3 Food Processing Operations

3.1 Introduction

The main processes used to produce foods of satisfactory biological standards and acceptable eating quality, are mechanical processes, heating, cooling, the use of additives, and fermentation processes. Each of these has a range of effects on the organoleptic properties of food. Recent developments in food processing methods include aseptic processing, irradiation (non-thermal), pulsed electric fields (non-thermal) and high pressure processing (non-thermal).

3.2 Mechanical Processes

Many raw food materials undergo a preliminary treatment by a mechanical process. Many first involve size reduction such as cutting into smaller pieces such as potatoes into small chips before frying. Size reduction processes can, however, involve injury to living cells and may therefore affect the appearance of the foodstuff in undesirable ways.

In some fruit and vegetables, enzymatic browning may occur. The grey-black discolouration found in cut potatoes and the brown discolouration found in cut apples is due to the action of the enzyme polyphenoloxidase (PPO) on phenolic compounds or tannins. These substances are normally colourless in intact living plant tissue. When cells are damaged by bruising or cutting during the preparation of food, the phenolic compounds are oxidised forming brown or black grey polymers. PPO is present in apricots, cherries, pears, bananas, avocados and sweet potatoes.

A similar enzyme reaction can occur between the vitamin C in fruits and the enzyme ascorbic acid oxidase. Such enzymatic reactions can be prevented or reduced several ways:

- Chilling reduces enzymatic reaction rates
- Lowering pH to below 2.5 inhibits enzyme activity
- Additives inhibit enzyme activity such as the use sodium metabisulphate, salt, sugar, potassium phosphate and ascorbic acid
- Heat inactivates enzyme activity such as the use of blanching
- Complete exclusion of air (oxygen) prevents oxidative reactions

Other mechanical treatments of foods include filtration and centrifugation, which are used to separate fluids from solids, or from liquids of different density. In a cream separator, less dense fat globules are separated from the water and dissolved lactose and proteins of milk.

The final form of mechanical treatment is protective packaging. This is a physical barrier such as a can, jar or plastic sachet, for protection against spoilage, organisms, dirt, and mechanical damage. Packaging technologies are classified into either modified atmosphere packaging (MAP) or controlled atmosphere packaging (CAP).

3.2.1 Raw Material Preparation

The objective of raw material preparation is the removal and separation of contaminating materials from the food in order to attain a suitable condition for further processing. Contaminants may be soil, micro-organisms and pesticide residues. Washing is widely applied as a first processing step to root crops, potatoes, fruits and vegetables. Soaking is predominantly applied to the processing of legume seeds.

Large volumes of water are often required for washing root vegetables, which carry a lot of soil, and also for leafy vegetables, which have a large surface area. Mechanical or air flotation techniques are used to assist soil removal and reduce the quantity of water used. Water re-circulation or re-use from other food process operations is commonly used. Waste water from pre-washing mainly contains field debris and soil particles with small fragments of the fruit or vegetable. Detergents can increase cleaning efficiency but also contribute to the chemical oxygen demand (COD) of the waste water.

Washing is carried out by vigorous spraying with water, which may be chlorinated, and by immersion, with the aid of brushes or by shaking and stirring. Surface active agents and warm water are sometimes used. The use of warm water, however, can increase both the chemical and microbiological spoilage, unless careful control on the washing process is carried out. Once loosened, soil can be separated and recovered by sedimentation.

The soaking of legume seeds in water varies with variety and species and with the duration and conditions of storage. Dry beans can be soaked in cold water for between 8 and 16 hours while high temperature soaking increases the rate of hydration.

Dry cleaning procedures are used for products which have a low moisture content and high mechanical strength such as nuts and grains. Typical equipment used includes air classifiers, magnetic separators, sieving and screening.

Most raw materials for processing may contain contaminants; have inedible components or irregular physical characteristics. Processing techniques such as sorting, grading, screening, de-hulling and trimming are therefore necessary to reach uniformity prior to further processing.

Sorting and screening are used to separate raw materials into categories on the basis of shape, size, weight and colour. In size-sorting, solids are separated into two or more fractions by sieving and screening. Size-sorting is important where over or under-sized material may lead to over of under cooking or cooling. Various types of screens and sieves, with fixed or variable apertures, are used while screens may be stationary, rotary or vibrating.

Shape-sorting is carried out either manually or mechanically such as with belt-and-roller sorters. Weight-sorting is used for more valuable foods such as cut meats, eggs, exotic fruits and vegetables. Image-processing is used to sort foods on the basis of length, diameter, number of surface defects and orientation of food on a conveyor. The images of the surface are digitally recorded by a digital camera or sensor and the data compared with pre-programmed specifications. Colour-sorting uses photo detectors to record reflected colour and compared with pre-set standards. Products are then either rejected by blasting away the compressed air or can be moved into a group with similar characteristics.

Grading is the assessment of a number of characteristics of a food to obtain an indication of the overall quality of a particular food. It is mainly carried out by trained operators. Fish and meats are all examined by inspectors for disease, fat distribution, size and shape. Other graded foods include cheese and tea. Grading is more expensive than sorting due to the high costs of skilled personnel. Trained operators have the benefit of being able to assess many characteristics simultaneously.

Trimming involves the removal of inedible parts or parts with defects and cutting to a size appropriate for further processing. It usually is carried out manually or by rotating knives.

Many vegetables and some fruits require peeling. Peeling can be achieved by mechanical cutting or abrasion, or by the application of steam, hot water or heated air. The use of caustic in peeling involves a dilute solution of sodium hydroxide and is used to soften the cortex so that the peel can be more easily removed by mechanical scrubbers or high pressure water sprays. This also removes any residual caustic and may lead to pH fluctuations in the waste water. Certain fruit such as tomatoes requires strong caustic solutions and the addition of wetting agents.

Flash steam peeling is carried out as a batch process. Roots and tubers are treated in a pressure vessel and exposed to steam at a pressure of up to 20 bar. The high temperature causes a rapid heating and cooking of the surface layer within 15 to 30 seconds. The pressure is then instantly released which causes flashing-off of the cooked skin. Remaining traces are sprayed off with water.

In knife peeling, fruits and vegetables to be peeled are pressed against stationary or rotating blades to remove the skin. Knife peeling is used for citrus fruits where the skin is easily removed causing little damage.

In abrasion peeling, the material is fed onto carborundum rollers or fed into a rotating bowl, which is lined with carborundum. The abrasive carborundum surface removes the skin, which is then washed away with water. Normally carried out normally at ambient temperature, this has a significantly higher product loss than flash steam peeling.

Developed for onions, a flame peeler consists of a conveyer belt which transports and rotates the onion through a furnace heated to temperatures in excess of 1000°C. The skin, which consists of a paper shell and root hairs, is rapidly burnt off. The skin is removed by high-pressure water sprays.

Grinding and milling are used for size reduction of solid dry material and used extensively in the flour milling, brewery, sugar and dairy industries. Various techniques and equipment are used for specific types of food for both dry and wet applications. In wet processes, smaller particle sizes can be attained while dry processes combined with sieving or air classification permits the collection of a particle size range. The common types of mill used in food industry include:

Hammer mills: The mill consists of a horizontal cylindrical chamber lined with a steel breaker plate. Hammers along its length disintegrate the material by impact force.

Ball mills: The mill consists of a slowly rotating, horizontal steel cylinder, half filled with steel balls between 2.5 and 15 cm in diameter. The particle size attained depends on the speed and size of the balls.

The purpose of cutting, slicing, chopping and pulping is to reduce the size of fibrous material usually to improve the eating quality or produce foods for further processing. These activities are applied in processing of meat, fish, cheese, vegetables, fruits, potatoes, and various other crops. Slicing equipment consists of rotating or reciprocating blades. The material may be pressed against the blades by centrifugal force. For slicing meat products, the material is held firm while it travels across the blade. Harder fruits such as apples are simultaneously sliced and decored.

Dicing is applied to vegetables, fruits and meats in which the material is first sliced and then cut into strips by rotating blades. These are then fed to a second set of rotating knives, which operate perpendicular to the first set and reduce the strips into cubes.

Many products such as meat, fish and vegetables require reducing to small particles. Mincing is mainly used for size reduction and homogenisation. In bowl chopping, material is placed in a slowly rotating bowl and subjected it to a set of blades rotating at high speed. This technique is widely used in the production of sausages in which the degree of comminution can be varied depending on knife-speed and cutting time. In extreme cases the material will be reduced to an emulsion.

3.2.2 Forming, Moulding and Extrusion

Forming, moulding and extruding are widely applied for the production of bread, biscuits, cheese, confectionery and pies. In forming and moulding, the material is prepared as a soft mixture which firms on processing such a baking.

Extrusion is widely used for the production of meat sausages, pasta products such as spaghetti and starch-based snack food. As a continuous process of shaping, the material is kneaded under high pressure and pressed continuously through openings of the required shape using the action of rotating screws. In cooking extruders, the material is also heat treated or cooked to solublise the starches.

3.3 Heating

As well as destroying pathogens and other spoilage organisms, heating is used to improve food palatability. Heating also provides a rapid means of removing moisture and as well as producing a number of physical and chemical changes.

3.3.1 Steam and Water Heating

Blanching is an important step in processing of fruits and green vegetables and involves their exposure to high temperatures for a short period of time. The primary function of blanching is to inactivate or retard surface bacterial and enzyme action, which causes rapid degeneration of quality. Blanching is also able to expel air and other gases from products.

Blanching may be carried out either by immersion in hot water (80°C to 100°C) or exposure to live steam depending on the fruit or vegetable to be blanched. The residence time in the blancher can vary from approximately one second to five minutes depending on the fruit or vegetable being blanched.

3.3.2 Evaporation

Evaporation is the partial removal of water from liquid food by boiling. Evaporation is used to pre-concentrate, increase the solid content and to change the colour of food. It is used to process milk, starch, coffee, fruit juices, vegetable pastes and concentrates, seasonings, sauces as well as sugar processing.

Steam or vapour is usually used as the heating medium, the latent heat of condensation is used to raise the temperature to the boiling point of the liquid food causing evaporation of the water. Since many liquid food products are heat sensitive it is often necessary to work at reduced temperatures. This is achieved by boiling under part vacuum. Evaporation occurs normally between 50°C to 100°C.

The most commonly used equipment consist shell and tube evaporators which are either climbing or falling film types. Wiped film evaporators and thin film evaporators are used for the evaporation of highly viscous products.

For large-scale evaporation requiring significant energy such as the processing of sugar beet or evaporation of milk and whey, multiple-effect evaporators are used. These use fresh steam to boil off water vapour from the liquid in the first effect. The evaporated water retains sufficient energy to be used as the heat source for the next effect, and so on. A vacuum is applied in a ple effect chain in order for the water to boil off. The liquid food is passed from one evaporator effect through the others so that it is subject to multiple stages of evaporation.

3.3.3 Pasteurisation, Sterilisation and UHT

The treatment of foods by heat is principally used in their preservation. It prevents bacterial and enzyme activity otherwise resulting in the loss of product quality. Various temperature-time combinations can be applied with each depending on product properties and shelf life requirements. For complete sterilisation, the product is canned or bottled and then heat-treated in a retort in hot water or steam in either a batch or continuous operation.

In pasteurisation, a heating temperature below 100°C is applied. This results in a partial reduction of the enzyme and bacterial activity within a product giving a limited shelf life. Sterilisation commonly means a heat treatment in excess of 100°C to achieve a stable and extended shelf life.

Ultra high temperature (UHT) processing uses a temperature exceeding 135°C for very short times. It is applied to low viscosity liquid products. This uses indirect heating in plate and frame or tubular heat exchangers. Direct steam injection or steam infusion can alternatively be used.

Batch wise pasteurisation is carried out in agitated vessels. For beer and fruit juices, pasteurisation is applied after bottling or canning. The packaged products are immersed in hot water or led through a steam tunnel. For continuous pasteurisation flow-through tubular or plate and frame heat exchangers with heating, holding and cooling sections are used.

3.3.4 Hot Air

Baking and roasting are forms of hot air heating involving both convective and radiative heat transfer. Baking is used to improve eating quality by way of taste and texture of a food. It is also a means of preservation by the destruction of micro-organisms and reduction of water activity at the surface of the food. The shelf life of most baked foods, however, is limited, unless they are refrigerated or packaged.

Operating either batch or continuously, baking is applied on a large scale to flour-based products such as bread and bakery products as well as to fruit and vegetables. Baked products include pies, pizza and snack foods. In the baking process, the moisture at the surface is evaporated and removed by circulating hot air. When the rate of moisture loss at the surface exceeds the rate of transport of moisture from the interior of the product to the surface, the surface dries out forming a crust.

The purpose of roasting is to dry and enhance the aroma as well as structure of the food product. Typical roasted products include coffee, cereals, nuts, cacao and fruits. In roasting, water contained within the product is evaporated and the moisture content may fall to below 1%. At temperatures exceeding 120°C chemical reactions may take place in the product. Maillard reactions (see 2.3) are particularly important in the formation of aromas in coffee and cacao. The duration of the roasting process is dependent on the product and the specific aromas that are required. The roasting of coffee may range from one to twenty minutes. The Maillard reactions are stopped either by cooling the product with air or by quenching with water followed by cooling with air.

As with baking, roasting ovens can operate either batch or continuously. Typical equipment for batch roasting ovens includes drum, column, rotating or fluidised bed roasters. In each, the product is heated and agitated simultaneously. The product can be in direct contact with the hot convective air or in contact with a heated conductive surface. In practice, it is usually a combination of both.

In drying and dehydration processes, the shelf life of foods is extended by the reduction of water activity. Typical applications include milk, coffee, tea, flavours, powdered drinks and sugar. In hot air drying, the heat transferred from the air to the product causes water evaporation. The main types of hot air dryers include bin, tray, tunnel, conveyor or belt, fluidised bed, kiln, pneumatic, rotary and spray dryers.

In fluidised bed dryers, there is good thermal control over the drying conditions. They have very high rates of heat and mass transfer and consequently short drying times. Drying can take place below 100°C.

3.3.5 Hot Oil

Frying involves cooking food in edible oil at temperatures in the region of 200°C. Vegetable oils are normally used. Raw material such as fish, meat and potatoes can be fried to produce products such as fish fingers, burgers and French fries.

Frying may be either batch or continuous. In continuous frying, the chamber contains the heated oil. A belt feeds the product into the main fryer belt and controls the frying time. The take-out belt at the end of the fryer lifts the product out of the oil, allowing the product to drain and transfer onto product inspection and packing belts. The residence time in the fryer can range from 30 seconds to 6 minutes depending on the product.

3.3.6 Heat Removal

Cooling and Chilling: The purpose of cooling and chilling is the reduction of the rate of biochemical and microbiological change, in order to extend the shelf life of fresh and processed foods. Cooling involves reducing the temperature of the food from the processing to the storage temperature. Chilling involves maintaining the temperature of a food at a temperature of between -1°C and 8°C.

The cooling of liquid foods is typically carried out by passing it through a heat exchanger which is cooled using water. In cryogenic cooling, the food is in direct contact with a refrigerant, which can be either solid, liquid carbon dioxide or liquid nitrogen. Refrigerant boiling, evaporation or sublimation removes the heat from the food causing rapid cooling.

Freezing: Freezing is a method of preservation where the temperature of a food is reduced below its freezing point and a proportion of the water undergoes a change in state to form ice crystals. Several types of food can be frozen including fruit, vegetables, fish, meat, baked products and ice cream. The equipment for freezing foods includes blast, belt, fluidised bed, cooled surface, immersion and cryogenic freezers.

In freeze-drying or lyophilisation, water is removed through sublimation and desorption. The aim is to preserve sensitive material that can not be dried by evaporation at elevated temperature because of the sensitivity to degradation of specific components at high temperature resulting is loss of taste or other quality aspects. The technique is typically used for drying coffee extract, spices, soup vegetables, instant meals, fish and meat. Typical lyophilisation equipment consists of a drying chamber with temperature controlled shelves. The chamber is cooled by refrigerant through the shelves and the chamber itself is under vacuum. A condenser is used to trap water removed from the product in the drying chamber and facilitate the drying process.

Example:

There is a 50% destruction of a vitamin at 115°C in 15 minutes where, for the vitamin, E is 109 $kJ.mol^{-1}$. Determine the extent of the vitamin destruction at 120°C after 15 minutes of processing.

Solution:

At the temperatures considered, the thermal destruction of a heat labile vitamin can be said to follow a simple first order reaction:

$$\frac{dV}{dt} = -kV$$

Thus the amount of vitamin remaining, x, is at time t is therefore

$$-k\int_0^t dt = \int_1^x \frac{dV}{V}$$

Integrating gives

$$kt = \ln\left[\frac{1}{x}\right]$$

The thermal destruction is dependent on temperature and can be given by the Arrhenius equation:

$$k = Ae^{\frac{-E}{RT}}$$

Assuming a first order model then the rate constant is

$$k_{115^\circ C} = \frac{\ln\left(\frac{1}{0.5}\right)}{15} = 0.046\,\text{min}^{-1}$$

From the Arrhenius formula

$$A = \frac{k_{115^\circ C}}{e^{\frac{-E}{RT}}} = \frac{0.046}{e^{\frac{-109000}{8.314\times(273+115)}}} = 2.174\times10^{13}$$

The rate constant at 120°C is therefore

$$k_{120^\circ C} = A\times e^{\frac{-109000}{8.314\times(273+120)}} = 0.0707\,\text{min}^{-1}$$

The fraction of vitamin remaining is therefore

$$x = e^{-kt} = e^{-0.0707\times15} = 0.346$$

That is, a 65% destruction of the vitamin. This result corresponds to a fixed temperature. In reality, there will be a period of heating which will correspond to an accumulative loss of the vitamin, which will slow again on cooling. The overall effect for a period of heating and cooling can be calculated using increments of time and accumulating the loss of vitamin.

3.4 Mixtures and Emulsions

Most foods are prepared and consumed as mixtures. Mixing is essential to encourage certain desirable reactions to occur between the constituents and various emulsions. This may involve the bringing together of dry, free-flowing solids through to complex viscous liquids, slurries, pastes and doughs. Agitation of these materials involves many complex interfaces and free surfaces. The flow properties of the components and those of the mixture at any point during mixing are both complex and time-dependent.

Emulsification occurs when two liquids which are not soluble in one another are dispersed into fine droplets within each other. Water-in-oil emulsions, such as butter, consist of very fine droplets of water containing dissolved salts, lactose and lactic acid are dispersed throughout the butter fat or oil phase. Oil-in-water emulsions, such as mayonnaise consists of minute droplets of a vegetable oil are dispersed in an aqueous solution of vinegar.

To prevent liquids in an emulsion from separating into two layers, an emulsifying agent is used. Egg yolk, which contains a lecithoprotein, is used as the emulsifying agent, and prevents the droplets of oil from coalescing. This is due to the structure of lecithoprotein which comprises two parts; a hydrophilic (water-loving) protein and hydrophobic (water-repelling) protein, which is attracted to lipid materials such as vegetable oil.

Mixing is one of the most commonly encountered operations in the food industry. As a blending process, it involves the combination of different materials and their spatial distribution until a certain degree of homogeneity is achieved. Various mixing operations can be distinguished.

Solid/solid mixing: Used for mixed feed, blends of tea and coffee, dried soup, cake mixes, custard, ice cream.
Solid/liquid mixing: Used for canned products, dough, dairy products
Liquid/gas mixing: Used for making ice cream, whipping cream.

A wide variety of food mixers are available with equally wide-ranging capabilities. Some are designed for specific applications such as emulsification or solid dispersion into liquids. Others tend to be required to carry out various duties. The design of most mixers is rarely based on theoretical considerations. Instead, design is often based on past experience.

The dispersion of food ingredients by the agitator may require high levels of shear as in the case of making fine dispersions and emulsions while the mixing of nuts into yoghurt, on the other hand, may require low shear. Many foods contain particles of different sizes, some of which are fragile. These particles may have to be dispersed into viscous liquids such as a sauce. It is therefore difficult to produce a uniform product composition in which particle segregation is often a problem.

Regardless of the shape or size of the mixer, its design features must ensure hygienic and safe operation, as well as provide for in-place cleaning. Mixers used in the food processing industries may be conveniently classified according to the materials to be mixed as dissolving and dispersion of liquids, blending of particulate material and mixing of solids and liquids to form doughs, batters and pastes.

3.4.1 Emulsification

Emulsification of foods is one of the most complicated unit operations since the nature of the final product is dependent on the method of preparation. Even the method of addition of components and the rate of addition can significantly affect the emulsion quality. Oil-in-water emulsions are widely used and may be produced in impeller-agitated vessels operating at high rotational speeds, colloidal mills or high-pressure valve homogenisers. Continuous processing may be achieved by in-line mixers, which consists of a high-speed rotor inside a casing into which the components are pumped and subjected to high shear. Emulsions are formed under extremely high specific power.

3.4.2 Mixer Performance

The performance of mixers in the food industry is typically expressed in terms of fluid velocity generated, total pumping capacity of the impeller, and total flow in the tank, or in terms of blending time or some readily evaluated solids-suspension criterion. If the application is relatively simple, a complete and detailed examination of the complicated fluid mechanics in a mixing tank is not usually necessary. If the process is complex then a full analysis of fluid shear rates and stresses, two-phase mass transfer, turbulence, and micro-scale shear rate and blending may be required.

It is sometimes possible to express a complex mixing process in terms of only one, or a few, simple velocity and pumping capacity relationships. Design in such a case is therefore straightforward and simple. Problems, however, can arise in distinguishing processes to which comparatively simple physical and visual concepts can be applied and those for which more elaborate qualitative and quantitative aspects are required to be considered.

3.4.3 Mixing of Powders, Pastes and Batters

The mixing of dry powders is normally carried out as a batch process in either vertical or horizontal mixers. Vertical mixers have a movable bowl in which the contents are mixed by mechanical agitation. Paddle agitators are commonly used and the shape of the impeller frequently conforms to the vessel walls. Planetary motion devices are commonly used in vertical mixers in which the agitator revolves in circle in addition to rotating on its own axis. This ensures that the entire mixer volume receives beating action and that there are no dead spaces.

Horizontal mixers are widely used for doughs in which gluten development is desirable. The mixers have a jacketed U-shaped trough. Water flowing through the jacket enables heat removal.

Example:

A largely aqueous-based liquid food is mixed in batch vessel. Assuming a Power number of 5 (for Re>5000) determine the power input through the impeller if an impeller has a diameter of 70 cm and speed of 30 rpm. The density and viscosity of the liquid food is 1000 kg.m^{-3} and 0.02 Pa.s, respectively.

Solution:

The Power number for an impeller is

$$N_P = \frac{P}{\rho N^3 D^5}$$

The power for mixing is therefore

$$P = N_P \rho N^3 D^5 = 5 \times 1000 \times \left(\frac{30}{60}\right)^3 \times 0.7^5 = 105W$$

The power is 105 W. As a check, the Reynolds number is

$$\mathrm{Re} = \frac{\rho N D^2}{\mu} = \frac{1000 \times \frac{30}{60} \times 0.7^2}{0.02} = 12250$$

A Power number of 5 is therefore valid for Re greater than 5000.

Example

Bubbles of CO_2 gas were found to rise in carbonated beverage of density 1030 kg.m^{-3} and viscosity 1.0 mPa.s for which the following observations were made:

Time (s)	1.0	2.0	3.0	4.0
Velocity (m.s^{-1})	0.0225	0.04	0.0625	0.3

Determine the diameter and age of the bubbles when they detach from the nucleation sites, and the rate at which CO_2 enters the rising bubbles (m^3(CO_2).m^{-2}.s^{-1}).

Solution

Assuming the bubbles to be spherical, the rate of transfer into the bubbles is assumed to be proportional to the area of the bubble. That is

$$\frac{d(\frac{4}{3}\pi r^3)}{dt} = f 4\pi r^2$$

The rate of change of bubble radius is therefore equal to the rate at which CO_z enters the bubble:

$$\frac{dr}{dt} = f$$

From the formation of the bubble, the radius at any time can be found by integrating to give

$$r = f\left(t + t_o\right)$$

The terminal velocity of a bubble of gas rising is approximately given by Stokes' law

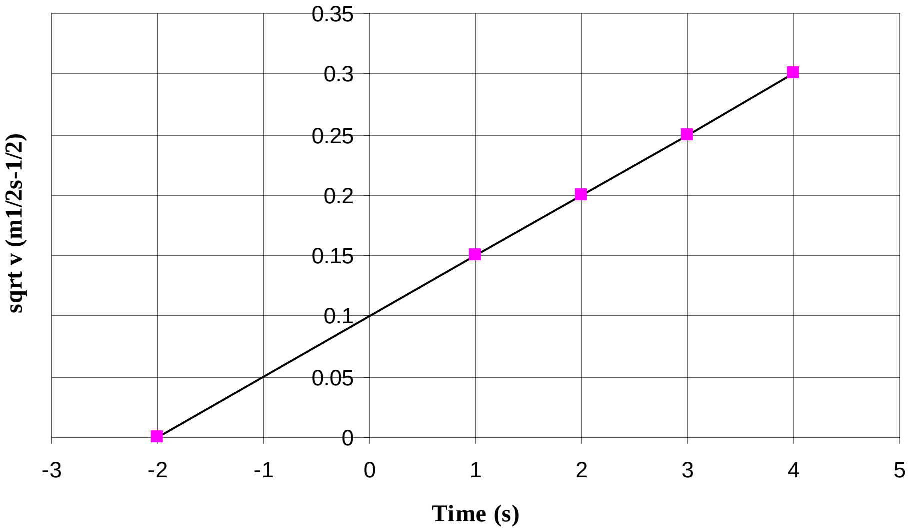
$$v = \frac{2\rho g r^2}{9\mu}$$

Then

$$\sqrt{v} = f\sqrt{\frac{2\rho g}{9\mu}}(t+t_o) = f\sqrt{\frac{2\times1030\times9.81}{9\times0.001}}(t+t_o)$$

This is a straight line

Time (s)	1.0	2.0	3.0	4.0
√Velocity ($m^{1/2}.s^{-1/2}$)	0.15	0.2	0.25	0.3



The bubble therefore forms 2.0 seconds before detachment at which the terminal velocity is 0.01 ms^{-1}. This corresponds to a bubble radius of

$$r = \sqrt{\frac{9\mu v}{2\rho g}} = \sqrt{\frac{9\times0.001\times0.01}{2\times1030\times9.81}} = 6.7\times10^{-5}\,m$$

That is, a diameter of 0.13 mm.

The rate of carbon dioxide transfer is therefore

$$f = \frac{r}{t + t_o} = \frac{6.7 \times 10^{-5}}{2} = 3.35 \times 10^{-5} m^3 (CO_2).m^2.s^{-1}$$

3.5 Novel Food Processing

In addition to conventional food processing, there are considerable demands on the food processing industry to develop new creative products in innovative ways. Some of the foods and processes do not conform to existing techniques and methods. A novel food is defined as a food which has not had an appreciable level of consumption or a process which has not previously been used. Such foods are required to be authorised according to the Novel Food Regulations legislation (EC) No 258197 of the European Parliament.

3.5.1 High Pressure Food Processing

The novelty and purpose of using high pressure instead of heat - as in conventional cooking - is to preserve and even improve food quality in terms of taste, flavour, texture and colour. Consumers nowadays generally expect the food that they buy to be of a high quality, minimally processed, 'natural', additive-free and high in nutritional value. The unique effects of pressure appear to be able to meet these requirements. Significantly, the covalent bonds of food components including saccharides, vitamins, lipids and pigments are able to resist the effects of high pressures in contrast to the highly damaging effects of heat. Pressure is generally only able to affect the weaker bonds and forces sufficient to alter the delicate molecular structures - as in the case of proteins.

High pressure food processing has been used in the destruction of micro-organisms, the activation and deactivation of enzymes, the change of functional properties such as foams, gels and emulsions, and the control of phase change such as fat solidification and ice melting point. The sterilisation properties of high pressure food processing have been compared to that of heat treatment. Like heat, micro-organisms differ significantly in their ability to withstand pressure. Bacteria, yeasts and moulds are readily killed by high pressure while bacterial spores and some viruses are particularly resistant; spores being only inactivated by pressure after germination. As an analogy to the heat treatment of pasteurisation, the pressure sterilisation is appropriately termed *pascalisation*.

Another difference between thermal and high pressure processing is that while heat is conducted through the exterior of foods to penetrate the interior, which takes time and often with over-cooking of the surface, pressure is applied instantaneously and uniformly. Also, unlike heat treated food, pressure processing is more dependent on the quality of the raw food material.

An interesting effect of high pressure is the depression of the freezing point of water. At 200 MPa, for example, the freezing point is reduced to -22°C. The problem with conventionally storing frozen food is that much of the textural quality is lost during the freezing or thawing often due to the damaging effects of ice crystals. A possible application of high pressure may be to cool food below its freezing point at high pressure and then by releasing the pressure instantly freeze the food. Tests have shown that the rapid and uniform freezing effect has been found to preserve better food texture on thawing.

The cost of pressure-processed food is currently higher than that of heat processed food even though pressure processing actually consumes less energy. The cost of reaching a pressure of 400 MPa is about the same as heating from only 20°C to 25°C. The reason for the high cost is because the equipment needed is very expensive and makes up about 80% of the total production costs. In spite of the high cost of the equipment, the sales of high pressure processes foods continue to rise despite retail prices being typically twice those of conventionally processed products. At the moment the improved quality to be gained by pressure processing has found a niche market among certain consumers who are willing to pay a premium. The future may well lead to pressure processed foods eventually being more commercially competitive and affordable to all.

The processing of foods by high pressure offers the creation of many entirely new and exciting food textures. Pressurised beef muscle has a texture like raw ham but without a change in taste. Fish and pork muscle become more glossy, transparent, dense, smooth and soft. Fruit-based jams, jellies, purées and juices have exceptional 'just squeezed' flavour and striking natural colour. Protein from soya, milk and eggs can form soft gels that can be used to make new types of desserts and yoghurts. The foaming and emulsifying properties of egg white albumins can also be influenced by pressure by careful control of the molecular unfolding.

The way in which food is pressurised is similar to the way food is heated. Solid-type foods are first sealed into plastic bags and then loaded in a thick-walled steel pressure vessel. Once loaded with food packages and closed, the vessel is filled with a liquid such as water mixed with a small amount of soluble oil for lubrication and anti-corrosion purposes. Liquid foods, on the other hand, are placed directly into the vessel. The thickness of the vessel wall is determined by the operating pressure, volume and the expected number of times the vessel is to be used.

After removing any remaining air from the vessel, the vessel is pressurised by a powerful piston. A variety of jams, fruit yoghurts, fruit jellies, salad dressings and fruit sauces are now already being processed by high pressure. Citrus juices can typically be made at a rate of up to 6000 litres per hour.

While the many technical problems that have previously hampered high-pressure research and development have now been overcome, there is still much of the fundamental science of high pressure to be understood, particularly at the molecular level.