Chapter 2

Literature review

2.1 Corn

2.1.1 Types of corn

Maize may be divided into various types depending on the characteristics of the seeds. The first maize type, dent, is the most widely grown type of maize in the U. S. It is characterized by a depression or dent in the crown of the seed. The side of the seed has a corneous starch, while the soft starch extends to the summit of the seed. Rapid drying and shrinkage of the soft starch results in the denting characteristic. The second type, flint maize, is rather widely grown in Europe, Asia, Central America and South America. In general, the kernels of the flint maize are hard and smooth and certain little soft starch. The third type, flour maize, is somewhat similar to the flint maize in plant and ear characteristics. The kernels are composed largely of soft starch and have little or no dent. The fourth type, popcorn, is an extreme form of the flint with the endosperm containing only a small proportion of soft starch. It is used primarily for human consumption as freshly popped corn and is the basis of popcorn confections. The fifth type, waxy corn, is so named because of the somewhat waxy appearance of the kernels. Waxy starch is composed entirely of branched amylopectin. The last one is sweet corn which is characterized by a translucent, horny appearance when immature and wrinkled condition when dry. It is grown primarily in the U.S. Sweet corn differs from the dent by only one recessive gene which prevents the conversion of some of the sugar into starch (Robert, 1958).

2.1.2 Sweet corn

Sweet corn has been cultivated in Thailand for many centuries. Whether the Thai brought the seed with them on their migration from south China or whether Buddhist missionaries from India were the first to introduce the seed. In Thailand sweet corn was formerly cultivated only for home consumption in form of roasted or steamed sweet corn for various cake and sweets (Berger, 1962).

Sweet corn is a common plant which is widely growth in Thailand. Katenin (2002) reported that Thailand is the important producer of sweet corn between 1999/2000 with an amount of canned sweet corn over 20,000 ton/year and a cost for over 600 million Bath. Fifty percent of sweet corn's production will be delivered as a raw material to industrial factories with the prices of 2.50-3.00 Bath/kg, whereas the price of 1.34 Bath/kg will be received by the farmers when sold in the market. Therefore the farmers who grow the plant will earn around 4,500-6,000 Bath/rai as reported by Department of agriculture (Pulum *et al.,* 2000).

Appropriated harvesting time of sweet corn should be done within 55-60 days after growing because a high sugar content will be obtained during this period. At the same time, harvesting time is a very important factor for controlling the quality of sweetness of the sweet corn. Delayed harvesting time could affect the sweetness, tenderness and other attributes of sweet corn high eating quality. The reason for this is because these attributes, particularly the sweetness and good odour, are affected by the production of ethanol, aldehyde, methanethiol, hydrogensulfide and dimethysulfide. Sweet corn is sometimes cooked and eaten "on the cob". Slightly immature ears may be picked for this purpose as the grains are softer (Azanza *et al*., 1996).

The properties of the sweet corn variety ATS-2 (Pulum *et al*., 2000) are as followed ;

The sweet corn variety of ATS-2, has a Brittle-1 gene which significantly affects the sweetness of the corn. Whereas, other corn varieties have Shurunken-2 genes controls. There are 3 dominant properties of ATS-2 which include ;

1. The ATS-2 variety gives a very high product yield and food factories will buy the corn as a raw material for 3.25 Bath/kg. The product yield of ATS-2 was higher than the product yield of ATS-1 while Super Agro, a popular variety, had the lowest product yield. The ATS-2 variety was the most popular sweet corn variety in 1999 due to its good properties.

2. The quality of the fresh sweet corn of ATS-2 variety is better than other varieties. Therefore food industries have a high preference towards the ATS-2 variety compare to the other varieties.

3. The plant of the sweet corn ATS-2 variety can strongly grow up and the sweet corn can be kept longer.

2.1.3 Chemical composition of sweet corn

The corn kernel, like other seeds, is an uniquely packed storage organ that contains all the necessary components required to propagate the species. Fortunately for the human race, it also contains high levels of starch, protein, oil and other nutritionally valuable substances. Scientific investigation of the macro and micro structural and chemical properties of corn has improved ability to utilize it in many food and industrial products (Sanley and Pual, 1987).

The protein content of corn is influenced by the available soil nitrogen. Dudley *et al.* (1974) have shown that the total protein contents of corn can vary from 4.4 to 26.6 % by selection for protein contents without regard to grain yields. Differences in kernel protein and yield responses to soil nitrogen levels may also be influenced by genetic differences in the capacity of genotypes to take up nitrogen from the soil and translocate it to the sink kernels. The lipid content of corn is influenced mainly by genetics (Dudley *et al.*, 1974) but not by fertility unless nutrients are severely restricted. Corn that does not mature properly may contain less oil than normal. The lipid content in sweet corn is about 5.2 %. Starch is the major carbohydrate in corn, making up 72-73 % of the kernel. Sugars, present mainly as sucrose, glucose, and fructose, amount to only 1-3 % of the kernel. The starch content in sweet corn is about 72.1 % (Sanley and Pual, 1987).

Sweet corn contains vitamin A (retinol), in form of carotenoid, is generally insoluble in water but dissolved in fat solvents. There are two classes of carotenoid which are carotenes and xanthophylls. The chromophore consists of a chain of conjugated carbon-carbon double bonds joining, in the case of beta-carotene, two beta-ionic rings. Increasing the number of these bonds progressively causes a displacement of light absorption towards longer wavelengths into the blue region of the spectrum, thus increasing apparent redness (Hutchings, 1999). For water-soluble vitamins, vitamin C (ascorbic acid) consists of two biologically active substances L-ascorbic acid and L-dehydroascorbic acid, both of which may be present in foodstuffs. The most abundant form is ascorbic acid, but dehydroascorbic acid will be present if storage or processing conditions have allowed oxidation to take place. This compound is highly polar, thus it is readily soluble in aqueous solution and insoluble in less nonpolar solvents. Thiamine (B_1) and pyridoxine, water soluble vitamins, are present in concentrations sufficient to be important in animal rations. Niacin is present at high concentrations in a bound form. The most abundant inorganic component is phosphorus. It is largely present as the potassium-magnesium salt of phytic acid. Phytin is an important storage form of phosphorus. The second and third are potassium and magnesium, respectively. Sulfur, the fourth most abundant element in corn, is largely present in an organic form as a constituent of the amino acid methionine and cystine (Sanley and Pual, 1987).

2.1.4 Utilization of sweet corn

Sweet corn has a wide variety of uses and its consumption as a food during its milky state is served as a basis for canning industries. The sweet corn grain is also used as raw material for numerous other products, such as corn meal, corn starch, sweet corn in salt solution, creamy sweet corn and corn milk. The use of corn for human consumption is general subjected to grinding or cooking, including roasting and steaming. For example, the corn meal is a result from grinding the corn. This product is one of the most commonly used food in U.S. Sweet corn can also be used as a basic raw material in fermentation processes. Carbohydrates from sweet corn may be used as a raw material for bacteria fermentation under carefully controlled conditions with a production of butyl alcohol, acetone, and other solvents (Sanley and Pual, 1987 and Prescott and Proctor, 1937).

2.2 Foam

In a sense, foams are much like oil in water emulsion. Both are dispersions of a hydrophobic in a hydrophillic liquid. A foam is a coarse dispersion of gas bubbles in a liquid or solid continuous phase, usually water. It is a colloidal state in the sense that the thin films separating adjacent gas cells in a foam are typically of colloidal dimension. Colloid scientists are interested in liquid foams. Solid foams are the province of engineers and physicists. Many solid food foams are derived from liquid foam for example bread, cakes, etc. A few terms are useful for distinguishing qualitatively between different kinds of liquid foams. In structural terms, there are two types of foams. The first one is a bubbly foam in which the amount of gas incorporated is low enough for bubbles to retain their roughly spherical shape for example ice-cream. The second one is a polyhedral foam in which the gas-to-liquid ratio is so large that the bubbles are pressed against one another in a honeycomb type structure (Dickinson, 1992).

In kinetic terms, it is convenient to distinguish between an unstable transient foam, for example champagne bubbles, whose life–time is measured in seconds or minutes, and a metastable permanent foam, for example meringue, whose life–time is measured in days. A transient foam can be made by taking a sample of slightly dirty water in a close half–full container and shaking the container vigorously (Dickinson, 1992).

Bubble formation and destruction are a common feature of everyday domestic and social life from a washing - up bowl to glasses of gin and tonic. In the food context, the most important gas used to make bubbles is carbon dioxide. This gas has the advantage of being non toxic and natural and being produced *in situ* during bread making and beer fermentation. Permanent food foams are stabilized by macromolecules or particles. As gas dissolves into the aqueous phase from a bubble that make its surface area decreases and since there is negligible desorbtion of adsorbed macromolecules or particles so there is a decrease in surface tension which stabilizes the Laplace pressure, which is the pressure at the concave side of a curved phase boundary or interface always is greater than at the convex side (Walstra, 1996), difference accross the film and so the bubble shrinks no further. The adsorbed macromolecules most commonly used to stabilize food foams are egg white proteins and milk proteins. Many dairy colloids like whipped cream and ice cream are emulsions as well as foam. They are primarily stabilized not by adsorbed protein films but by a matrix of partly aggregated fat globules at the air–water interface. Major food ingredients apart from fat having a significant effect on food foam structure and stability are starch and egg yolk in baked products and sugar (Dickinson, 1992).

Foam and emulsions have much in common in terms of their colloid stability but there are several important differences from the physical point of view. First, gas bubbles are about 10^3 times as large as emulsion droplets because gas is much more soluble in water than oil in water or water in oil. Second, the surface tension of a gas bubble is several times of the interfacial tension of an emulsion droplet. Third, a bubbly foam has a strong tendency to cream because in addition to the large bubble size, the density difference between the phases is more than ten times of an emulsion. Fourth, gas bubbles are about 10^5 times as compressible as emulsion droplets. Fifth, gas bubbles are more easily deformed because of their large size. Sixth, liquid foams are much more susceptible than emulsions to disturbing influences, e.g. evaporation, dust, draughts, temperature gradients, vibration, and addition of foam breaking chemicals because of the much larger dimensions of liquid films in foams than those in emulsion. One top of all these, the disproportionation of foam bubbles is much faster than emulsion droplets. The overall effect of all these physical factors is that small bubbles are hard to make and tend to disappear rapidly and a foam with large bubbles is susceptible to fast drainage and rupture. Stability is best achieved with insoluble adsorbed layers of coagulated protein for examples egg–white in meringue or immobile particles for example fat globules in whipped cream or by converting the liquid foam into a solid foam as in baking of a cake (Dickinson, 1992).

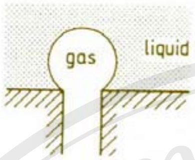
While foam formation is a process which usually imparts desirable features to a wide range of food products, it can be a nuisance during certain processing operation for example during the fermentation of beer or the discharging of milk into tanks, bottles, or cartons. During filling operations, the creation of milk foam may lead to wetting of sealing surfaces or variability in filling levels. Foam formation can also be a problem in the laboratory in situations where is necessary to prepare emulsions or gels free from air bubbles (Dickinson, 1992) .

2.2.1 Foam formation

In relation to foam formation, the amount of air incorporated is described by an ‘overrun’. This is the gas–to–liquid ratio in an aerated product expressed as a percentage on a volume basis. So, a 200 % overrun means that 1 litre of liquid has taken up 2 litres of gas to form 3 litres of foam (Dickinson, 1992) .

There are three ways to make aerated foodstuffs at home or in factories. The first way is agitation of a given amount of liquid in an unlimited amount of air (whipping).

During the whipping process, air is introduced into the liquid in form of large bubbles, which are subsequently broken down into small bubbles. Whipping egg-white or cream in an open bowl is an example of a process in which the amount of liquid is given and the amount of air is in principle of the first way. In whipping, air is brought into the liquid in the form of large bubbles which are diminished in size as a result of the mechanical agitation later on. The limited amount of air taken up by the liquid in the stationary state is in some way related to the geometry of the apparatus and to the foam properties. Since, as soon as the whipping rod becomes completely covered by the foam, no new air can be entrapped by the system as illustrated in Fig 2.1. For the second way is agitation of a mixture of gas and liquid in which both volumes are given. It common uses in the food industry. It is often performed by first injecting the required amount of gas in a given amount of liquid. Bubbles are formed at an orifice, and they leave the orifice at a size which is determined, amongst other things, by the viscous or buoyancy forces exerted on them by the streaming liquid. Later on, in the same apparatus, these bubbles are diminished in size by means of a pin stirrer, a whipping rod, or a static mixer as illustrated in Fig 2.2. Choco-mousse and ice-cream are examples of food produced in this way. The last way is allowing gas to be generated from the liquid in the form of bubbles. Either gas is generated *in situ* in the liquid, which means that the liquid has to be saturated with gas or the liquid is oversaturated with gas and bubbles are formed by heterogeneous nucleation is two different procedures of this way. Bread baking is an example of the *in situ* production of gas bubble. In this case carbon dioxide is generated by yeast cells. Examples of bubble formation from an oversaturated liquid by means of heterogeneous nucleation are to be found in foam production in beer and other carbonized beverages, in the production of instant whipped cream using nitrous oxide and a syphon, and in the production of expanded products by means of an extruder. For practical reasons, high pressures have to be avoided, and so gases such as carbon dioxide and nitrous oxide, which have good solubility in water, are used in most cases (Dickinson and George, 1988).



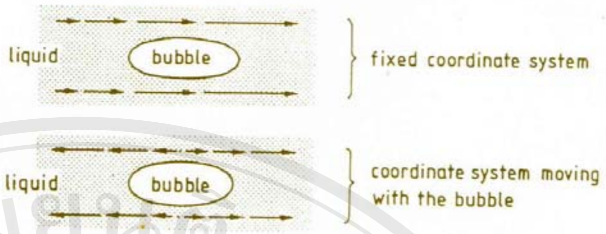


Fig. 2.1(right) Deformation of gas bubble subject to extensional flow by the surrounding liquid (Dickinson and George, 1988).

Fig. 2.2 (left) A gas bubble at an orifice (Dickinson and George, 1988).

2.2.2 Stability of foam

In a polyhedral foam, liquid films (lamellae) between bubbles are thin and flat. In order to satisfy the condition of mechanical equilibrium, the films meet each other at an angle of 120^0 as illustrated in Fig 2.3. The meeting point is called a Plateau border. Owing to the curvature of the interface, the pressure in the Plateau border is lower than that in the bubble. The stability of a polyhedral foam depend on two distinct processes. There are film drainage and film rupture (Dickinson, 1992).

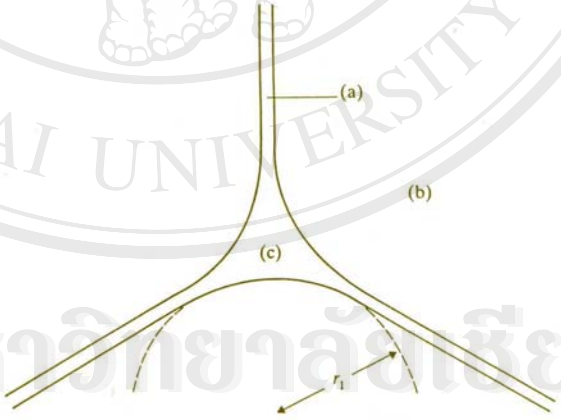


Fig. 2.3 Sketch of three liquid films meeting at a Plateau border with radius of curvature (c). The pressure in the thin film (a) is equal to the pressure in bubble (b) but is higher than the pressure in the Plateau border (Dickinson, 1992).

Film Stability

The drainage of a thin liquid film can be stopped completely if two film surfaces repel each other when they come close together. When the repulsion is strong enough to compensate for the Plateau border suction, the van der Waals attraction between the surfaces, and the disturbances caused by thermal motion, a so-called equilibrium film can be formed. Equilibrium films stabilized by low molecular weight ionic surfactants derive stability from their charged surfaces and the presence of ions in the film liquid. Interpenetration of the electrical double-layers on the two surface leads to a repulsion which depends strongly on the surface potential and the concentration and valency of the ions. Such films have typical equilibrium thicknesses of 4 – 10 mm. Food foams usually contain macromolecular surfactants such as proteins or polysaccharides, and here the equilibrium films are sterically stabilized with equilibrium thicknesses an order of magnitude larger than for low-molecular-weight surfactants (Dickinson and George, 1988).

In a different approach to film stability, the behavior of a wavy disturbance as illustrated in Fig. 2.4. Such a wave, called the symmetric mode, may break a film if it grows, and give rise to a stable film if it is damped. According to the theory, the wave is damped considerably when the film surface has elastic properties. This is because the thick and thin parts of the film have to be formed when the film is subjected to a symmetric wave, and the transport of liquid between thick and thin parts takes place by means of viscous flow between motionless film surfaces so long as the surface elasticity exceeds the aforementioned value. The energy consumed by the viscous flow causes damping of the wave. Most practical systems have a surface elasticity which exceeds the indicated value, and so the films are stable as far as this mechanism is concerned(Dickinson and George, 1988).

Foam in food systems can be stabilized by a Pickering mechanism. This means that particles of the proper size, shape and wetting behavior can stabilize films. To ensure that they are kept at the air-water interface, the surface of the particles must be such that the contact angle as illustrated in Fig 2.5 lies in the range from 30^0 to 90^0 . When two such surfaces come close together, further drainage of film liquid is prevented by the particles which act as spacers. To prevent lateral movement of the particles when the two surfaces come close together, the final requirement for the proper performance of the stabilizing mechanism is that the particles form a network of sufficient strength at the air-water interface (Dickinson and George, 1988).

The application of these stabilizing mechanisms for equilibrium films to aerated food has to be done with care. This means that the stability can be governed by physical mechanisms that are completely different from the equilibrium ones described above. Some of these foam breaking processes are described in the following section (Dickinson and George, 1988).

Fig. 2.4 A disturbance of a liquid film in the form of a symmetric wave (Dickinson and George, 1988).

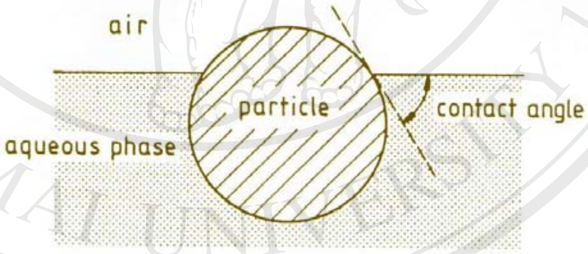


Fig. 2.5 Wetting of a solid particle at the air –water interface. By convention the contact angle is measured through the more dense phase (Dickinson and George, 1988).

2.2.3 Disproportionation

The diffusion of gas from small bubbles into big bubbles is referred to as disproportionation. In the absence of a stabilizing film of polymer molecules or particles, disproportionation occurs remarkably quickly. Overall, it is probably the most important type of instability in foams unlike in emulsion which is often insignificant. The driving force for disproportionation is the Laplace pressure difference over a curved bubble surface which results in a higher pressure within a small bubble than within a large one. As Henry's Law gas solubility increases with pressure, so more gas dissolves near the small bubble than near the large one and so the latter grows at the expense of the former. This causes gas transport for example by diffusion from small bubbles to big bubbles. This process is self-accelerating. Fig 2.6 shows the change in radius with time for bubbles in water filled with CO_2 or N_2. The difference in scale for the two gases arises because the solubility of CO_2 is 57 times higher that for N_2 (Dickinson, 1992).

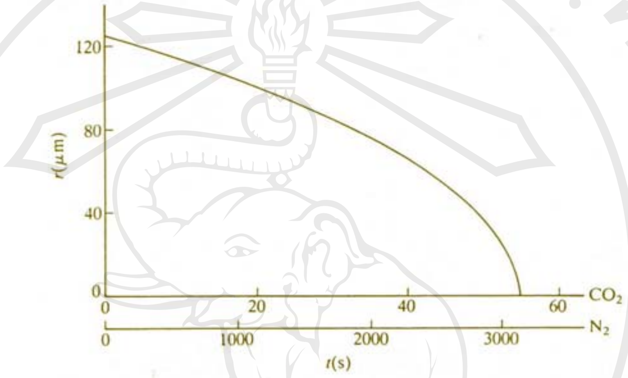


Fig. 2.6 Theoretical rates of disproportional for carbon dioxide and nitrogen at 20 °C and 1 atmosphere pressure (Dickinson, 1992).

2.2.4 Drainage

The drainage of liquid from a foam and the creaming of gas bubbles in a liquid are related phenomena as both describe the relative movement of bubbles and dispersion medium. In creaming, the movement of bubbles is larger than the movement of liquid; in drainage, the movement of liquid is more important than the movement of bubbles. In describing liquid flow through a polyhedric foam, a distinction has to be made between the drainage mechanisms for the two main building blocks of such foam. There are the thin liquid films and the Plateau borders. Gravity is the driving force for drainage of a thin liquid film. Gravity acts on the film liquid in two ways. The first one is gravity acts directly on the liquid in a film which is not horizontal. And the second one is gravity acts indirectly through suction of the Plateau border. Two mechanisms can contribute to film drainage are viscous flow of liquid through the interior of the film and a rather complicated process called marginal regeneration. The first mechanism, a thin liquid film stabilized with a surfactant has a property called the Gibbs film elasticity. This means that the viscous flow through a vertical film takes place in such a way that the film surfaces are mainly motionless. So the liquid moves just as if it was between two parallel solid walls. The second mechanism, marginal regeneration, consists of exchange of film parts of different thickness with the Plateau border. It is a much more effective film drainage process than the simple viscous flow of film liquid under gravity. The process of the marginal regeneration is illustrated schematically in Fig 2.7, where thick and thin parts of a film are each in contact with a Plateau border. For the sake of clarity, the two Plateau border are situated opposite each other although in reality the thick and thin parts of the film lie side by side as the same Plateau borders. Assuming that both Plateau borders have the same suction, there is a net force acting in the direction of the big arrow due to the fact that the border section exerts a bigger force on the thicker film than on the thinner one (Dickinson and George, 1988).

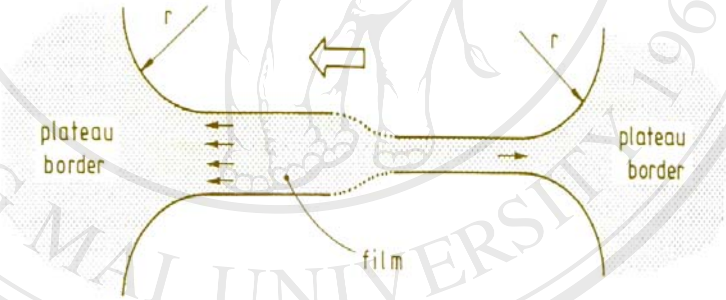


Fig. 2.7 Schematic representation of process of marginal regeneration. The thick film region is drawn into a Plateau border in direction of big arrow (Dickinson and George, 1988).

2.2.5 Foam breaking

Several ways in which a film can be destabilized are characterized by a common feature. Formation of a thin spot may arise by means of a pressure gradient in the film liquid, by mean of surface tension gradient acting on the film liquid, or by evaporation of the film liquid (Dickinson and George, 1988).

Hydrophobic particles. When a hydrophobic particle touches both surfaces of a film, the contact angle causes the film surfaces contacting the particle to be forced into a convex shape, the higher Laplace pressure in this part of the film leads to liquid flowing away from the particle, and the process continues until the liquid breaks contact with the particle and a hole is produced. The mechanism operates only when the particle contacts both film surfaces, which means that the particle size has to be at least equal to the film thickness (Dickinson and George, 1988).

Spreading particles. In a thin liquid film, when particles are present which spread over the film surface, the film may collapse for one of two reasons. The first one is the original stabilizing surfactant is displaced by the spreading material, which in turn is not able to stabilize the film; the last one is the spreading causes the film surface to move away from the particle, which leads to a movement of film liquid away from the particle, resulting in a local thinning of the film and ultimate film breakage. Please see the illustration in Fig 2.8 (Dickinson and George, 1988).

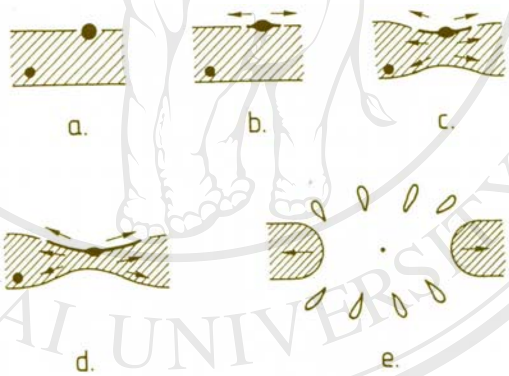


Fig. 2.8 Schematic representation of the consecutive stages whereby a spreading particle cause local film thinning ultimately leading to film collapse (Dickinson, 1992).

2.3 Drying Theory

Drying in the context of food dehydration, is removal of water from a material by artificial thermal means. Therefore drying involves water (mass transfer) and the application of heat in some manner (heat transfer) (Hertzendorf and Moshy, 1970).

There are three ways to dry a material by heat, the first way is conduction. Conduction heat transfer is a very effective and efficient mechanism. It involves contact between the material and a heating surface and it is typified by high heat fluxes. The second way is radiation that involves heat transfer without physical contact. A high temperature radiating source emits infrared waves which can be intercepted by an object lying in the line of light. The last one is convection. It involves transfer of heat from a moving fluid, in the case of drying from heated air. Heat is distributed throughout the material by conduction. For radiation heat transfer is accomplished by simple temperature differences between the material being heated and the heat source. Heat transfer rates are proportional to the area to which heat is applied, the temperature difference, and to a transfer coefficient. For the case of conduction, the transfer coefficient can be considered to be directly proportional to the thickness of the material through which the heat is being transferred. Thus, drying thin films or small particles is advantage. Convective heat transfer is more difficult to describe with a theoretical model and convective heat transfer coefficients are usually obtained empirically (Hertzendorf and Moshy, 1970).

There are two steps of mass transfer in drying. The first step is transferring water to the surface of the material being dried and the second is removal of water vapor from this surface. In the drying of fluid materials, the water is frequently brought to the material's surface by means of liquid diffusion, involving a concentration gradient. In certain situations vaporization can occur internally and water vapor then diffuses to the surface of the material (Hertzendorf and Moshy, 1970).

The mechanism of water vapor removal from a material's surface is primarily a function of the difference between the vapor pressure of water at the material's surface and the vapor pressure of water in the dryer system. The mechanism of water vapor removal depends upon the system pressure and the type of drying system employed. The water vapor evolved during drying is taken up by the drying air. The saturation level of the dryer air is a function of its initial water loading, its temperature, the relative amount of air to water vapor evolved and air recirculation patterns. Heating the dryer air serves not only as a mean of transferring heat to a product, but also increases its capacity to hold water vapor. A stagnate air system would provide only a limited capacity to absorb water vapor evolved during drying. A moving air stream overcomes this limitation, and through turbulent mixing, aid in moisture removal from a product's surface (Hertzendorf and Moshy, 1970).

According to the classification of Hertzendorf (1967) fluid materials may be dried by being physically supported on a tray, drum or moving belt or being wiped on a heated surface or being dispersed in an air stream as in spray drying. The first two methods ready lend themselves is generally restricted to air convection (Hertzendorf and Moshy, 1970).

Air convection driers

Cabinet, tray, and pan driers are examples of air convection driers in which food may be loaded on trays or pan in comparatively thin layers up to a few centimeters. A typical construction for this type of drier is shown in Fig 2.9. Fresh air enters a cabinet (B), is drawn by a fan (D) through a heater coils (C) and is then blown across food trays (G) to be exhausted (H). In this case, the air is heated by an indirect method. Screens (F) filter out any dust that may be in the air. The air passes across and between the trays in this design. Other designs have perforated trays and the air may be directed up through these. The air is exhausted to the atmosphere after one pass rather than being recirculated within the system. Recirculation is used to conserve heat energy by reusing part of the warm air. In recirculating designs, moist air, after evaporating water from food, may have to be dried before being recirculating to prevent saturation and slowing down of subsequent drying. Cabinet, tray, and pan driers are usually for small-scale operations. They are comparatively inexpensive and easy to set in terms of drying condition. They may run up to 25 trays high and operate with air temperatures of about 95 °C dry bulb and with air velocities of about 2.5-5.0 m/s across the trays. They are commonly used to dry fruit and vegetable pieces, and depending upon the food and the desired final moisture, drying time may be of the order of 10 or 20 h (Potter, 1986).

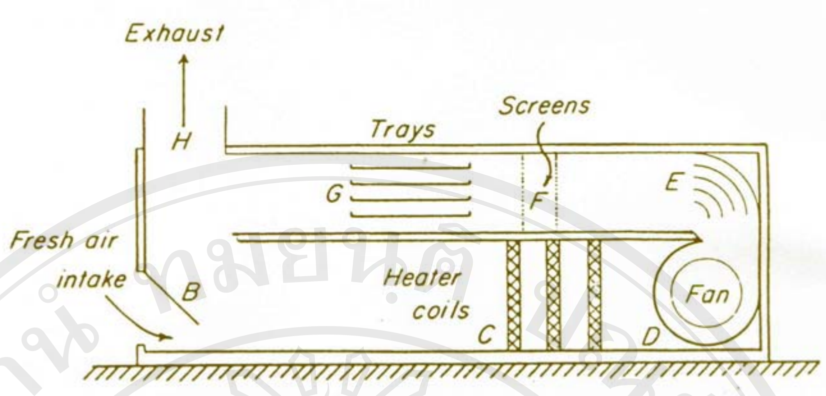


Fig. 2.9 One type of cabinet or tray driers (Potter, 1986).

2.4 Foam-mat drying

In foam–mat drying a liquid material is converted into a stabilized foam by incorporating gas into it. The foam is then spread out in a sheet or mat and dried. The structure of the foamed material permits high initial rates of water removal, resulting in relatively short dehydration cycles, and the use of moderately low air temperatures. The open porous structure of the dried product permits rapid rehydration, even in cold water (VanArsdel and Copley, 1964).

Since the foam–mat process requires a suitably stable foam most materials are usually required an addition of a small amount of a foam stabilizing agent. Good quality of foam-mat dried powders have been produced from a wide range of food materials including tomato paste; orange, grape, apple, pineapple and lemon juices; coffee and milk (Bates,1964).

A succinct synopsis of the salient features of the foam-mat drying process is presented below (Hertzendorf and Moshy, 1970).

1. The foams used are dense, a minimum of 0.1 g/ml has been used.
2. Foams are dispersions of gas bubbles in a continuous liquid phase.
3. Foam must persist throughout the drying process such as they must mechanically hold their structure under the condition of drying.
4. In order for liquids to foam they should have a fairly high consistency. Film-forming ability may result naturally from the solids present, or it may be induced by specially treating one of the components naturally present, or by

adding a film-forming component, of which many exist. Only a few, however, are legally acceptable for food, such as solubilized soy protein, glycerol monostearate, propylene glycol monostearate, and sucrose palmitate.

5. The choice of gas for foaming is usually not critical. Nitrogen, air and nitrous oxide have been used satisfactorily. However, economics may be a determining factor.
6. Best results are obtained with the maximum degree of subdivision of the bubbles. The smaller and more uniform the bubbles are, the more rapid and complete will be the drying.
7. Foams should flow fairly well under shear or pressure; they are compressible.
8. Drying belts or conveyors may be made from stainless steel or teflon, and the foam may be spread as a thin layer or as cylindrical extrusions, with cratering being one on a volume basis. The foamed material may be "cratered" on a perforated conveyor or tray an dried by blowing jets of air up through the perforations.
9. Fruit juice concentrates 0.32 cm thick typically require 15 min in 160^0 F air to dry to a final moisture of 2%. Air temperatures may be varied in stages.
10. The foam-mat dried products are quite low in density, with many gas bubbles remaining in the dry product.

The success of foam-mat drying depended upon preparing a suitable and stable foam. Foam to be used in foam-mat drying must be able to withstand a number of mechanical operations including pumping, spreading, cratering and extrusion as well as drying. And they must be strong enough to retain the extruded or cratered shape. Foams must retain their typical open structure throughout the drying process. This structure is desired for rapid drying and for ease of detraying. If foam break or drain excessively, drying time is increased, the product quality is reduced and detraying is made more difficult. On the other hand, excessively stable foams retain too many gas inclusions in the dry state so it will reduce apparent color intensity (Karim and Wai, 1998).

Food such as egg white, beef extract concentrate and whole milk concentrate, which naturally containing soluble proteins or monoglycerides, can usually be foamed without additives. Most food, however, require some foam stabilizing additives (Dickinson, 1992).

2.4.1 Foaming agent

Most food are a dispersed system. A few are homogeneous solutions, like cooking oil and some drinks. The properties of a dispersed system cannot be fully derived from its chemical composition, since they also depend on physical structures. Manufactured foods, as well as some natural foods, may have a somewhat simpler structure such as beer foam is a solution containing gas bubbles, milk is a solution containing fat droplets and protein aggregates such as casein micelles, egg-white is an excellent foaming material because of special functional properties of its constituent proteins. However most food require some foam stabilizing additives. The foam stabilizing additive is one kind of surfactants that can reduce surface tension to help foam stability. Sometime the word surfactant is used for small-molecule surfactants only. Also, surfactants are often called emulsifiers or foam stabilizing, even when the surfactant is not involved in making an emulsion (Dickinson, 1992).

2.4.1.1 Function of surfactants

Surfactants in food, whether small-molecule amphiphiles or protein, can produce several effects which are as followed (Fennema, 1996);

1. Due to the lowing of interfacial tension, the Laplace pressure is lowered and the interface can be more easily deformed. This is important for emulsion and foam formation and for the avoidance of foam breaking.
2. The contact angle is affected, which is important for wetting and dispersion event. The contact angle determines whether a particle can adsorb on a fluid interface and to what extent it then sticks out in either fluid phase. These aspects have an important bearing on stability of some emulsion and foam.
3. A decrease in interfacial free energy will proportionally slow Ostwald ripening. Ostwald ripening is the growth of large particles or droplets at the expense of small ones due to mass transport of soluble disperse phase material through the continuous phase.

4. The present of surfactants allows the creation of surface-tension gradients and this may be their most important function. It is essential for formation and stability of emulsion and foam.
5. Adsorption of surfactants onto particles may greatly modify interparticle forces, mostly enhancing repulsion and thereby stability.
6. Small-molecule surfactants may undergo specific interactions with macromolecules. They often associate with proteins, thereby materially altering protein properties. Another example is the interaction of some polar lipids with amylase.

Macromolecules can be very surface active. Several synthetic polymers are used as surfactants. Copolymers, where part of the segments are fairly hydrophobic and other hydrophilic, are especially suitable. They tend to adsorb with trains, loop and tail and also as protein often are the surfactants of choice (Fennema, 1996) as shown in Fig 2.10.

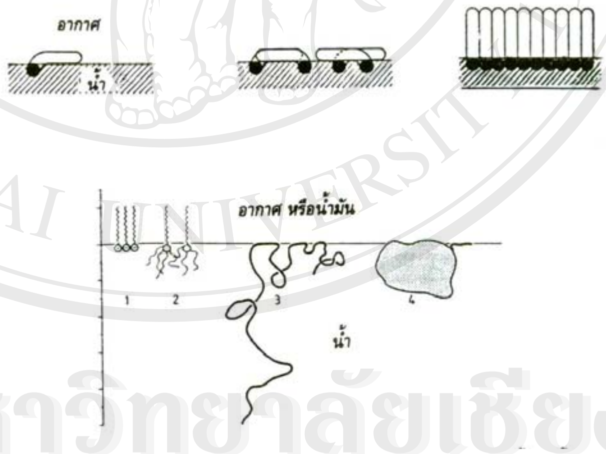


Fig. 2.10 Mode of adsorption of various surfactants at oil-water or air-water interface: 1, soap; 2, Tween; 3, a fairly small polymer molecule; 4, a globular protein. To the left is a scale of nanometers. The picture is highly schematic. The pictures in the first row are an arrangement surfactants at air-water interface (Rattanapanon, 2002)

2.4.1.2 Glyceryl monostearate (GMS)

GMS, also known as monostearin is a mixture of variable proportions of glyceryl monostearate, glyceryl monopalmitate, and glyceryl esters of fatty acids present in commercial stearic acid. GMS is prepared by glycerolysis of certain fats or oils that are derived from edible sources or by esterification, with glycerin, of stearic acid that is derived from edible sources (Igoe and Hui, 1996).

GMS was found to be superior over other edible foam inducers for aqueous food system by Bates (1964). Emulsion can be prepared at 70 °C, which is stable if held at about 70 °C (Ratchaniyom, 2002 and Sankat and Castaigne, 2004).

2.4.1.3 Methocel

Methocel is a trade name and it is manufactured by Dow Chemical, U.S.A. Methocel is one type of stabilizing agents that is composed of cellulose polymer chains as the main component. The compound will not react with food components when it is added as a food additive. The physical appearance of methocel is a white powder that has a high purity, provides low energy and can be used in small amount of concentrations. The compound has a property as a binder, a suspension agent, and a colloidal emulsifier. As a gum, methocel can provide the property of thermally gel and has a function as surfactant for film foaming in food both at high and low temperatures. The chemical compound of methocel was classified mainly from its component cellulose ether, which is methylcellulose (MC) and hydroxypropyl methycellulose (HPMC). Both of these celluloses that perform as a polymeric backbone cellulose for methocel have anhydroglucose units and are shown in Fig 2.11 (Dow Chemical company, 1962).

The different types of methocel is determined by the ratio of its two functional groups which are hydroxypropyl and methoxyl. The ratio of these functional groups can affect the solubility, viscosity and thermal gel point of methocel solution. This ratio is mainly affected by the degree of substitution for the hydroxyl group at anhydroglucose units. For example if there is a substitution for two functional groups, then the degree of substitution (D.S.) will be 2. The viscosity of methocel solutions is in the ranges between 3 – 100,000 cP (Dow Chemical Company, 1962).

Methocel can dissolve and disperse in warm water as a suitable temperature. When the temperature is going down, the component will become a gel. The gelation of methocel that is occurred at the interfacial of food emulsion can happen when the polymer chain moves to the air / water interface of the food. This movement will lead into a thin film gelation that will give a result in stabilizing foam to maintain its typical open structure throughout a drying process. This structure is highly desirable for rapid drying and for case of detraying. The viscosity of methocel solution can give a more significant effect, in which at higher concentration, the gelation's temperature will be lowered (Dow Chemical Company, 1962).

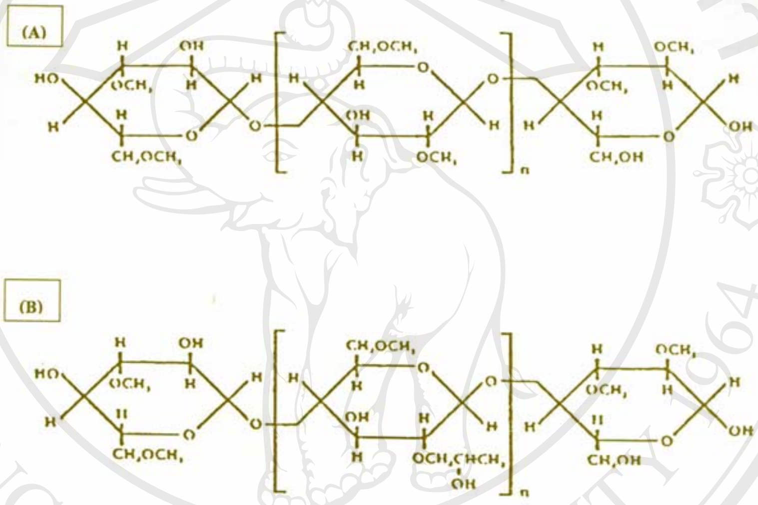


Fig. 2.11 Structure of methyl cellulose (A) and hydroxypropyl methycellulose (B) (Dow Chemical Company, 1962).

2.4.2 Development of the foam-mat process.

Morgan *et al*. (1959) have reported the development of foam-mat drying process for potato pastes with 25 % total solid, milk with 36 % total solid and orange juice with 40 % total solid and coffee. An addition of edible foam stabilizers, such as egg albumen and fatty acid monoglycerides was done for milk and orange juice. Beside that, mixtures of mono- and diglycerides and fatty acid esters of sucrose were used in coffee solution. Each stabilizer was added at a level of 1 % on a dry solid basis. The result foam was spreaded on a drying tray or belt for a 0.32 cm thick layer and dried using a cross flow air at temperatures between 73–105.5 ^{0}C. In case of potato paste, the first 80 % of drying cycle was operated at air temperatures of 89 ^{0}C and the last 20 % at 67 ^{0}C. The temperature step was done to avoid product degradation. The moisture content of the final product was 2.5 % if the drying process was carried out for 65 min.

Morgan *et a*l. (1961) discussed different types of foam stabilizers and the method of their preparation. They studied the used of soy protein and egg albumen for pineapple concentrate and peach puree, respectively. The two foam stabilizers were prepared as 10 % aqueous solutions prior to use. For sucrose monostearate, the stabilizer was dissolved in warm ethanol and added at a concentration of 0.2 % based on a solid basis to 30 % of coffee extracts. Another stabilizer, GMS was found to be the most versatile foaming agent at about 1 % concentration level. It was also effective to be used with orange juice concentrate (55-65 % total solids); tomato paste (30 % total solids); prune, apricot, pear and strawberry purees; grape, lemon, apple and prune juice; molasses and various vegetable purees.

Hart *et al.* (1963) investigated various type of foaming agents. GMS was found to be the most effective foaming agent in producing foams for the widest range of food products. Solubilized soy protein was also effective for a number of food products. In addition because of the water solubility of the protein, the powder solution was not cloudy on reconstitution. In batch tests, foam formation was affected by the type and rate of agitation, temperature and the foaming gas. The rate of foam formation varied directly with agitator speeds, generally leveling with increasing time. Some materials such as tomato paste were adversely affected by over-whipping as manifested by the breakdown of previously developed foam structure. Food temperature during foaming was sometimes critical. Many foams failed to show sufficient stability during drying despite their good initial appearance.

Graham *et al*. (1965) reported some experiments about different moisture content levels and bulk volume of foam-mat dried citrus juices. Decreasing the bubbles size of foamed orange juice concentrate would facilitate drying processes in achieving a low moisture content of 1 % compaction of the products. The most suitable foam stabilizer for a 60 ^{0}Brix orange juice concentrate was a mixture of Gunther D-100 and methocel at a ratio of 4:1. The foaming process was done using a high-shear Oakes mixer, followed by cooling to about 22 ^{0}C in a wiped-film heat exchanger. The foam deposited in a 0.32

cm layer on crater trays was dried to 1 % moisture content in 12 min. For a foam-mat dried lemon juice at 52 ^{0}Brix, with 29 % citric acid, it was added with 1.4 % GMS on a solid basis and mixed using an Oakes mixer to make a warm stable foam that had a density of 0.27 g/ml. The foam was then dried to 1.4 % moisture powder in 14 min.

Ginnette *et al*. (1963) described the conditions for producing an acceptable foam-mat drying tomato product using a crater dryer. A tomato concentrate with a solid level of about 30 % was foamed using GMS at a level of 0.6–1.5 % on a solid basis as a stabilizer. Drying to 2.5–3 % moisture content was typically accomplished in 15 min with air temperatures of 116.7 ^{0}C, 88.9 ^{0}C and 72.2 ^{0}C in three drying stages. Superficial through-circulation air velocities in the three dryer zones were 300,100 and 50 rpm, respectively.

Gunther (1964) issued a patent on addition of water-soluble cellulose ethers (methocels) to stabilize mashed banana for foam-mat drying. Banana did not require a whipping agent to produce a suitable foam but the addition of a thermally-gelling cellulose ether stabilized the foam during the elevated temperatures encountered in drying processes.

Bates (1964) studied the formation of stable foams capable of being oven dried to yield fruit powders for pineapple concentrates at 45 ^{0}Brix and 61 ^{0}Brix; passion fruit juices and nectar base; guava purees and nectar base; banana, papaya, mango, and avocado purees; coconut milk; and sucrose water systems. Variables influencing foam formation and stabilization were chemical nature of fruit, soluble solid contents, pulp fractions, temperature of foaming and mixing time, type of foaming agents and type and concentration of foam stabilizers. Variables of less importance influencing foam density were concentration of foam and consistency of fluid. Acceptable oven-stable foams and formulations could be done for all products studied except avocado purees and coconut milk. A drying temperature of 88.9 ^{0}C for 15 min was used to reduce foam of 0.30 g/cc formed from fluids of 20 to 61 ^{0}Brix to a moisture content below 2 % when the foams were extruded as strips of 0.32 cm. GMS was found to be superior over other edible foam inducers for tomato juices and aqueous food systems. It was also used for retaining the puffed structure created in the initial stage of vacuum drying of mango pulps.

Ratchaniyom (2002) studied the product characteristics of foam-mat drying longan juices. Three types of foaming agents were examined for their compatibility with longan juices. It was found that the most suitable foaming agent was a mixture of methocel 65 HG 0.13 % and GMS 0.13 % based on a weight basis. The effects of temperatures and time during drying were studied by determining the rate of moisture removal, final moisture contents and the quality of the dried product. The results showed that the suitable condition to dry longan juices was drying at 70 ^{0}C for 50 min with a constant air velocity of 1 m/s and a foam thickness of 5 mm. The moisture content of the dried product was 3 % based on a dry weight basis, a_w was 0.12, and rehydration of the longan powder was 2.5 %. The color values represented by L, a^* and b^* of the longan powder were 70.64 , 4.28 and 16.79, respectively.

Karim and Wai (1998) studied foam-mat drying of starfruit *Averrhoa carambola L.* purees by adding various concentrations of methocel. Overrun and density of the foams from various concentrations of methocel were compared. Relative stability of the foam was determined by comparing the amounts of the juice separated from the foam at 70^{0}C. Drying rates at two drying temperatures (70 and 90 ^{0}C) were also studied. Quality of the dry and reconstituted powders was evaluated with a simple sensory evaluation and a Hunterlab instrument. The maximum value for the overrun and stability of the foam was obtained using a methocel concentration of 0.4 % (w/w). Falling rate was observed for foam dried at both drying temperatures. Drying time could be shortened by as much as 30 min when the drying temperature was increased from 70 to 90 ^{0}C. However, obvious color and flavor changes were observed in the products dried at 90 ^{0}C. This study has indicated that under the experimental conditions employed, reasonably good powder characteristics could be obtained.

Falade *et al.* (2003) studied foam-mat drying of cowpea using GMS and egg albumin (EG) as foaming agents. GMS and EG were incorporated into cowpea pastes which had concentrations of 22 and 25 % total solids at 2.5, 5.0, 7.5, 10.0, 12.5 and 15 % (w/w), and whipped for 3, 6, 9, 12, 15, 18 and 21 min at 15, 25 and 35 ^{0}C foaming temperatures. Foam density was measured and expressed in g/cm^3. Cowpea foams were dried at 60 ^{0}C, which had a temperature of wet bulb of 35 ^{0}C for 48 min. Sensory attributes of the fresh products and reconstituted pastes were evaluated. Generally, the foam density decreased with increase concentrations of GMS and EG in cowpea pastes. The foam density decreased with a decrease in total solids of the cowpea pastes. The minimum foam densities were obtained in the cowpea foams with GMS and EG after 9 and 21 min of whipping, respectively. EG-stabilized foams were unstable for drying.

Sankat and Castaigne (2004) studied the foaming of ripe bananas and the forced air-drying characteristics of the resulting banana foam mats. Fresh banana puree with a density of 0.93 g/ml was foamed to a density of 0.50 g/ml after 12 min of whipping by an addition of 10 g/100 g soy protein as a foam inducer. GMS did not induce foaming while commercially available food ingredients, Dream Whip and gelatine induced foaming but such foams were not suitable for subsequent drying. Banana foam mats were dried at temperatures from 45 to 90 ^{0}C in a forced air, cabinet dryer, to a hard, porous and brittle solid which was amenable to grinding so as to produce a dehydrated banana powder.

Bunthawong (2004) studied about the appropriate process and quality of instant makeang powder produced by foam-mat drying methods. The result was the mixture of methocel and carboxyl methyl cellulose (CMC) which was suitable as a foaming agent at 47 % of extracted makiang juice. The foam which was produced after foaming using this foaming agent was low in density (0.04 g/ml) but high in foam overrun (690.07 %).

2.4.3 Maltodextrin

The hydrolyzed product, hydrolysis of starch by means of heat and acid or specific enzymatic treatments or combined acid and enzyme hydrolysis, yields a spectrum of depolymerized oligomers, mainly consists of D-glucose, maltose, and a series of oligosaccharides and polysaccharides such as maltose oligosaccharides, maltotriose, and maltotetraose mixtures. The wide range of hydrolyzates available are described in terms of their “Dextrose Equivalent” (DE) value, which is a measure of the total reducing power of all sugars present relative to glucose as 100 and expressed on a dry weight basis. Therefore, a degradation product with a high DE has been subjected to a greater degree of hydrolysis than one of a lower DE (Chronakis, 1998).

Maltodextrins are hydrolysis products of starches with DE lower than 20 and for DE more than 20 the term syrup solids or dextrins is used. They represent a mixture of saccharides with a broad molecular weight distribution between polysaccharides and oligosaccharides and are available as white powders mostly or concentrated solutions. In contrast to native starches, the maltodextrins are soluble in water (Chronakis, 1998).

The addition of maltodextrins as food additives has been introduced in the last 25 years. Maltodextrins with low DE values are claimed to display in part the desirable characteristics of fat from the mid to late 1980s. They have received considerable attention for developing fat and calorie-reduced products. Some of their important functional properties include gelling, crystallization prevention, promotion of dispersibility, freezing control, and binding (Chronakis, 1998).

2.4.3.1 Production

The acid conversion process to produce maltodextrin consists of treating a suspension of purified starch with a small amount of strong acid at a fairly high temperature. Hydrochloric acid 0.02 to 0.03 M is usually used and temperatures of 135 to 150 ^{0}C for 5 to 8 min are applied. A measurement of a pH range between 1.6 to 2.0 is not a very sensitive means of controlling acid addition and is normally performed volumetrically or by conductivity measurements, while adjustment of DE is carried out by varying the reaction temperature in a normally fixed time. When sufficient saccharification has taken place, the acid is neutralized, and the mixture is filtered, decolorized and concentrated to the required solids content. In modern methods, the conditions are arranged to keep the time of conversion as short as possible in order to minimize side reactions with partial degradation resulting in bitter taste, off colors and dextrin haze on storage. Today, the acid hydrolysis is particularly recommended for production of dextrins with DE<5 (glucose syrups) (Chronakis, 1998).

In order to have a full continuous hydrolyzates production process, the use of continuous conversions catalyzed by enzymes or combinations of acid and enzymic processes are placed. The actual process used for the production of maltodextrin is often patented and typically involves mixing enzyme and starch slurry, heating at the gelatinization temperature of starch which is about 75 ^{0}C, holding there for a fixed time, and then heating to a higher temperature which is about 105 ^{0}C or acidifying the product to pH 3.5 to inactivate the enzyme. The optimum conditions (i.e., temperature, pH) for a particular enzyme frequently depend on the organism from which it is produced. Finally, the soluble material is separated from the insoluble fibers by centrifugation and neutralized for subsequent spray drying under vacuum (Chronakis, 1998) .

Enzyme-catalyzed conversion with mostly α-amylase (1,4-α-D-glucan glucanohydrolase, EC 3.2.1.1) from *Bacillus subtilis* and pullulanase, pullulan 6-glucanohydrolase, EC 3.2.1.41, are now used for production of gelling maltodextrins. The enzyme α-amylase is an endo-acting enzyme hydrolyses the $(1\rightarrow 4)$- linkages in α-D-glucans but cannot hydrolyze α-$(1\rightarrow 6)$-linkages at the branch points. As a result, maltodextrins produced by α-amylase will have an extensive hydrolysis of amylase but only a partial hydrolysis of amylopectin, takes place. However, a low amount of high-molecular-weight amylase still remains. The maximum activities of the α- amylase are usually in the acid region between pH 4.8 and 6.5, but the activity-pH profile and location of the pH optima differ depending on the enzyme source, with examples of pH optima ranging from pH 3.5 to pH 9.0. The pH optimum for plant and microbial α- amylases is generally lower than for the animal α-amylases. Pullulanase is specific for $1\rightarrow 6$ linkages in α-D-glucans and therefore acts as a debranching enzyme to provide a series of $(1\rightarrow 4)$ linked -α-D-glucopyranose oligosaccharides. Most pullulanases have pH optima between pH 5.0 and 7.0 and usually temperature optima of 45 to 50^0C (Chronakis, 1998).

Enzyme catabolized or a combination of acid and enzymic hydrolysis of starch have distinct advantages compared with the acid process. The hydrolysis obtained is more specific, depending on the enzyme or the combination of enzymes selected, and a greater flexibility in the final composition of the product is usually achieved. Enzymic processes provide a greater amount of fermented sugars and less formation of undesirable components from thermal processing, while there is no need to remove salts formed during acid neutralization. It can be conducted at wider pH values and lower temperatures and pressures (an economic advantage of requiring less energy), while the processes are easier to control. Nevertheless, the use of enzymes for starch hydrolyzate is not a completely continuous process, and several attempts have been made to use insoluble enzymes by immobilization techniques. In addition to the practical problems using immobilized form of the enzymes on porous matrices, an economic question also arises.

Improved characteristics of enzymes can be expected to expand with the use of genetic engineering (Chronakis, 1998).

2.5.3.2 Compositional characteristics

As a digestion product from starch, maltodextrins contain linear amylase and branched amylopectin degradation products. Maltodextrins, therefore, are considered as D–glucose polymers in which the individual α-D–glucopyranosyl residues are joined by $(1\rightarrow 4)$ linkages to give linear chains with a degree of $(1\rightarrow 4, 1\rightarrow 6)$–linked or $(1\rightarrow 6)$-linked branch points. However, varying the DE among maltodextrins polysaccharides does not necessarily mean that they differ only in dextrose content. Moreover, maltodextrins with the same DE value can have very different properties that reflect the composition of the component rising from the hydrolysis reactions. The type of starch, oats, rice, tapioca, potato, etc is also an important factor determining the molecular segments of maltodextrins. The ratio of linear amylose chain molecules to branched amylopectin varies according to the source of starch. The majority of starches contain between 15 and 35 % of amylose. These maltodextrins have an average molecular weight comparable to other polysaccharides and much less than that of conventional amylopectin. Alkali-modified cassava starch is also a good source of maltodextrins. In addition, native starches differ in water content, and besides amylose and amylopectin, several noncarbohydrate components are present, such as lipids, proteins, and minerals (Chronakis, 1998).

2.5.3.3 Physicochemical characteristics

As a digestion product of starch, maltodextrins contain linear and branched amylose and amylopectin degradation products with the size that extends from oligomers to macromolecules. In the sol state these molecules are hydrated and expanded, and the extended helical regions are interrupted by short and disordered regions. At high concentrations helices aggregate, forming crystalline domains. Therefore, maltodextrins have a significant portion of average chain length long enough to form thermally reversible gels. The sol-gel transition is a slow process accompanied by dehydration and combined with the growth of helices of sufficiently long molecular chains or chain segments. The transition depends on the temperature, concentration, time, and structural peculiarities (Chronakis, 1998).

Variations in DE values result in maltodextrins with varying physicochemical properties. Hygroscopicity, solubility and their effectiveness to reduce the freezing point increase with increasing DE, while viscosity, cohesiveness and coarse crystal prevention increase as DE decreases. It is possible, however, by altering the temperature of hydrolysis to produce maltodextrins preparations that have similar DE values but different proportions of high and low molecular weight saccharides. Differences in these saccharides profiles are expected to yield maltodextrins with different physicochemical properties. In particular, solubility and solution stability will be influenced by high molecular weight components, while viscosity, crystallization, and sweetness will depend on the amount of low molecular weight components. The low moleculear weight fraction contains principally linear chains, presumably originating from amylose and outer chains of amylopectin. The high molecular weight fraction is fully excluded and composed entirely branched molecules, amylopectin (Chronakis, 1998).

Maltodextrins are suitable ingredients to replace fat in food and contribute and or reproduce the fat like mouthfeel in a variety of produce. This sensation presumably originates from the three-dimensional network of submicron particles in structured water layers, that function as the structure of fat. The network is loosely associated and the particle gel structure has a large surface area and high degree of water immobilization. For instance, acid hydrolyzed starch under specific conditions can form crystallites that are essentially intact and organized laterally. This system has low degree of association and the aggregates are very small particles (about 0.02 µm). In a continuous oil phase this loosen association linked to the fat crystals and deform similarly. As well, the particle size of irregularly shaped maltodextrin aggregates are 3 to 5 µm in diameter, approximately the same size as the fat crystals which presumably contribute to the fat like mouthfeel. Maltodextrins have the capacity to participate in Maillard reactions and can be used as non browning carriers for drying sensitive products (Chronakis, 1998).

2.4.3.4 Mechanism of network formation of maltodextrin gels.

The mechanism of network formation for maltodextrins can be inferred from the gelation of starch that is based on the creation of co-axial double helices by 1,4 –linked α-D-glucan chains and the lateral aggregation of these intermolecular association. Maltodextrin gels result from coupling interactions between soluble amylase molecules and sufficiently branched and linear chains of amylopectin molecules. The hydrated linear amylose fractions that have a conformation characterized by extended helical regions and interrupted by short disordered regions are responsible for the initiation and acceleration of the gelation. In pure amylase gels conformational ordering occurs from the helical junctions of chains with an average helix length longer than 50 to 70 residues, while shorter oligomers than Degree of Polymerization (DP) 6 have been found to co-crystallize with longer chains. Long outer linear segments of branched amylopectin molecules also interact with the amylose chains. These helical species aggregate to form crystalline domains, which are embedded in a polymer solution with disordered chain segments. Because a portion of the molecule is sufficiently long and can be involved in the formation of several crystalline domains, at proper concentrations an aggregated network in such domains represents the junction zones of the polysaccharide. The junction zones extend over very small dimensions and despite the heterophase state the mechanical properties of the maltodextrin gels corresponded to those of a single phase system. The importance of high molecular weight stable helices capable of foaming ordered domains as essential constituents of the three-dimensional network have been established, as well as the formation of shorter structures by cooperatively associating with oligomers (Chronakis, 1998).

2.4.3.5 Food application of maltodextrin

Maltodextrins have the ability to form gels and retain water, and therefore are used in the food industry as a texture modifier, either for gelation, retention of water, and to a certain extent substitution of fat. They perform multifaceted functions in food systems including providing resistance to caking, adding texture and body, forming films, binding flavor and fat, serving as oxygen barriers, giving surface sheen, aiding dispersibility and solubility, freezing control and preventing crystallization and as product extenders. Maltodextrins are also cheaper in comparison with other major edible hydrocolloids, and their solutions have a bland flavor and smooth mouthfeel. Despite their multifunctional performance, usually the addition of hydrolyzed starch is not enough to provide the proper texture, sensory qualities, and satisfy consumers desires without an addition of other carbohydrates and proteins (Chronakis, 1998).

Reductions in blood cholesterol levels may be achieved by dietary changes other than replacing animal fat. For example, maltodextrin made from oats, by the action of its component; glucan, increases high-density lipoprotein cholesterol and decreases low density lipoprotein cholesterol. In addition, maltodextrins are easily digested in the intestinal tract, more quickly than starch and somewhat slower than glucose, tending to elevate blood glucose levels. Some of the main applications are to formulate salad dressings, fillings and gravies, rehydration drinks, dairy products including frozen desserts, meat analogues, baked goods pastries, snacks, cakes, confectioneries, encapsulation of flavors and colorants, and in a variety of specific other products. Maltodextrins can be used to replace oils in low-calorie salad dressings. In certain pourable and spoonable dressings, maltodextrins have combined with natural and synthetic gums such as xanthan and cellulose-based gums. A 25% maltodextrin solution can replace 30 to 50% of oil in a 30% oil spoonable salad dressing, or the maltodextrin can be dry blended and added to the liquids in the paste portion of the formula. Maltodextrins are easily miscible with nutritive fats and oils and give emulsions that are stable under refrigerator conditions. Lower DE maltodextrins result in a better fat binding. In frozen desserts, maltodextrins in combination with cellulose gums prevent large ice crystals from forming during freezing process and control crystallization and melt-down (Chronakis, 1998).

The reduction in the amount of fat initially saw the development of spreadable products with half the amount of fat found in traditional embodiments, 80% in butter and margarine, and then the formulation of dispersions with a 20% fat content. Today, very low fat preparations have been launched to the market with a fat phase as low as 3 to 0% of the product. Naturally, to preserve the solid-like appearance of low-calorie substitutes, maltodextrins were introduced to structure the increasingly larger aqueous phase. The idea there was to intelligently manipulate the exclusion phenomena between polymers and to form micron-sized homogenous phases that alternate through thin interfaces in the mixture and creating a so-called plastic dispersion that imitates the smooth texture and creamy mouth feel required (Chronakis, 1998).

Maltodextrins could replace dried milk in meat analogues without a disadvantage to taste or aroma. A slight decrease in the pH values from 5.9 to 5.5, which was obtained by this substitution favored to the stability of color and flavor. Maltodextrins and dextrins interfere with meat protein gelation and produced dense, low-yielding sausages compared with textural studies of sausages containing crosslinked starches and starches with substituted and oxidized modifications. Their effects vary according to the origin of the starch, induced modifications, conditions of use, and the nature of the product to which they are added. On the other hand, there are no specific investigations about the properties of mixed meat proteins with maltodextrins (Chronakis, 1998).

Maltodextrins have been proven useful to reduce Maillard reactions and used in microencapsulation of food components such as fat and oils, vitamins, minerals, and colorants. The microencapsulated materials are covered by a film coating material that protects the core but releases the contents under the desired conditions. Maltodextrins reveal important matrix forming properties in wall systems. Their surface active characteristics of high DE molecules protected encapsulated orange peel oil against oxidation. Capsules containing a wall material from a mixture of maltodextrin as a stabilizer, egg yolk lecithin, gelatin and caseinate showed an optimal protection for squid oil against oxidation. The thermal stability was greater and the shelf-life was longer than free squid oil and encapsulated squid oil prepared without them (Chronakis, 1998).

Retention of volatile flavor compounds decreased as maltodextrin DE increased, although other individual studies showed that samples having DE between 10 to 20 could be satisfactory utilized as a wall material for flavor encapsulation. Combinations of whey proteins and high DE maltodextrins are effective wall systems for microencapsulation of volatiles. Such wall systems provide high volatile retention levels and limit the proportion of solvent extractable core. This proportion was reduced with increasing DE value of carbohydrate. When low DE maltodextrins were incorporated at a high proportion into whey containing wall systems, they adversely affected the emulsion characteristics and caused structural defects in dried products (Chronakis, 1998).

2.5 Instant powder

The production of instant powder is a process using fruits or vegetables as raw materials for making fruit and vegetable juices. Afterwards, the juice is taken into a dryer to make powder. The method is very interesting for food producers in Thailand because producing high moisture content of drinking, such as fruit juices and modified fruit juices, etc. will be easier to spoil compare to a drink in form of instant powders. Drying methods are able to reduce the moisture content in food. By doing this, the chances of microorganisms to grow in food will also be reduced. The principle of the instant powder production is one kind of drying methods. The product that comes from this process will be in a powder form and it has a good solubility in water even in cold water. Beside that, the powder has a very low moisture content about 5 % and it is stable during storage at room temperature for a year or longer. A major criterion for the quality of dehydrated foods is that when the dehydrated foods are reconstituted by an addition of water, the reconstituted beverage should be very close to or virtually indistinguishable from the original food material used in their preparation (Bunthawong, 2004).

Fruit juice is widely accepted as a drinking beverage for consumers nowadays. However, the consumers need to pay an extra cost to keep the juice. Therefore, changing the juice into a form of instant powder will reduce this extra cost. The powder form of a fruit juice should have good properties such as it can be dehydrated within 1-2 min and the reconstituted juice should have color, taste and flavors similar to the original fruit juice according to consumer's acceptance. The other property of the powder is that it can be kept for a long time without losing its good quality. The powder form of fruit juice is looked like small particles that can reduce the weight and volume of the original juice for about 8 and 4 times, respectively. These reductions can result in lower shipping and container costs (Soponronnarit, 1989).

There are 3 types of instant powder, which is divided by its producing method (Wiriyajaree, 1992) ;

1. A production of an instant powder from a fresh juice that is made from an extraction of a fresh fruit juice, which is passed into a spray dryer to make a form of fine droplets and then sprayed into a counter-current flow of heated air to become powders. Subsequently, the process is developed using a freeze dryer in a vacuum condition. The

fruit juice is freezed and the water will then be sublimed directly into vapor. The solid which is left from this process will not have a significant change but it will have pores inside the product. Therefore, the solid can be returned into a juice easily and its solubility will be increased. Food products that can be produced using this method include coffee, milk and fruit instant powder. However, a high production cost will be needed to produce these products.

2. A production of modified instant powders that is produced by coating flavoring substances on main substances such as sugar, starch or milk powder. Flavoring substances which are used in this process can come from synthetic or natural materials, including color and the flavoring substances of fruit juices. The coating process of flavoring substances on main substances is done by spraying the flavouring substances several times on the surface of the main substances in order to let the flavor absorb into the main substances. After that the substance are dried in an oven and grinded into powders.

3. A production of a soft drink instant powder, which is a modified type of soft drinks that consist sodium bicarbonate. When the powder is dissolved in water, carbon dioxide will occur.

A production of a high quality instant powder should consider (Soponronnarit, 1989).

1. Quality of raw material. Raw materials should have a high quality. When preparing fruit juice concentrates using a boiling method, the process should be done carefully to prevent any significant changes in color and odour. The heat used in boiling will not only vaporize water but it will also cause some losses of volatile components from a fruit juice. The appropriate temperature for heating a fruit juice is at 54 °C for 2-3 h. At this condition, volatile components and color will not be lossed. In the other hand, volatile components will be lossed easily at 63 ^{o}C. Losing volatile components in concentrate fruit juices may effect the powder's quality.

2. Drying method. During heated air-drying, it is desirable that products remain stable and retain their typical open structure to facilitate rapid drying, internal moisture movement within the products and rehydration. Normally instant powders should be

dissolved in cool water. Drying methods can be classified into many categories such as freeze drying, puff drying, foam-mat drying and foam spray drying.

3. Drying temperature. The temperature that is used for drying should not be too high to avoid any heat damage. A series of drying steps can be applied by using high temperatures at the beginning of the drying process and then follow by lower temperatures at the end to provide high drying rate and reduce any heat damages.

4. Agglomeration. Agglomeration is a process that allows instant powders which are very fine to absorb moisture by spraying water. The powders will be agglomerated into bigger forms and then dried. This process improves rehydration property and solubility of the powder.

5. Food additives. There are two types of food additives that can be added in instant powders. The first one has a function as preservatives or gives chemical effects such as sulfur dioxide (SO_2). This preservative will prevent color and flavor changing during drying and storage. The second one has physical effects including alginates, soya protein and glyceryl monostearate. The second type of food additive can help food products to retain their structure during drying.

Good characteristics of instant powders will include(Bunthawong, 2004);

1. Wettability. Instant powders should have a big surface area. The bigger the surface area of instant powders, the easier the water absorption will be occurred.

2. Sinkability. Sinkability of instant powders depends on the size and density of the powder. If a powder has a high solubility, the trend of sinkability will also be high.

3. Dispersibility. Dispersibility is the ability of instant powder to get wetted without formation of dry lumps in water.

4. Solubility. Solubility and solubility rate depend on the characteristics or the chemical ingredients of food.