UNIT OPERATIONS IN FOOD PROCESSING

COURSE OUTLINE

- Lecture 1 Introduction
- Lecture 2 Material and Energy balances
- Lecture 3 Material handling and related preliminary operations
- Lecture 4 Mechanical separation
- Lecture 5 Theory and applications of Membrane separation processes
- Lecture 6 Theory and applications of Contact equilibrium separation processes
- Lecture 7 Food Freezing

LECTURE ONE

BASIC PRINCIPLES OF UNIT OPERATION IN FOOD PROCESS ENGINEERING

- The study of process engineering is an attempt to combine all forms of physical processing into a small number of basic operations, which are called unit operations.
- Food processes may seem bewildering in their diversity, but careful analysis will show that these complicated and differing processes can be broken down into a small number of unit operations.
- For example, consider heating of which innumerable instances occur in every food industry. There are many reasons for heating and cooling - for example, the baking of bread, the freezing of meat, and the frying of yam slices in oils.
- But in process engineering, the prime considerations are firstly, the extent of the heating or cooling that is required and secondly, the conditions under which this must be accomplished. Thus, this physical process qualifies to be called a unit operation.

UNITS AND DIMENSIONAL ANALYSIS

- All engineering deals with definite and measured quantities, and so depends on the making of measurements.
- To make a measurement is to compare the unknown with the known, for example, weighing a material compares it with a standard weight of one kilogram.
- The result of the comparison is expressed in terms of multiples of the known quantity, that is, as so many kilograms.

Dimensions

- These dimensions include length, mass, time and temperature.
- For convenience in engineering calculations, force is added as another dimension. Force can be expressed in terms of the other dimensions, but it simplifies many engineering calculations to use force as a dimension e.g. (Weight =mg).
- Dimensions are represented as symbols by: length [L], mass [M], time [t], temperature [T] and force [F]. Note that these are enclosed in square brackets which are the conventional way of expressing dimensions.

Units

Dimensions are measured in terms of units. For example, the dimension of length is measured in terms of length units like μm, mm, m, km, etc. So that the measurements can always be compared, the units have been defined in terms of physical quantities. For example:

★ the metre (m) is defined in terms of the wavelength of light;

★the standard kilogram (kg) is the mass of a standard lump of platinum-iridium;

★the second (s) is the time taken for light of a given wavelength to vibrate a given number of times;

LECTURE TWO

MATERIAL AND ENERGY BALANCES

- ✓ Material quantities, as they pass through food processing operations, can be described by material balances.
- ✓ Such balances are statements on the conservation of mass.
- ✓ Similarly, energy quantities can be described by energy balances, which are statements on the conservation of energy.
- ✓ If there is no accumulation, what goes into a process must come out.

- ✓ This is true for batch operation. It is equally true for continuous operation over any chosen time interval.
- ✓ Material and energy balances are very important in the food industry.
- ✓ Material balances are fundamental to the control of processing, particularly in the control of yields of the products and needs to be reviewed periodically

Basic principles of material (mass) and energy balances

If the unit operation, whatever its nature is seen as a whole it may be represented diagrammatically as a box, as shown in Fig. 1 The mass and energy going into the box must balance with the mass and energy coming out.

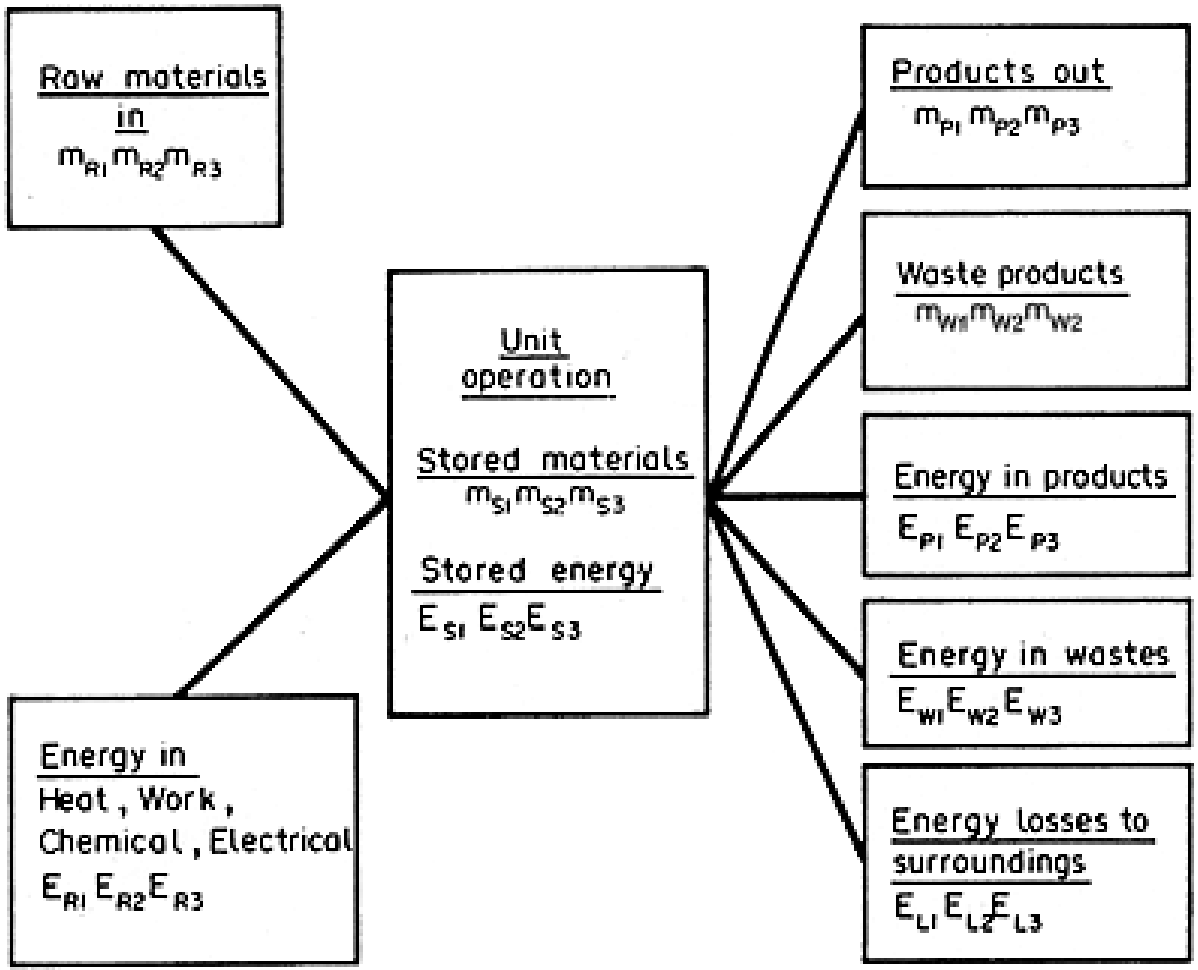

Figure 1. Mass and energy balance

MATERIAL HANDLING AND RELATED PRELIMINARY OPERATIONS

- At the time of harvest or slaughter, most foods are likely to contain contaminants, to have components which are inedible or to have variable physical characteristics (for example shape, size or colour).
- It is therefore necessary to perform one or more of the unit operations of cleaning, sorting, grading or peeling to ensure that foods with a uniformly high quality are prepared for subsequent processing.

Cleaning

- Cleaning is the unit operation in which contaminating materials are removed from the food and separated to leave the surface of the food in a suitable condition for further processing.

- Peeling fruits and vegetables, skinning meat or descaling fish may also be considered as cleaning operations. In vegetable processing, blanching also helps to clean the product.

- The presence of contaminants (or foreign bodies) in processed foods is the main cause of prosecution of food companies.

- Cleaning should take place at the earliest opportunity in a food process both to prevent damage to subsequent processing equipment by stones, bone or metals, and to prevent time and money from being spent on processing contaminants which are then discarded.

Types of Cleaning

- **Wet cleaning**

- Wet cleaning is more effective than dry methods for removing soil from root crops or dust and pesticide residues from soft fruits or vegetables.
- It is also dustless and causes less damage to foods than dry methods. Different combinations of detergents and sterilants at different temperatures allow flexibility in operation.

➢ Dry cleaning

- Dry cleaning procedures are used for products that are smaller, have greater mechanical strength and possess a lower moisture content (for example grains and nuts).
- After cleaning, the surfaces are dry, to aid preservation or further drying.
- The main groups of equipment used for dry cleaning are:

✓ air classifiers

✓ magnetic separators

✓ separators based on screening of foods

Sorting

- Sorting is the separation of foods into categories on the basis of a measurable physical property.
- Like cleaning, sorting should be employed as early as possible to ensure auniform product for subsequent processing.
- The four main physical properties used to sort foods are size, shape, weight and colour.

Grading

- This term is often used interchangeably with sorting but strictly means ‘the assessment of overall quality of a food using a number of attributes’.
- Sorting (that is separation on the basis of one characteristic) may therefore be used as part of a grading operation but not vice versa.
- Grading is carried out by operators who are trained to simultaneously assess a number of variables. For example, eggs are visually inspected over tungsten lights (termed ‘candling’) to assess up to twenty factors and remove those that are for example, fertilised or malformed and those that contain blood spots or rot.

MECHANICAL SEPARATION

- Mechanical separations can be divided into four groups - sedimentation, centrifugal separation, filtration and sieving.
- In sedimentation, two immiscible liquids, or a liquid and a solid, differing in density, are separated by allowing them to come to equilibrium under the action of gravity, the heavier material falling with respect to the lighter.
- This may be a slow process. It is often speeded up by applying centrifugal forces to increase the rate of sedimentation; this is called centrifugal separation.
- Filtration is the separation of solids from liquids, by causing the mixture to flow through fine pores which are small enough to stop the solid particles but large enough to allow the liquid to pass. Sieving, interposing a barrier through which the larger elements cannot pass, is often used for classification of solid particles.

Sedimentation

- Sedimentation uses gravitational forces to separate particulate material from fluid streams.
- The particles are usually solid, but they can be small liquid droplets, and the fluid can be either a liquid or a gas.
- Sedimentation is very often used in the food industry for separating dirt and debris from incoming raw material, crystals from their mother liquor and dust or product particles from air streams. In sedimentation, particles are falling from rest under the force of gravity.

Centrifugal separation

- The separation by sedimentation of two immiscible liquids, or of a liquid and a solid, depends on the effects of gravity on the components. Sometimes this separation may be very slow because the specific gravities of the components may not be very different, or because of forces holding the com-ponents in association, for example as occur in emulsions.

Sieving

- In the final separation operation in this group, restraint is imposed on some of the particles by mechanical screens that prevent their passage.
- This is done successively, using increasingly smaller screens, to give a series of particles classified into size ranges. The fluid, usually air, can effectively be ignored in this operation which is called sieving.
- The material is shaken or agitated above a mesh or cloth screen; particles of smaller size than the mesh openings can pass through under the force of gravity.
- Rates of throughput of sieves are dependent upon a number of factors:

✓ nature and the shape of the particles,
✓ frequency and the amplitude of the shaking,
✓ methods used to prevent sticking or bridging of particles in the
✓ apertures of the sieve and
✓ tension and physical nature of the sieve material.

CONTACT EQUILIBRIUM PROCESSES

- Biological raw materials are usually mixtures, and to prepare foodstuffs it may be necessary to separate some of the components of the mixtures.
- One method, by which this separation can be carried out, is by the introduction of a new phase to the system and allowing the components of the original raw material to distribute themselves between the phases.
- For example, freshly dug vegetables have another phase, water, added to remove unwanted earth; a mixture of alcohol and water is heated to produce another phase, vapour, which is richer in alcohol than the mixture.
- By choosing the conditions, one phase is enriched whilst the other is depleted in some component or components.

- The maximum separation is reached at the equilibrium distribution of the components, but in practice separation may fall short of this as equilibrium is not attained.
- The components are distributed between the phases in accordance with equilibrium distribution coefficients which give the relative concentrations in each phase when equilibrium has been reached.
- The two phases can then be separated by simple physical methods such as gravity settling. This process of contact, redistribution, and separation gives the name contact equilibrium separations. Successive stages can be used to enhance the separation.

- The two features that are common to all equilibrium contact processes are the attainment of, or approach to, equilibrium and the provision of contact stages.
- Equilibrium is reached when a component is so distributed between the two streams that there is no tendency for its concentration in either stream to change.
- Attainment of equilibrium may take appreciable time, and only if this time is available will effective equilibrium be reached.
- The opportunity to reach equilibrium is provided in each stage, and so with one or more stages the concentration of the transferred component changes progressively from one stream to the other, providing the desired separation.
- Some examples of contact equilibrium separation processes are:
  1. Gas absorption
  2. Extraction and washing
  3. Distillation
  4. Crystallization

MEMBRANE SEPARATION PROCESSES

Reverse osmosis

- Membranes can be used for separating constituents of foods on a molecular basis, where the foods are in solution and where a solution is separated from one less concentrated by a semi-permeable membrane.
- These membranes act somewhat as membranes do in natural biological systems.
- Water flows through the membrane from the dilute solution to the more concentrated one. The force producing this flow is called the osmotic pressure and to stop the flow a pressure, equal to the osmotic pressure, has to be exerted externally on the more concentrated solution.

- Osmotic pressures in liquids arise in the same way as partial pressures in gases: using the number of moles of the solute present and the volume of the whole solution, the osmotic pressure can be estimated using the gas laws.
- If pressures greater than the osmotic pressure are applied to the more concentrated solution, the flow will not only stop but will reverse so that water passes out through the membrane making the concentrated solution more concentrated.
- The flow will continue until the concentration rises to the point where its osmotic pressure equals the applied pressure. Such a process is called reverse osmosis and special artificial membranes have been made with the required "tight" structure to retain all but the smallest molecules such as those of water.

Distillation

- Distillation is a separation process, separating components in a mixture by making use of the fact that some components vaporize more readily than others.
- When vapours are produced from a mixture, they contain the components of the original mixture, but in proportions which are determined by the relative volatilities of these components.
- The vapour is richer in some components, those that are more volatile, and so a separation occurs. In fractional distillation, the vapour is condensed and then re--evaporated when a further separation occurs.

- It is difficult and sometimes impossible to prepare pure components in this way, but a degree of separation can easily be attained if the volatilities are reasonably different.
- Where great purity is required, successive distillations may be used.
- Major uses of distillation in the food industry are for concentrating essential oils, flavours and alcoholic beverages, and in the deodorization of fats and oils.

Evaporation

- Frequently in the food industry a raw material or a potential foodstuff contains more water than is required in the final product.
- When the foodstuff is a liquid, the easiest method of removing the water, in general, is to apply heat to evaporate it.
- Evaporation is thus a process that is often used by the food technologist.
- The basic factors that affect the rate of evaporation are the:

  a. rate at which heat can be transferred to the liquid,
  b. quantity of heat required to evaporate each kg of water,
  c. maximum allowable temperature of the liquid,
  d. pressure at which the evaporation takes place,
  e. changes that may occur in the foodstuff during the course of the evaporation process

FOOD FREEZING

- Freezing is the reduction in temperature generally by super cooling followed by crystallization of water, nucleation and finely crystal growth.
- **Super cooling:** Occurs when temperature of water is lowered below the freezing point and crystallization does not occur. The super cooling provides the means of determining the in depth effect of a reduction in temperature relative to the initial freezing point.
- **Crystallization:** is the formation of a systematically organized solid phase from a solution or vapour. Crystallization consists of nucleation and crystal growth. The former is the association of molecules into tiny particles of site sufficient to survive and this serve as a site for crystal growth.

Refrigeration: This is the process by which heat is removed from a confined place and material for the purpose of maintaining a lower temperature.

- It is measured in British thermal unit or refrigeration unit e.g. 1 BTU = 1.055KJ. 1 BTU is defined as the heat required to raise 1 pound of water by 1^{o} Fahrenheit.
- The standard unit of generating heat capacity is 1 tonnes of refrigeration.
- This is derived on the basis of removal of latent heat of fusion of 1 tonnes or 2000 pounds of water at 32^{o} F or 0^{o}C to produce 1 tonne of ice.

Methods of quick freezing

- Freezing by indirect contact with a refrigerant
- Freezing in a blast of cold air
- Freezing by direct immersion in a refrigerating medium

1. **Freezing by indirect contact with refrigerant:** Food may be frozen by being placed in a contact with a metal surface which is cooled by a refrigerant or packaged or packed in a can and cooled by immersion in a refrigerant. Also food packaged in paper boxes may be frozen by contact with refrigerated metal plate which may be moving or stationary.

2. **Air Blast freezing:** To obtain very cold air, a blast of air is directed through refrigerating coil. For greater effect, the cold air blast is confined in an insulated tunnel. The material to be frozen may be placed on a moving belt within variable of moved countercurrent and the air blast.
3. **Freezing by direct immersion (FBDI):** FBDI in low temperature drying was the beginning of quick freezing. Since liquid are good heat conductors, a product can be frozen rapidly by direct immersion in low temperature liquid for example brine and sugar solutions.

Freezing time

The definition of freezing time is a function of two instances i.e. when freezing starts and when it stops.

- It is very difficult to determine the freezing time (θ) since freezing will occur at different rate and at different point in a piece of food.
- The freezing will be faster at some point on the surface and in the body of the piece of food, there is a point which cools slowest.
- The highest temperature at which ice crystals have a stable existence in a food material is known as the freezing point of that material and this signals the starts of freezing time.
- Because of the nature of materials of food and the presence of water soluble constituents, all water does not crystallize at this temperature, this is known as cryoscopic effect.