FOOD ENGINEERING (ABE 417)

Food is any substance eaten by people. It could be a produce or product edible by a particular society; measured by the weight of edible material that has been harvested, gathered or caught for human consumption as that is ensured by the population of the area under consideration. Therefore, food engineering is considered as the application engineering principles and practice in management of farm produce from the time harvest to market.

Why do we produce food? Food is produced for human consumption. The world population is increasing daily, especially, in forest developing countries population growth in geometric order while the total food production is in arithmetic order. Therefore, to meet food demands, the yield or output production must be improved. What has been produced must be protected against pest, rodents, fungi etc and harvest losses on farm.

The rising demand by consumers for better quality crops, food products and fibre has made agricultural processing of crops inevitable. The processing of agricultural raw materials is increasing both on the farm and in central locations. This has created new industries to supply better quality products in more readily usable forms. The need to make products available all year round calls for processing into stable products or storage of the raw products.

What is Engineering? Engineering has been defined as the art and science of utilizing the forces and materials of nature for the benefit of man and the direction of man's activities toward this end. The science of engineering is that phase of the field which is exact and rational, while the art of engineering refers to the ability to judge, estimate, and manipulate the uncertainties of engineering to a satisfactory solution of a problem.

Therefore, food engineering can be defined as the art and science of transformation of agricultural materials into final products or the conservation of material and products.

1.0 HEAT AND MASS TRANSFER

Most food processes, such as cooking, pasteurization, sterilization, drying, evaporation, distillation, chilling, freezing etc. involve some sort of heat transfer. Most agricultural processes involve exchange of materials between different parts (phase) of the system, often combined with heating or cooling. Therefore, heat and mass transfer are based on essentially similar physical principles. Both processes obey laws that are, in principle, identical.

The basic laws of transport can be expressed in general terms as follows. The rate of transport (i. e. the quantity transported per unit time) is proportional to the driving force and inversely proportional to the resistance of the medium to the transport.

$$q = \frac{dQ}{dt} = \frac{f}{R} \quad kf \; (k = {}^{1}/_{R})$$

where q = dQ/dt = the rate of heat transfer, f = driving force, R = resistance of the medium to heat transfer and k = compliance or conductance of the medium to heat transfer.

Generally, heat transfer is used in drying process.

Three conditions of heat transfer:

(i) To provide energy for vapourization, distillation, drying, etc.

(ii) To maintain desirable temperature for bacterial growths in fermentation of gari processing, making of potatoes chips, etc.

(iii) To remove heat i. e. reduce the temperature to avoid undesirable temperature.

Heat transfer relates to the rate at which hear energy moves. Its motive force is temperature difference. Generally, heat flows from hot to cool medium.

Mass Transfer

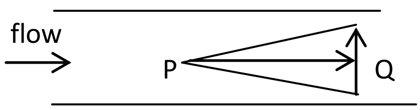
Mass transfer may take place according to two mechanisms, by molecular flow or by forced convective flow. When there is a concentration gradient of the considered component between two points of the system, mass transfer is produced by molecular flow. However, when the entire mass moves from one point to another, the transfer is produced by forced convection flow.

According to the physical nature of the media, different situations can occur and the mass transfer is carried out by me or by both of the transport mechanisms considered.

(i) When there is no concentration gradient of the considered component, and if the medium is a fluid, there can only be convective transport.

(ii) When there is a concentration gradient of the component, and the medium is a fluid in repose, the mass transfer is carried out by molecular flow, due only to molecular diffusion (is a crystal of colorant in a beaker).

(iii) When there is a concentration gradient and the medium is a fluid moving in a laminar regime, mass transfer is carried out by the two mechanisms (i.e. a colorant injected into of a tubing.



(iv) When the medium is a fluid in which there are turbulence and concentration gradients, the mechanisms of molecular and forced convention mass transport occur simultaneously.

Mechanisms of heat and mass transfer

Heat transfer occurs via three fundamental mechanisms: conduction, convection and radiation.

Conduction refers to the transfer of heat through a stationary medium the mass transfer equivalent of conduction (conductive mass transfer) in molecular diffusion through a stationary medium.

Convection occurs when heat travels along with a moving fluid. In mass transfer, convection (convective, mass transfer) refers to a situation whereby molecular diffusion occurs simultaneously with the bulks flow.

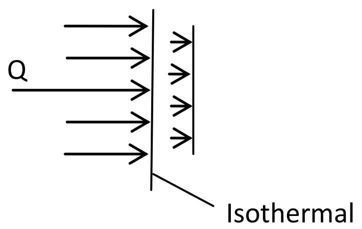
Radiation is the transfer of heat in the form of electromagnetic radiation. Unlike conduction and convection, radiative heat transfer does not require the presence of a material medium between the two points.

In practice, more than one mechanism may be involved in a transfer process. The transfer and mode depends on mobility of the medium molecules, i.e. ability to vibrate, speed of molecular movement and heat direction. Heat could be uni-directional or multi-directional.

Fourier's Law of heat Conduction

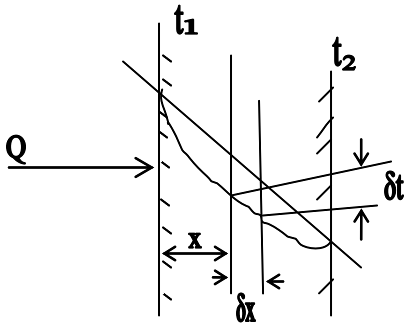
Assumptions:

(1) Temperature is uniform over surface and perpendicular to the direction of heat conduction



i.e. *The parallel plain surfaces are isothermal.*

(2) Temperature at any point does not vary with time i.e. rate of heat flow through successive surfaces are constant.



$$Q = -KA\left(\frac{\delta t}{dx}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (a)$$

where Q = heat rate (w, or J/S)

A = cross section –area (m^2)

t = temperature ($^0/c^{1^k}$)

x = distance through conductivity medium (m)

k = thermal conductivity of material (w/m ^{0}/c), $J.S^{-1}.m^{-2}.k^{-1} = w.m^{-1}.k^{-1}$

For uniform flow (steady-state), k is constant. Thus,

$$Q = -KA\left(\frac{\delta t}{dx}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (b)$$

$$\int_1^2 Qdx = \int_1^2 -KAdt$$

$$Q(x_2 - x_1) = -KA(t_2 - t_1)$$

$$Q = \frac{-KA(t_2 - t_1)}{x_2 - x_1}$$

The Fourier and Fick Laws

In media with no considerable internal mobility (e.g. solids), heat travels by conduction and mass travels by molecular diffusion. These transfers are governed by fourier's and fick's laws respectively.

For heat transfer:

$$\frac{dQ}{Adt} = -k\frac{\delta T}{\delta x} \quad \text{(fourier's 1}^{st}\text{ law)} \quad \ldots\ldots\ldots\ldots\ldots \text{(i)}$$

$$\frac{dmB}{Adt} = d_B = D_B\frac{\delta C_B}{\delta x} \quad \text{(fick's 1}^{st}\text{ law)} \quad \ldots\ldots\ldots\ldots\ldots \text{(ii)}$$

Where t = time(s). M = mass of substance B transferred, mol, C_B = concentration of substance B, $mol.m^{-3}$, D_B = diffusivity (coefficient of diffusion) of molecular specious, B through the medium, $m^2.s^{-1}$.

At steady state, equations (i) and (ii) can re-write as:

$$\frac{dQ}{Adt} = \frac{q}{A} = -k\frac{dT}{dx}$$

$$\frac{dmB}{Adt} = J_B = -D_B\frac{dC_B}{dx}$$

The boundary conditions for the integration of equation (i) & (ii)

$T = T_1$ and $C - C_1$ at $x = x_1$

$T = T_2$ and $C - 2$ at $x = x_2$

Assuming K and D_B are constant

$$q = \frac{Q}{t} = KA\frac{(t_2 - t_1)}{x_2 - x_1}$$

$$m_B = \frac{m_B}{t} = D_BA\frac{(C_{2B} - C_{1B})}{x_2 - x_1}$$

Example 1. Calculate the rate of heat transfer through a 3 x 4m concrete wall. One face of 0.2m thick wall is at 22^0C and the other face is at 35^0C. The thermal conductivity of the concrete is 1.1 $w.m^{-1}.k^{-1}$.

Solution

$$q = \frac{Q}{t} = KA\frac{(t_2 - t_1)}{x_2 - x_1}$$

$$= 1.1 \times (3 \times 4)\frac{35 - 22}{0.2}$$

$$= 858w \text{ or } J/S$$

Table 1. Thermal conductivity and thermal diffusivity of some materials

Material	*T(0C)*	*K (w.m^{-1}.k^{-1}.)*	*α(m^2.s^{-1})*
Air	20	0.026	21 x 10^{-6}
Air	100	0.031	33 x 10^{-6}
Water	20	0.599	0.14 x 10^{-6}
Water	100	0.684	0.17 x 10^{-6}
Ice	0	2.22	1.1 x 10^{-6}
Milk	20	0.56	0.14 x 10^{-6}
Edible oil	20	0.18	0.09 x 10^{-6}
Apple	20	0.5	0.14 x 10^{-6}
Meat (lamb leg)	20	0.45	0.14 x 10^{-6}
Stainless steel	20	17	4 x 10^{-6}
Glass	20	0.75	0.65 x 10^{-6}
Copper	20	370	100 x 10^{-6}
Concrete	20	1.2	0.65 x 10^{-6}

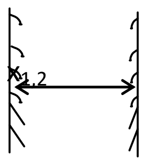
(*Source: Zeki Berk, 2009)*

Steady-state conductive heat and mass transfer processes

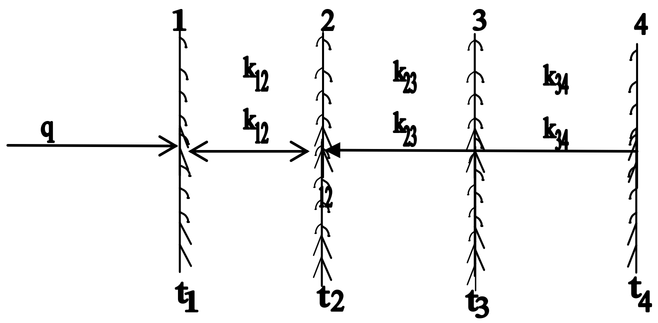
(a) Steady-state conduction through a single slab (two parallel wall)

K = constant

$$Q = - KA \frac{(t_2 - t_1)}{x_2 - x_1}$$



(b) Steady-state conduction through a multilayer slab (composite wall)



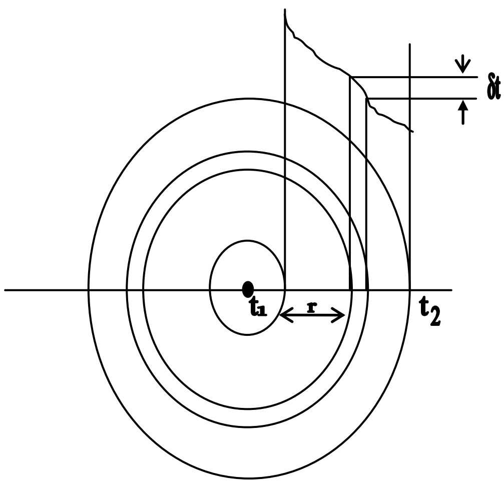
Heat flow through each component = q = Q/A = KA $\frac{(t_4 - t_1)}{X_4 - x_1}$

$$q = - K_{12} \frac{(t_2 - t_1)}{x_{12}} = - K_{23} \frac{(t_3 - t_2)}{x_{23}} = - K_{34} \frac{(t_2 - t_2)}{x_{34}}$$

This implies

$$(t_2 - t_1) = - \frac{qx_{12}}{k_{12}} ; \ (t_3 - t_2) = \frac{-qx_{23}}{k_{23}} ; \ (t_4 - t_3) = - \frac{qx_{34}}{k_{23}}$$

(c) Steady –state transfer through varying area:



Consider any cylindrical tube of thickness dr. Area of flow/unit length of t is 2πr and its temperature gradient is $\frac{dt}{dr}$. Heat flow par unit length =

$$q = - K\pi r \frac{dt}{dr}$$

i.e. $q = K2\pi r \frac{dt}{dr}$

At steady flow state (unit length)

$$q \int \frac{dr}{r} = - K2\pi \int dt$$

$$q \ In\ r\ 1^2, = - K2\pi(t_2 - t_1)$$

$$q = \frac{- K2\pi\,(t_2 - t_1)}{In \frac{r^2}{r_1}}$$

∴ for the total length (L) of the tube

$$Q = \frac{2\pi Lk\,(t_2 - t_1)}{Ln \frac{r^2}{r_1}}$$

Example 2: A 5cm outside diameter steel pipe is carrying steam at 150^0C, the pipe is insulated with a cylindrical shell of insulator 3cm thick ($k = 0.03 w.m^{-1}.k^{-1}$). Calculate the rate of heat loss per meter of pipe length, if the temperature of the outer surface of the insulation is 35^0C.

Solution:

Assume the outer wall of the steel pipe is at the temperature of the steam.

$$\frac{Q}{L} = q = \frac{2\pi k\,(t_2 - t_1)}{In \frac{r^2}{r_1}} = 2\pi \times 0.03 \times \frac{150 - 35}{In\,(\frac{5.5}{2.5})}$$

$$= 27.5 w.m\text{-}^1$$

$$-(t_4 - t_1) = - (t_2 - t_1) \quad - (t_3 - t_2) \quad - (t_4 - t_3)$$

$$- (t_4 - t_1) = q \ \left(\frac{x_{12}}{k_{12}} + \frac{x_{23}}{k_{23}} + \frac{x_{34}}{k_{34}} \right)$$

$$q = k \left(\frac{t_4 - t_1}{(x_4 - x_1)} \right)$$

Generally,

$$q = u\,(t_4 - t_1)$$

where $u = \frac{k}{x_{41}} \Rightarrow (t_4 - t_1) = q.\frac{1}{u}$

$\therefore \quad \frac{1}{u} = \frac{x_{12}}{k_{12}} + \frac{x_{23}}{k_{23}} + \frac{x_{34}}{k_{34}}$

u = overall heat transfer coefficient

$\frac{1}{u} = \sum \frac{\Delta x}{k}$

$Q = -AU(t_4 - t_1)$

Example 3:

The external wall of a cold storage room is made of 3 layers, as follows, from the inside out:

(a) Stainless steel sheet, 2mm thick ($k = 15\ w.m^{-1}.k^{-1}$)

(b) Thermal insulation, 80mm thick ($k = 0.03\ w.m^{-1}.k^{-1}$)

(c) Concrete, 150mm thick ($k = 1.300\ w.m^{-1}.k^{-1}$)

The inside face is at -18^0C. The outside is at 20^0C. Calculate the heat flux through the wall and the temperature at the insulator – concrete interface.

Solution:

The total thermal resistance of the is

$$U = \frac{x}{k} = \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} = \frac{0.002}{15} + \frac{0.08}{0.03} + \frac{0.15}{1.3} = 0.13 \times 10^{-3} + 2.67 + 0.11$$

$$\simeq 2.78 m^2.k.w^{-1}$$

$$Q = \frac{T_4 - t_1}{u} = \frac{20-(-18)}{2.78} = 13.67\ w.m^{-2}$$

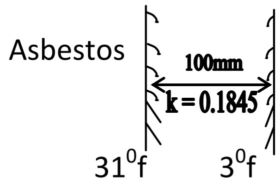
Since stainless sheet is a good conductor, the thermal resistance is negligible and since the same flux crosses the layers, the temperature T at the insulator concrete interface can be calculated.

$$q = 13.67 = \frac{0.03\{T^1 - (-18)\}}{0.08} = \frac{K_{insulator}(T_1 - t_{inside})}{x_{insulator}}$$

$\therefore T = 0.08 \times 13.67/0.03 = 18 = 18.5^0C$

Exercise 1. Find the rate of heat flow through asbestos partition in cool storage plant. The wall is 6m long, 4m wide and 100mm thick. The temperature of the two surfaces are maintained at 30^0f and 3^0f.

Solution:



$A = L \times B = (6 \times 4)\ m^2 = 24m^2$

$t_1 = \{(31 - 32)\frac{5}{9} + 273\} = {}^0k = 272.5^0k$

$t_2 = \{(3 - 32)\frac{5}{9} + 273\}\ {}^0k = 257.4^0k$

$Q = KA \frac{(t_2 - t_1)}{x_{12}}$

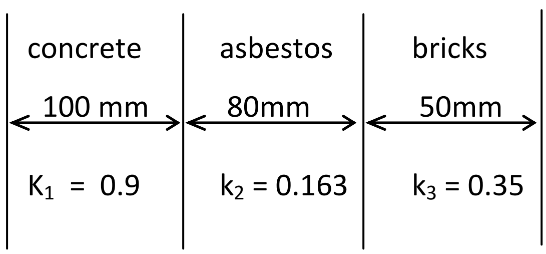
$= \frac{0.1845 \times 24\ (272.5 - 257)}{100/10^3}$

$= \frac{0.1845 \times 24\ (272.5 - 257)}{0.1}$

$= 668.3J.$

Exercise 2. The exterior wall of a cool room is 5m long and 3m high is built of 100mm thick concrete, 80mm of asbestos, 150mm of building bricks. Find the steady state heat transfer rate when the outside temperature is 80^0f and the cool room is 0^0f.

Solution:



$t_1 = 80^0C$ $t_4 = 0^0f$

$q = u(t_4 - t_1)$

$\frac{1}{u} = \Sigma\frac{\Delta x}{k} = \frac{100/10^3}{0.9} + \frac{80/10^3}{0.163} + \frac{50/10^3}{0.35}$

$= \frac{1.029}{10^3}$

$u = 0.9718 \times 10\text{-}3$

$Q = Au(t_4 - t_2)$

$Q \text{ at } A = 5 \times 3 = 15m^2$

$t_4 = (80 - 32)\frac{5}{9} + 273 =$

$t_1 = (0 - 32)\frac{5}{9} + 273 =$

$Q = 15 \times 0.9718 \times 10^3$

$Q = 648.7J$

Heat Requirements for Vaporization

The energy, which must be supplied to vaporize the water at any temperature, depends upon this temperature. The quantity of energy required per kg of water is called the latent heat of vaporization, if it is from a liquid, 0^- latent heat of sublimation if it is from a solid. The energy required to vaporize water under any given set of conditions can be calculated from the heats given in steam table as steam and water vapour are the same thing.

Exercise 3. *Heat energy in air drying*

A food containing 80% water is to be dried at 100^0C down to moisture content of 10%. If the initial temperature of the food is 21^0C, calculate the quantity of heat required per unit weight of the original material for drying under atmospheric pressure. The latent heat of vaporization of water at 100^0C and at standard atmosphere pressure is 2257KJkg^{-1}. The specific heat capacity of the food is 3.8 K.J kg^{-10}C^{-1} and water is 4.189KJkg^{-10}C^{-1}. Find also the energy requirement/kg water removed.

Solution

Calculating for 1 kg food

Initial moisture = 80%

800g moisture are associated with 200g dry matter.

Final moisture = 10%,

100g moisture are associated with 900g dry matter,

Therefore (100 x 200)/900g = 22.2g moisture are associated with 200g dry matter.

1 kg of original matter must lose (800 – 22) g moisture = 778g = 0.778kg moisture.

Heat energy required for 1 kg original material

= heat energy to raise temperature to 100^0C + latent heat to remove water.

= (100 – 21) x 3.8 + 0.778 x 2257

= 300.2 + 1755.9

= 2056KJ

Energy/kg water removed, as 2056KJ are required to remove 0.778kg of water.

= 2056/0.778

= 2643KJ.

Exercise 4. Using the same material as in *exercise 3,* if vacuum drying is to be carried out at 60^0C under the corresponding saturation pressure of 20kPa abs (Δ vacuum of 81.4 kPa), calculate the heat energy required to remove the moisture per unit weight of raw material.

Heat energy required per kg raw material:

= heat energy to raise temperature to 600C + latent heat of vaporization at 20kPa abs

= (60 – 21) x 3.8 + 0.778 x 2358

= 148.2 + 1834.5

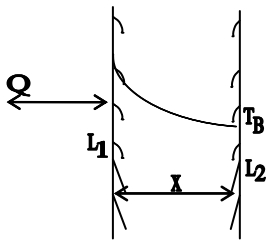
= 1983 K.J.

Heat Exchangers – design and application

Heat exchangers are devices for the exchange of heat between two fluids separated by a heat conducting partition. They are used to heat or cool foods and their design and operation depend on the properties of the foods being processed and the degree of heating required. Heat exchangers are extensively used in the food industry for heating (e.g. pasteurizers), cooling (chilled water generators) and heat induced phase change (freezing, evaporation). Each one of the two fluids may be confined or unconfined (free), stagnant or flowing. The partition is a heat conducting solid wall, usually made of metal.

Overall Coefficient of heat transfer

Consider heat exchange between two fluids A and B, separated by a heat conducting wall.



Assume $T_A > T_B$. Heat travels from A to B, through three thermal resistance in series:

(i) The resistance to connective heat transfer from fluid A to the contact area of the wall.

(ii) The resistance of the wall to conductive heat transfer

(iii) The resistance to convective heat transfer from the wall surface to fluid B.

The rate of heat transfer, given by the overall temperature difference $T_A - T_B$ is:

$$Q = A \frac{T_1 - T_2}{\frac{1}{h_1} + \frac{x}{h} + \frac{1}{h_2}}$$

Where: A = heat transfer area, m^2

h_1, h_2 = convection heat transfer coefficients on the side of A and B respectively.

$w.m^{-2}. k^{-1}$

T_1, T_2 = bulk temperature of A and B respectively, K

x = thickness of the wall, m

k = thermal conductivity of the wall, $w.m^{-2}. k^{-1}$.

An overall coefficient of heat transfer, u ($w.m^{-2}. k^{-1}$). Is defined as:

$$\frac{1}{u} = \frac{1}{h_1} + \frac{x}{h} + \frac{1}{h_1}$$

$\therefore$ $Q = UA\Delta T$

Factors Affecting Overall coefficient of heat transfer:

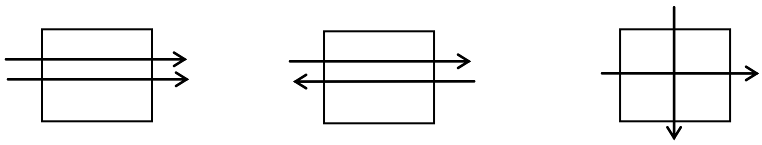
(i) Properties of the two fluids i.e. flow conditions, flow pattern, geometry, physical dimensions, the thickness.

(ii) Thermal conductivity of the wall.

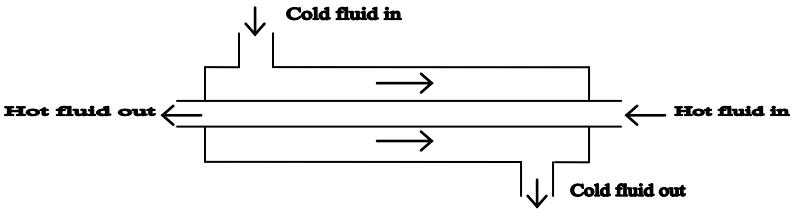
The three resistances, usually not equal significance.

Heat Exchange between flowing fluids

In continuous heat exchangers, both fluids are in movement. There are three main types of flow patterns: parallel, countercurrent and cross-flow.



Parallel and counter current flow are most common in liquid – to – liquid and liquid – to – condensing vapour heat exchange. As a result of flow, the temperature of each may drop from one point in the exchange to another.



heat transfer in a shell-and-tube heat exchanger

The hot and cold fluids will be indexed h and c.

Energy balance

$$dq = G_l\,(cP)_c dTc$$

$$dq = -\,Cu\,(cP)_h\,dT_h$$

where G = mass flow rate, kg.s^{-1} . Therefore the flow rates and the specific heats are constant.

$$dq = udA\,(T_u - T_c) = udA\,\Delta T$$

$$\frac{d(\Delta T)}{dq} = \frac{d(\Delta T)}{udA\,\Delta T} = \frac{(\Delta T)_2 - (\Delta T)_1}{q}$$

Separating the variables and integrating between point 1 & 2 for the entire exchanger assuming constant u, gives.

$$Q = uA \left| \frac{(\Delta T_2) - (\Delta T_1)}{\ln \frac{(\Delta T)_2}{(\Delta T_1)}} \right|$$

= $Q = UA\,\Delta T_{ml}$ where ΔT_{ml} is the expression in brackets.

Example:

A tubular heat exchanger will be used to heat tomato paste from 60 to 105^{0}C, prior to holding, cooling and aseptic filling into drums. The exchanger consists of two concentric tubes. Tomato paste is pumped through the inner tube. Steam condenses at 110^{0}C in the annular space. Calculate the required heat transfer area.

Data:

Tomato paste mass flow rate = 5000kg/h

Tomato paste specific heat: 3750j/kg.k

Convective heat transfer coefficient, tomato side: 200W/m^2.k

Convective heat transfer coefficient, steam side: 2000W/m^2.k

Wall of tube (stainless steel). Thickness = 2mm; thermal conductivity = 15W/mk.

Solution:

$$Q = UA\,\Delta T_{ml}.$$

$$Q = \frac{dm}{dt} C_p (T_2 - T_1) = \frac{5000}{3600} \text{ x } 3750 \text{ x } (105 - 60) = 2343\ 75 \text{ J/s}$$

$$\frac{1}{u} = \frac{1}{hi} + \frac{1}{ho} + \frac{x}{k} = \frac{1}{200} + \frac{1}{20000} + \frac{0.002}{15} \simeq \frac{1}{200}$$

$$\therefore\ u = 200\text{W/m}^2\text{.k}$$

$$\Delta T_{ml} = \frac{(\Delta T)_2 - (\Delta T)_1}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)} = \frac{(110-105) - (110-60)}{\ln \frac{110-105}{110-60}}$$

$$\therefore\ A = \frac{Q}{U\Delta T_{ml}} = \frac{234375}{200x16.6} = 70.6\text{m}^2$$

Fouling

In food processing plant, the efficiency of heat exchangers may be considerably reduced during operation, as a result of the deposition of various kinds of materials with relatively low thermal conductivity on the exchange surface. The nature of these materials depends on the fluids treated; denatured proteins in the case of milk, burnt pulp in the case of tomato juice, caramelized sugar in the case of syrups, scale in the case of hard water etc. In the food industry, fouling may also result in loss of product quality (burnt favor, dark specks all). Fouling often determines the maximum operation time between two interruptions for cleaning.

The resistance of the fouling film to heat transfer is simply added to the overall resistance. The building of fouling is often not uniform over the entire exchange surface. For example, the rate of deposition is higher in locations where flow is slower.

An approximate estimate of fouling resistance is given as:

$$\frac{1}{u} = \frac{1}{u_0} + \beta t$$

where u = overall heat transfer coefficient of the 'dirty' exchanger

u_0 = overall heat exchange coefficient of the 'clean' exchanger

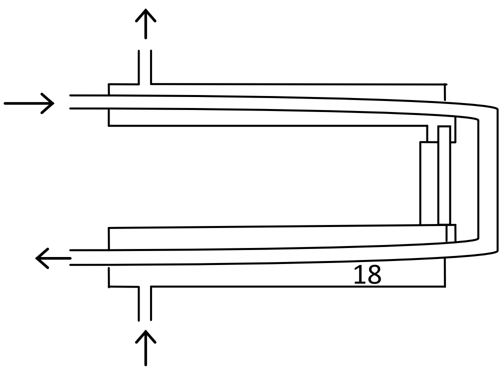
β = fouling factor $w^{-1}.m^{2}.\ k^{-1}.s^{-1}$

t = times.

Application of heat exchanger in food process industry.

A few of the many heat exchanger type utilized in process industry are suitable for food applications.

(1) Tubular heat exchangers: the simple representative of this group consists of a pair of concentric tubes for ease of cleaning; the food product usually flows in the inner tube and the heating or cooling medium in the outer annular space.



Tubular heat exchanger

(2) Shell-and-tube exchangers: generally, consist of bundle or set of tubes contained in a shell and a supporting plate fastens the bundle. In this type of heat exchangers, one fluid circulates inside the tubes, and the other are circulates outside the tubes and inside the shell. Tubular heat exchangers are particularly suitable for heats or cooling highly viscous products and where relatively high pressures must be applied. They are therefore utilized for the bulk in-flow sterilization of products containing solid particles or for heat treatment and cooling of tomato paste prior to aseptic packaging.

(3) Plate heat exchangers: they consist of a stack of corrugated thin metal plates, pressed together so as to form two continuous flow channels for the fluids exchanging heat. Gaskets are placed between the plates to prevent leakage.

The advantages of the plate heat exchangers:

(i) Flexibility: the capacity can be increased or decreased by adding or removing plates.

(ii) Sanitation: by opening the stack, both sides of the entire exchanger area are made accessible for cleaning and inspection.

(iii) High heat transfer coefficient, due to increased turbulence in the narrow flow channel.

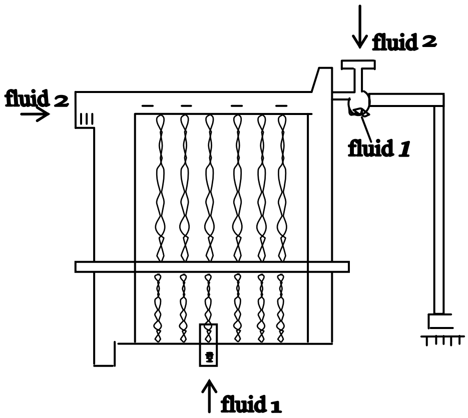
(iv) Compactness: high exchanger surface to volume ratio

Disadvantages:

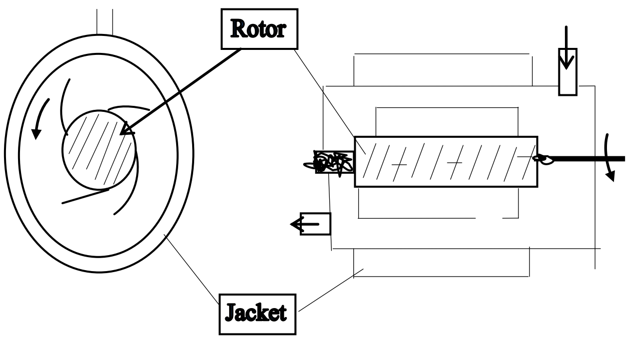
(i) The narrow size of the flow channels results in high pressure drop.

(ii) It limits its use to low viscosity fluids not containing large suspended particles.

(iii) It needs gaskets.



(4) Scraped surface heat exchangers: They consist of a jacketed cylinder equipped with a central rotating dasher with scraping blades. They can be horizontal or vertical. The product is fed into the cylinder. The rapidly (600 – 700. rpm) rotating dasher spreads, scrapes and moves the products as a film over the wall. The heating and cooling fluid is fed into the jacket. Scraped surface heat exchangers are used for heating and cooling highly viscous fluids and for slush-freezing.



A scrape surface heat exchanger

Order forms of exchange by definition are: heating vessels, cooking kettles, microwave heating, ohmic heating, etc.

Food Packaging

Packaging is an important aspect of the food manufacturing process. Since its main purpose is the preservation of food over a long period of time, foods are packaged in container. The main function of a container is that of containing the food, also, it provides protection against possible physical chemical and microbial deterioration. Historically, foods were preserved in different types of container made of wood, metal, or glass.

Functions of Packaging

1. *Containment*: One of the primary and obvious objectives of the package is to contain the product. This is essential for the efficient transportation, storage and distribution of the production. In addition, containment allows repartition of the product into portions of known weight or volume and facilitates stock-keeping and merchandising. The shape and dimensions of the package determine to a large extent the space requirement for storage, transportation and display.
2. *Protection and preservation*: By placing a more or less effective barrier between the food and the environment, the package protects the food from physical, chemical, microbial and microbial attack from the exterior and this has a decisive effect on the shelf life of the product. At the same time, the package protects the environment from the food, by preventing spillage, odor release, dust etc. In thermal processing, the package dictates the type of processing and vice versa. The package, be it a metal can, a glass jar or a plastic pouch, is expected to prevent recontamination of the thermal stabilized food inside. In recent years, packaging materials containing persevering substances have been developed, giving rise to a promising new area

known as “active packaging”. Also, packaging materials with specific transport properties are the key factor in the preservation method known as the “modified atmosphere” technique.

3. *Convenience*: Convenience has long been and continues to be among the chief ‘selling’ attributes of foods and packaging contributes considerably to the convenience factor, in many ways. Adapting the size of the package to the needs of particular consumer group. (family size, individual, special sizes of food service delivery, etc.) is one of the steps taken by industry to enhance product convenience through the package. Pressurized packages (for whipped cream), aerosols (for coating, flavouring, oiling, etc.), easy-open and/or re-sealable packages, package that can serve as heating utensils as plates, cups, bowls etc. from which the food can be eaten or drunk directly are among the convenience-driven developments of packaging technology.
4. *Communication*: the quantity of information printed on a food package has been increased constantly. In addition to text and graphics serving the purpose of product and brand identification and product promotion, the printing usually includes essential data such as list of ingredients, nutritional data, production date and/or a limit date for selling, price, a barcode and information needed for product traceability.

Levels of packaging

(i) *Primary package*: This is a package in direct contact with the food. It is the package in which a unit of the product is presented to the retail market. Examples of primary packages are: can of milk, wrap of dodo ikire, bag of beans, etc.

(ii) *Secondary package*: A number of primary packages are usually contained in an outer package for transportation, storage and delivery is called secondary package. Examples are can of milk in a carton box containing dozen(s).

(iii) *Tertiary package*: This is a number of secondary packages collated into a 'lot'.

Packaging Methods

Packing can be done either manually or mechanically which in turn could be either systematic or random. Filling can be done by count or by weight.

(i) *Manual systematic packing*: Here there is a certain pattern adopted so that the maximum volume is utilized fully. Normally, systematic manual packing is filled by count. The best example is the packing of orange and pear.

(ii) *Mechanical systematic packing:* This is a semi-automated method. It is like a carton of trays are on the other. The worker shifts the tray of fruit into a frame, then presses the pedal below and the tray drops gradually in the carton or box. Another method is by vacuum. This is the system used in packing eggs.

(iii) *Manual Random packing:* The random packing is sometimes called volume packing. So in manual random packing, there is no particular pattern adopted. The fruits are filled by count or weight randomly until the volume is fully occupied.

(iv) *Mechanical Random or Volume packing:* This consists of filling the carton, can or even bag by count or weight and then vibrating the container mechanically so that the fruits settle down and utilize the maximum volume.

Packaging Materials

A great variety of materials are used for packaging foods. According to the function they carry out, these materials can be classified as containers used in transportation and containers use for sale and the consumer. Container for transportation protect the food during its transport and distribution, as in the case of wooden and metal boxes, barrels, drums, and bags, among others. Containers for retail sale to consumers are those that contain the product in small quantities, and in addition to protecting the food, they also provide information about its content, as it in the case of glass bottles, plastic containers, trays, bags and wrapping.

Metals

Metal containers offer the advantage of superior mechanical strength, impermeability to mass transfer and to light, good thermal conductivity and resistance to relatively high temperature. In production of metallic containers, steel and aluminum are generally used. These types of materials are used in the canning of foods and drinks. Due to their resistance to high temperatures, steel and aluminum are suitable materials for the pasteurization and sterilization processes of packed products. On the other hand, this type of materials do not allow visualization of the internal contents, usually heavy, which can increase the cost of transportation and corrosion can also be present (internal and external).

A steel sheet with low carbon content constitutes the tin used in containers with a thickness from 0.15mm that is covered with a tin layer on both sides, with the purpose of avoiding corrosion and to avoid the transfer of metals into the food, tin sheets are re-covered with a polymeric lacquer film. Aluminum has same function as the steel but higher in weight.

Glass

Glass is a material that is often used in the manufacture of food containers. The advantages of glass as a packaging material are: transparence (to light and microwaves), inertness, impermeability, rigidity, thermal resistance, reused ability and general consumer appeal. Its disadvantages are fragility and weight, because glass containers are transparent to light, photochemical reactions can cause deterioration of the food. For this reason, coloured glass is sometimes used, as in the care of amber bottler used for bottling beer or green bottles that are used for wine. Because glass is resistant, there is need to avoid sudden thermal crashes. Heating should be carried out slowly. In practice, many foods are packed in glass containers, such as milk, beer, wine, nonalcoholic beverages, sauces, vinegar, pickles and fruit juices, etc.

Wood

Wood is a material that has been used in production of boxes and pallets that are generally used when a high grade of mechanical protection in transport and storage of food product, is necessary. However, recently, boxes and used in the transport and storage of fruits and vegetables are being manufactured from plastic, which has caused a lower use of wood.

Paper, Cardboard and Plant Tissues

Paper is made from wood and is a very often used material in food packaging in the form of cardboard, laminate and corrugated cardboard. Its cost is low in comparison with other materials, it has a good rigidity, and it can be printed on. On the contrary, paper is very sensitive to humidity, and environmental humidity can affect it negatively. Used paper can be recycled, though not advisable to wrap food with recycled paper products.

Cardboard is usually used in the production of boxes and can be of different quality depending on the product that will be contained in the package. If fatty or wet foods will be contained in the package, the cardboard can be covered with wax or polymers. Cardboard is used in manufacture of trays for eggs and fruits carton for used for products that are already packed, canned or bottled in other materials.

Tissue manufactured with jute and cotton are also used in food packaging. Jute is usually used in the production of bags to store and transport bulk foods, as in the case of sugar, grains, flour, salt, etc.

Polymers

Polymers are materials that are more and more often being used in food packaging, substituting other types of materials. Their advantages include; shape versatility and wide spectrum of properties. However, depending on the polymer type, the possibility of interactions with food may exist and contamination of the food may occur. Polymers are quite impermeable to gases, water vapour, and oxygen. Most Polymers are thermoplastic, which indicates that they are able to be thermo sealed. Polymers are used in the production of flexible films, that is, for those to which some substance can be added to confer specific properties. Flexible films adapt to the form of the contents, allowing for more space during storage and transport.

Food Quality Control

1. Effect of Evaporation on food Quality

(a) Thermal Effects

During evaporation, foods are susceptible to thermal damage, depending on the time-temperature profile of the process; following are some examples of thermal damage types associated with evaporation:

(i) Non-enzymatic (maillard) browning

(ii) Induction of 'cooked taste' in fruit juice

(iii) Loss of carotenoid pigments (e.g. lycopene in tomato juice)

(iv) Protein denaturation (milk)

The rate and extent of browning discoloration is concentration dependent. As the concentration of the food increases during evaporation, so does its sensitivity to high temperature. This type of quality loss is common almost to all fruit juices and particularly to citrus products. Loss of 'fresh' taste and induction of 'cooked taste' is common to most fruit juices and particularly to tomato, citrus, apple and grape juices. Some cooked taste in tomato concentrates to be used as such is not objectimable. However, if the concentrate is to be reconstituted as tomato juice by dilution with water, cooked taste is considered a defect. Cooked taste is due to the formation of precursors of dark pigments in non-enzymatic browning.

(b) Loss of Volatile Flavour Components

A certain proportion of the desirable volatile components, known as the 'aroma', 'fragrance' or 'essence' are lost when fruit juices or coffee extract are concentrated by evaporation. The extent of aroma loss depends on the volatility of the flavor substances in relation to that of water.

Classification of Fruit Aromas:

(i) High volatility aromas: These are practically lost completely when only 15% of the juice has been evaporated i. e. apple aroma.

(ii) Medium volatility aromas: These are lost almost completely when 50% of the juice is evaporated i.e. plum, grape.

(iii) Low volatility aromas: These are lost to the extent of about 80% when 50% of the juice is evaporated i.e. peach, apricot

(iv) Very low volatility aromas: These are of which 60 – 70% or less are lost when 50% of the juice is evaporated.

Natural aromas are complex mistures of volatile organic compounds (alcohols, aldelyders, ketones, esters, phenolic substance, terpanes, etc. The different components of a given aroma do not have the same volatility. During evaporation, some components are lost to a greater extent than others. Loss of volatiles is not always undesirable. The process of 'deodorization', applied sometimes to milk and cream consists of partial removal of objectionable odorous volatiles by vacuum evaporation.

2. Effect of Frozen Storage on Food Quality

Frozen storage, even at fairly low temperature does not mean the absence of deteriorative processes. On the contrary, frozen foods may undergo profound quality changes during frozen storage. While the rate of reactions is generally slower in frozen foods, the expected shelf life and therefore the time available for the reactions to take place, is long. Some of the frequent types of deterioration in frozen foods are protein denaturation resulting in toughening of muscle foods, protein-lipid interation, lipid oxidation and oxidative changes in general (e.g. loss of some vitamins and pigments).

A large number of commodities change in chemical composition and sensory characteristics. Logically, lower storage temperature always results in higher quality; while storage time reduce food quality i.e. loss of a certain vitamin, loss of colour loss of organoleptic score.

Mass transfer phenomena during frozen storage (oxygen transfer, loss of moisture) may be a major cause of quality loss. The quality of packaging is therefore, particularly important in frozen foods. Another type of change in frozen foods during storage is the process of recrystallization. Smaller crystals are more soluble than large one. Equally, small ice crystals have a lower melting point than large one. Consequently, if the storage temperature undergo fluctuations, small ice crystals may melt and then solidify on the larger crystals. Recrystallization is particularly objectionable in ice cream, where conversion of small ice crystals to large ones results in loss of the smooth, creamy texture. The remedy is, of course, avoiding temperature fluctuation during storage as much as possible.

Heat and Cold Preservation of Foods

Food preservation refers to methods used for keeping food from getting spoilt. \food spoilage is any adverse change that makes food unfit for human consumption and this process can be due to chemical and physical changes; for example, browning and bruising, growth of unwanted pathogenic microorganism and infestation by insects or other pests. Generally, human food consists of resources of either plant or animal origin, which cannot be kept after harvest or slaughter and starts deteriorating rapidly.

Methods of Food preservation

Ensuring that harvested commodities are alive with sustained chemical and respiration processes and the need to maintain moisture content and quality of produce during storage and to reduce disease are very important steps in post harvest storage.

Extension of shelf life of foods can be carried out using refrigeration and freezing (cold), canning, drying and dehydration, smoking (heat), others are film packaging, chemical or food additives, forced-air cooling, modified/controlled atmospheric storage, irradiation and high-pressure food processing.

(A) Cold preservation: Refrigeration is the cooling of space and/or material below the general environmental temperature. It is applied to food material for the purpose of preservation. Refrigeration is used to extend the useful life of fresh and processed food that is required to be stored or transported from one place to another. The first patent for mechanical refrigeration was issued in 1934 in Great Britain to the American inventor Jacob Perkins.

Exposure of microorganisms to low temperature reduces their rates of growth and reproduction. This principle is used in refrigeration and freezing. The microbes are not killed. In refrigerators held at 5^0C, foods remain unspoilt. In a freezer at -5^0C, the crystals formed tear and shred microorganisms. This may kill many microbes but some are able to survive, like salmonella spp. and streptococci. For these types of microorganisms rapid thawing and cooking are necessary. Deep freezing at -60^0C forms smaller crystals and which reduces the biochemical activity of microbes.

Frozen foods have the advantage of resembling the fresh product more closely than the same food preserved by other techniques. Frozen foods also undergo some changes as freezing causes water in food to expand and tends to disrupt the cell structure by forming crystals. In quick freezing the ice crystals are smaller, producing less cell damage that if a product is frozen slowly. The quality of the product, however, may depend more on the rapidity with which the food is prepared and stored in the freezer than on the rate at which it is frozen.

Pre-cooling may be carried out using forced air, water, liquid and vacuum. Vacuum cooling is recommended for hydro cooling and liquid icing cannot be used for highly moisture-sensitive containers or produce. The rate of cooling, further storage, shipping conditions and capital and labour costs are determining factors in choosing any pre-cooling method for some plant products.

(B) Heat Preservation

(i) Canning: The process of canning is sometimes called sterilization because the heat treatment of the food eliminates all microorganisms that can spoil the food and those that are harmful to humans, including directly pathogenic bacteria and those that produce lethal toxins. Most commercial canning operations are based on the principle that destruction of bacteria increases 10-fold for each 10^0C increase in temperature. Food exposed to high temperatures for only minutes or seconds retains more of its natural flavor.

(ii) Drying and Dehydration: The terms drying and dehydration are applied to the removal of water from food. To the food technologist, drying refers to natural desiccation, such as by spreading fruit on racks in the sun, and dehydration designated drying by artificial means, such as with a blast of hot air. However, fruit can be freeze dried by high vacuum maintained in a special cabinet containing frozen food until most of the moisture has sublimed. Removal of water offers excellent protection against the common causes of food spoilage. Microorganisms cannot grow in a water-free environment, enzyme activity is absent and most chemical reactions are greatly retarded.

Drying was used in ancient times to preserve many foods; vegetables, fruits, meat, fish and some other foods, the average moisture content of which may be as high 80%, may be dried to one-fifth of their original weight and about one-half of their original volume. The disadvantages of this method of preservation include the time and labour involved in dehydrating the food before eating. Furthermore, reconstituting the dried product may be difficult because it absorbs only about two-thirds of its original water content and this process tends to make the texture tough and chewy.

(iii) Smoking: Smoking us used for preserving fish, meat, ham, sausage, maize cob, etc. The smoke is obtained by burning wood under a low draft. During the process of smoking, the and preservative action is provided by bactericidal chemicals like formaldehyde and creosote in the smoke and by the dehydration that occurs in the smoke house.

(C) Others

(i) Packaging

Food packaging and appropriate storage is very useful in increasing shelf life of food products by slowing the growth of spoilage organisms, and reducing phsysico-chemical and biochemical degradation and biochemical degradation processes as well as maintaining the nutritional and sensory qualities of minimally processed plant foods. The use of modified atmospheres, gas flushing and vacuum packaging change the atmosphere surrounding of the food (e.g. fresh produce) in a such a way that the food's shelf life is extended. Vacuum packaging is normally used to remove air from a package's headspace and to a limited degree from the food itself to eliminate spoilage of the food by oxidation. Also, antimicrobial- packaging technology can be combined with lactic acid fermentation technology, making use of the hurdle concept to extend the shelf life of foods without refrigeration.

(ii) Chemical/Food additives

Salt, sugar and benzoate are widely used in the food industry; salt is a bactericidal agent that can be used to preserve fish or meat (pork), either as dry salt or brine, while sugar is a major ingredient of jams and jellies. Sugar acts in much the same way as salt, inhibiting bacterial growth after the product has been heated. To ensure effective preservation, the total sugar content should at least make up to 65% of the weight of the final product. Other preservatives are sodium benzoate, calcium propionate, ash, sulphur dioxide, crude antioxidant extract from plants, etc.

(iii) Food irradiation

Food irradiation can help to reduce high rates of food losses, especially with respect to cereals, root crops and dried foods. Irradiation delays ripening of fruits and vegetables, inhibits sprouting in bulbs and tubers, disinfects grains, cereal products, fresh dried fruits and vegetables of insects, and destroys bacteria in fresh meats. Irradiation can extend the shelf life of several types of seafood stored at low temperatures and optimal radiation doses of 0.75 – 2.5kGy can extend storage life by 2 – 6 weeks at 0 -5^{0}C.

(iv) High-pressure

High-pressure treatment in a preservation method which does not involve high temperatures, and avoids undesirable alterations caused by thermal treatment of food such as vitamin loss, reduced bioavailability of essential treatment of food such as vitamin loss, reduced bioavailability of essential amino acids, lost of flavor and modification of taste and colour. Major advantages of using high pressure are inactivation of microorganisms and quality retention and shelf-life extension. High-pressure treatment is used for fruit jams, fruit juices, sauces, oysters and packaged cured ham.

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