate period = 0.1 kg $H_2O/(m^2$ s)
    Product size = cube with 5-cm sides
    Initial product density = 950 kg/m³

    cube: surface area of the product during drying
    dry all direction
    $(0.05\ m)^2$ per side ⇒ $(2.5 \times 10^{-3}\ m^2)$ per side
    6 sides ⇒ 0.015 m^2 per cube.
    → drying rate : 0.1 $\frac{kg\ H_2O}{m^2 . s}$ × 0.015 m^2 = 1.5×10^{-3} kg H_2O/s // amount of water removed every sec
    volume
    ↳ initial product mass
    $m = \rho V$: 950 $\frac{kg}{m^3}$ × $(0.05^3\ m^3)$
    = 0.11875 kg. product.
    ⇒ 0.11875 kg · product × 0.23 kg solid / kg product. = 0.0273 kg solid.
    - total removed water
    = 2.92 kg H_2O / kg solid × 0.0273 kg solid = 0.07975 kg H_2O
    • time for constant-rate drying
    = 0.07975 kg H_2O / 1.5×10^{-3} kg H_2O/s = 53.2 s.

Dehydration Systems

Tray or Cabinet Dryers

- 

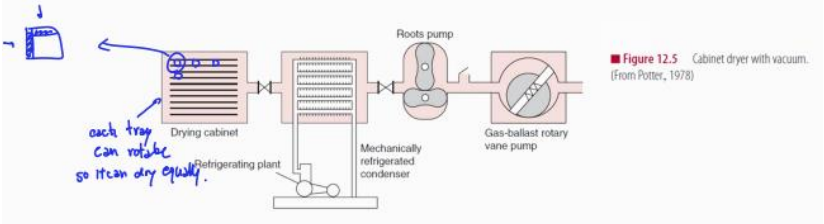
- Heat transfer on the product surface
- Air movement over the product is at relatively high velocities
- 

Figure 12.5 Cabinet dryer with vacuum. (From Potter, 1978)
- Use vacuum chamber to maintain the lowest possible vapor pressure.

Tunnel Dryers

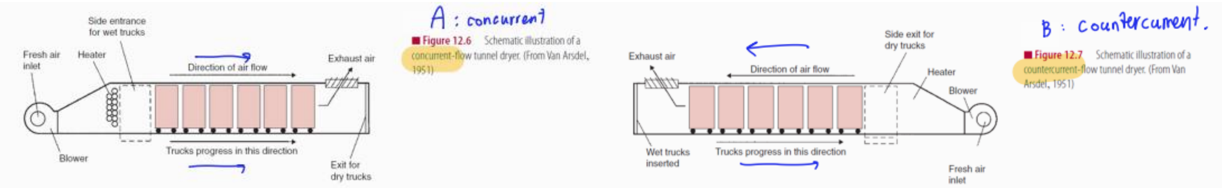
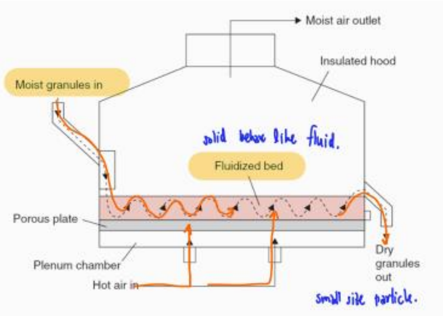
- 

Figure 12.6 Schematic illustration of a concurrent-flow tunnel dryer. (From Van Arsdel, 1951)
Figure 12.7 Schematic illustration of a countercurrent-flow tunnel dryer. (From Van Arsdel, 1951)
- Heated drying air is introduced at one end and move through tunnel containing trays being carried on trucks.
- Product can move in either concurrent direction or countercurrent direction as the air flow.
    - Concurrent system: high-moisture product is exposed to high-temperature air and evaporation assist in maintain low product temperature. Low-moisture product is exposed to low-temperature air at near tunnel exit.
    - Countercurrent system: lower-moisture product is exposed to high-temperature air. Overall efficiency maybe higher, but quality consideration may not allow its use.

Puff-Drying

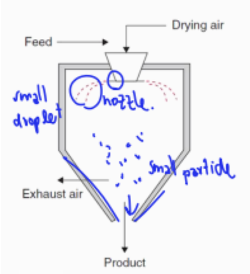
- Suitable for high-porosity product with rapid rehydration; fruits and vegetables.
- Explosion puff-drying; relatively small piece of product to high pressure and temperature.

Fluidized-Bed Drying

- 

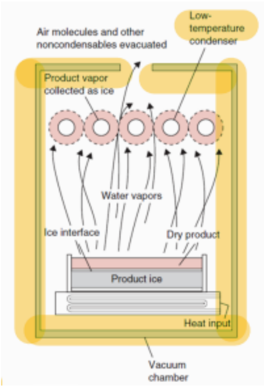
- Product pieces are suspended in heated air.
- The movement of the product created by fluidized particles, yield equal drying product surfaces.
- Smaller particles can maintain in suspension with lower air velocities.

Spray Drying

- 

- Suitable for liquid product.
- Nozzle spray small droplet and drop small particle in exhaust air.
- The small particle size of dried solids promotes easy reconstitution when mixed with water.

Freeze-Drying

- 

- Reducing the product temperature, sublimation of ice can be achieved.
- Heat transfer through the dry product layer, slowly due to low thermal conductivity of highly porous structure in a vacuum.
- Mass transfer will occur in the dry product later, water vapor is expected to limit the rate due to molecular diffusion in vacuum.
- Advantages: superior product quality.

Drying-Time Prediction

Constant-rate Drying Period

- Moisture removal rate
  - $\boxed{\dot{m}_c = \frac{w_o - w_c}{t_c}}$ (initial MC – critical MC / time)
    - $\dot{m}_c$ = moisture removal rate during constant rate drying (s^{-1})
    - w_c = critical moisture content (kg water/kg dry solids)
    - w_0 = initial moisture content (kg water/kg dry solids)
    - t_c = time for constant-rate drying (s).
- Rate of heat transfer; product surface to heated air.
  - $\boxed{q = hA(T_a - T_s)}$
    - q = rate of heat transfer (W)
    - h = convective heat transfer coefficient ($W/[m^2 \cdot K]$)
    - A = surface area of product exposed to heated air (m^2)
    - T_a = heated air temperature (°C)
    - T_s = product surface temperature (°C).

- Water vapor mass transfer
  - $$\boxed{\dot{m}_c = \frac{k_m A M_w P}{0.622 R T_A}(W_s - W_a)}$$
    - k_m = convective mass transfer coefficient (m/s)
    - A = product surface area (m^2)
    - M_w = molecular weight of water
    - P = atmospheric pressure (kPa)
    - R = universal gas constant (8314.41 m^3·Pa/[kg·mol·K])
    - T_A = absolute temperature (K)
    - W_a = humidity ratio for air (kg water/kg dry air)
    - W_s = humidity ratio at product surface (kg water/kg dry air).
- Time of constant-rate drying based on mass transfer
  - $$t_c = \frac{0.622 R T_A (w_o - w_c)}{k_m A M_w P (W_s - W_a)}$$
- Example
  - **Example 12.5** Air at 90°C is being used to dry a solid food in a tunnel dryer. The product, with 1 cm thickness and a 5 cm by 10 cm surface, is exposed to the heated air with convective mass transfer coefficient of 0.1 m/s. Estimate the constant-rate drying time, when the initial moisture content is 85% and the critical moisture content is 42%. The air has been heated from 25°C and 50% RH. The product density is 875 kg/m³.

    relative humidity

    Given

    Initial moisture content, $w_o = 0.85/0.15 = 5.67$ kg water/kg solids
    Critical moisture content, $w_c = 0.42/0.58 = 0.724$ kg water/kg solids
    Air temperature, $T_a = 90°C$
    Convective mass transfer coefficient, $k_m = 0.1$ m/s
    Product surface area, $A = 0.05 \times 0.1 = 0.005\ m^2$
    Molecular weight of water, $M_w = 18$ kg/mol
    Atmospheric pressure, $P = 101.325$ kPa

    • given external information
    Heated air 25°C 50% RH
    • humidity ratio (W_a)
    = 0.01 kg water / kg dry air
    • humidity ratio (W_s)
    = 0.034 kg water / kg dry air
    • wet bulb T = 33.7°C

    ① initial - final = 90°C - 33.7°C = 56.3°C
    ⇒ 56.3 + 273 = 329.3 K → T_A
    // absolute temperature

  - ② $$t_c = \frac{0.622 R T_A (\omega_o - \omega_c)}{k_m A M_w P (\omega_s - \omega_a)}$$

    $$= \frac{\left(0.622 \frac{kg\ H_2O}{kg\ dry\ air}\right)\times\left(8.314 \frac{m^3 \cdot kPa}{kg \cdot mol \cdot K}\right)\cdot(329.3\ K)\left(5.67 - 0.724 \frac{kg\ H_2O}{kg\ solid}\right)}{\left(0.1 \frac{m}{s}\right)\left(0.005\ m^2\right)\left(18 \frac{kg\ H_2O}{mol}\right)\left(101.325\ kPa\right)\left(0.034 - 0.01 \frac{kg\ H_2O}{kg\ dry\ air}\right)}$$

    $= 3.925 \times 10^5$ s/kg solid

  - each piece of product ⇒ 0.01 cm × 0.05 cm × 0.1 cm = $5 \times 10^{-5}\ m^3$ → $5 \times 10^{-5}\ m^3 \times 875 \frac{kg}{m^3} = 0.04375$ kg

    → 0.04375 kg × 0.15 $\frac{kg\ solids}{kg\ product}$ = 6.5625×10^{-3} kg solids

    $t_c = 3.925 \times 10^5$ [s / kg solid] × 6.5625×10^{-3} kg solids

    = 2575.85 s → $\underline{\underline{42.9\ mins.}}$

Falling-rate Drying Period

- W_c critical MC to W_e equilibrium MC
- Moisture diffusion
  - For infinite-plate/infinite-slab
    - $$t_F = \frac{4d_c^2}{\pi^2 D} \ln\left[\frac{8}{\pi^2}\left(\left|\frac{w_c - w_e}{w - w_e}\right|\right)\right]$$
  - Infinite cylinder geometry
    - $$t_F = \frac{d_c^2}{\beta^2 D} \ln\left[\frac{4}{\beta^2}\left(\left|\frac{w_c - w_e}{w - w_e}\right|\right)\right]$$
  - Spherical product
    - $$t_F = \frac{d_c^2}{\pi^2 D} \ln\left[\frac{6}{\pi^2}\left(\left|\frac{w_c - w_e}{w - w_e}\right|\right)\right]$$
    - d_c = characteristic dimension
      - half-thickness of the slab or the radius of the cylinder or sphere (m)
    - D = effective mass diffusivity (m^2/s)
    - t = drying time (s)
  - **Example 12.6**

    The drying of a noodle occurs during the falling-rate period between the critical moisture content of 0.58 kg water/kg solids and a final moisture content of 0.22 kg water/kg solids. The mass diffusivity for water vapor within the noodle is 2×10^{-7} cm²/s and the noodle thickness is 3 mm. The equilibrium moisture content is 0.2 kg water/kg solids. Estimate the falling-rate drying time.

    $$t_F = \frac{4d_c^2}{\pi^2 D} \ln\left[\frac{8}{\pi^2}\left(\frac{w_c - w_e}{w - w_e}\right)\right]$$

    Assume : noodle geometry is "infinite slab"

    Given

    Characteristic dimension (half-thickness), $d_c = 0.0015$ m
    Mass diffusivity, $D = 2 \times 10^{-7}$ cm²/s $= 2 \times 10^{-11}$ m²/s
    Critical moisture content, $w_c = 0.58$ kg water/kg solids
    Equilibrium moisture content, $w_e = 0.22$ kg water/kg solids
    Final moisture content, $w = 0.2$ kg water/kg solids

    $$t_F = \frac{4 d_c^2}{\pi^2 D} \ln\left[\frac{8}{\pi^2}\left(\left|\frac{w_c - w_e}{w - w_e}\right|\right)\right]$$

    $$= \frac{4(0.0015\ m)^2}{(3.14)^2 (2 \times 10^{-11}\ \frac{m^2}{s})} \ln\left[\frac{8}{(3.14)^2}\left(\left|\frac{0.58 - 0.22}{0.2 - 0.22}\right|\right)\right]$$

    $$= 1.22 \times 10^5\ s = 2036\ min. = 33.95\ hr$$

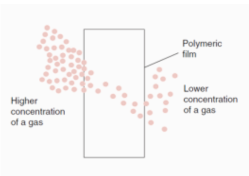
- Dehydration process for foods reduce mass of food and maybe reduce volume.
- Product quality result will be opposite to the cost comparison. Freeze-drying process produces the highest-quality product, with extra drying cost. Lowest-quality product from lowest-cost process; tunnel and cabinet drying. Suggesting a direct trade-off in quality and cost.

Lecture 5 – Packaging Concepts

Packaging Concepts

- Developments in food packaging response to consumer expectations; focused on extending the shelf life of the product.
- 4 basic functions of a food package:
    - Containment → defined by food product, depends on types (liquid, solid, gas, powder)
        - Directly related to packaging materials
            - Glass
                - Absolute barrier for gas, vapor, aroma but none for light-sensitive.
                - Main disadvantage is weight.
                - Reusable and recyclable, chemically inert.
                - Rigid, strong, difficult to break
            - Metal
                - Used in shelf-stable food products e.g., fruits and vegetables.
                - Used for thermally processed food.
                - Use steel, tin, and aluminium; heavy and complex to manufacture.
            - Plastic
                - Either thermoplastic or thermoset polymers.
                - Thermoplastic → flexibility in design based on specific needs
            - Paper
                - Most versatile and flexible, used widely.
                - Lack of barrier to oxygen, water, vapor and agents that may cause deterioration of product quality.
    - Protection → key function to maintain quality
        - Direct or indirect contact of oxygen, nitrogen, carbon dioxide, vapor, aroma influenced properties of packages. Some food might be sensitive to those which can cause deterioration from oxidation. Shelf life is impacted by CO_2
    - Communication → Present information, description, composition on the outside surface
        - Include label both legally required and commercially information to market.
    - Convenience → depends on the package design.
        - Opening, dispensing, resealing, prep product before consuming etc.
    - Other factors: efficiency in packaging manufacturing, environmental impact, food safety.

Mass Transfer in Packaging Materials

- Important requirement in packaging system is to provide barrier to moisture.
- Rancidity can be minimized by keeping it away from light, reduce oxidation by using good oxygen barrier, aroma and flavour maintain by barrier for particular aroma.
- Steps in mass transport through polymer material
    - 

    - 1. Gas vapor or liquid dissolve in higher concentration area side of film.
    - 2. Gas diffuse through and move toward lower concentrations area.
    - 3. Gas desorption from the surface of film

Permeability of Packaging Material to Fixed Gases.

- O_2, N_2, H_2, and CO_2 are called fixed gases. They show ideal behaviour in permeability thorough packaging material
- CO_2 penetrate 4-6 times faster than O_2, O_2 is 4-6 times faster than N_2

Innovations in Food Packaging

- Role of packaging in improvement of safety, shelf life, convenience of food product.
- 3 categories of packaging for foods
  - Passive (conventional/traditional)
    - Serve as physical barrier between the product and environment surrounding.
    - Metal cans, glass bottles, and flexible packaging materials ensure most properties of environmental are prevented from making contact but are not responsive for any of the change within the container.
  - Active (reaction to improve passive)
    - 1. Simple active
      - Not incorporate active ingredients or functional polymer
      - Response to change within package such as MAP: Modified atmosphere packaging system.
        - MAP control the atmosphere e.g., films that help in maintain desired oxygen and carbon dioxide concentration.
        - MAP extend shelf-life and used to pack fresh food or minimally processed food.
    - 2. Advance active
      - Contain active ingredients or functional polymer
      - 2 categories:
        - Oxygen scavenger
          - Absorbs an unwanted agent within package.
          - Ex. Small sachets inserted to reduce oxygen.
        - Ethylene scavenger
          - Ethylene triggers ripening, senescence and reduce shelf-life
      - Moisture content can also be the limiting factor, can controlled by dehumidifier (small sachets) to regulate humidity level.
  - Intelligent (Smart)
    - Sense changes in the environment and response with corrective action
    - 4 Objectives: improve quality and value, increase convenience, change in gas permeability, protect against theft or counterfeit or tamper.
    - 2 categories
      - Simple Intelligent
        - Incorporate sensor; e.g., quality or freshness indicators, color, physical condition, microbial growth.
        - Internal gas-level indicator tells gas concentration based on color changes such as oxygen and carbon dioxide.
        - Can also use connection to internet too such as traceability in supply chain until reach customer. E.g., RFID, Barcode, 2D-code.
      - Interactive Intelligent
        - Incorporate mechanism to respond to signal. Such as change permeability properties.

        - Breathable films developed based on respiration rate as temperature function.
        - Detection of theft, counterfeiting, tampering can be done by using hologram, special inks, laser tags etc.
- Food Packaging and Product Shelf Life
    - Packaging may have significant impact on shelf-life
    - We can develop mathematical relationship then we can quantify the impact.

Lecture 6 – Innovative Technology

Fermentation and Enzymes

Fermentation

- Fermented foods subjected to actions of edible microorganisms which enzymes produce polysaccharides, proteins, lipids to nontoxic product.
- LAB: Lactic acid bacteria used in most fermentation process of dairy, vegetables, and meat.
    - Probiotics → Bacteria and yeast; Prebiotics: nutrients for probiotics.
- Yeast involved in alcoholic beverages fermentation.
- Currently capable of up-scaling and designing more efficiently.
- Fermentation of dairy products
    - Milk, yogurt, cheese, and other artisan product.
    - Improve taste, texture, flavour, nutrition, benefit health
    - LAB such as lactobacillus are presents.
    - Most popular one is yogurt; Lactobacillus bulgaricus responsible for yogurt production by pasteurized milk fermentation
- Fresh meat fermentation
    - Drying, with smoking and salt addition to create sausages such as salami
- Vegetables and fruits
    - Canning, freezing, drying to improve safety and shelf life.
- Alcoholic Beverage Fermentation
    - Wine and Beer
    - Yeast used to produce ethanol (edible alcohol) from its sugar metabolism
- SSF: Solid-state fermentation
    - Fermentation that involves solids in absence or near absence of free water.
    - Mainly use yeast and fungi.

Enzymes

- Commonly used in biotechnology and become competitive in market
- Biocatalyst used to increase the shelf-life.
    - Proteinase or peptidase (aminopeptidases) used in dairy industry
    - Lipolytic used in dietary or cheese products.
    - Bakery is also added during the rheology dough growing
    - Hemicellulases used in preparation of baked product.
    - Brewing process, endogenous enzyme of barley such as amylases.
- SFE: Supercritical fluid extraction
    - Similar to distillation and liquid solvent extraction.
    - Belong to the supercritical solvent undergoes a state change, take advantage of the high dissolving ability.
    - Critical point is described as the end of vapor-pressure curve in phase diagram
    - Mostly used in food, pharmaceutical and cometic industries.
    - Viable for green processing
        - SFE required less energy, used nontoxic solvent such as CO_2, and consumer awareness from using chemical solvents in food and natural products.

Nonthermal Technologies

- 3 Categories
  - Existed a long time but not applied in industrial level
    - Ultrasonic
  - Not applied because lack of sufficient knowledge on effects or equipment
    - Cold plasma
      - High energy gas
      - Plasma sterilization
      - Ethylene oxide and radiation sterilization for heat-sensitive material treatment alternative to conventional high sterilization method.
      - Promote efficient microorganism inactivation and minimize damage
    - DPCD: High dense phase carbon dioxide
      - Pressurized carbon dioxide
      - Alternative to nonthermal pasteurization technique.
      - CO_2 Temperature and pressure dependent.
      - Effective in vegetative bacteria.
  - Applied in industries but still some hesitation
    - High hydrostatic pressure
      - Most important non-thermal tech.
      - Using high pressure but still maintain low temperature
      - Applied in the pasteurization process to extend the shelf life
      - Treat at ambient temperature
      - Considered as mildly elevated temperature
      - Assure safety, shelf life extension and nutrient preservation.
    - Ozonation
    - PEF: Pulsed electric fields
      - Inactivate microorganism with minimal effects on nutrients and flavour.
      - Using high voltage pulse in short period of time.
      - Occurs such as resistance heating, electrolysis, cell membrane disruption contributes to microorganism inactivation.
    - UV light
      - Use to reduce germ by using radiation in the UV region.
    - IR
      - X-rays and gamma rays
      - Cobalt-60 used in IR.
      - Food passed through radiation will receive label
      - Unit of radiation is Grays (Gy) = 1 Joule of absorbed energy per kg product.

          -