Drying in food processing biology essay

Science, Biology

Introduction

The drying (or dehydration) process can be defined as " the application of energy, under controlled conditions, to remove the majority of the water present in a food by evaporation". This definition, therefore, excludes other unit operations which remove water from foods, for example mechanical separations and membrane concentration, evaporation and baking as these normally remove much less water than dehydration. The main purpose of dehydration is to extend the shelf life of foods by a reduction in water activity. This inhibits microbial growth and enzyme activity, but it’s important to remember that the processing temperature is usually insufficient to cause their actual inactivation. Therefore anyincrease in water content during storage, for example cause by faulty packaging, will result in rapid spoilage. The reduction in weight and volume of food reduces transport and storage costs. For some types of food, dehydration provides a convenient product for the consumer or more easily handled ingredients for food processors but drying causes deterioration of both the eating quality and the nutritional value of the food. The design and operation of dehydration equipment therefore aim to minimize these changes by the selection of appropriate drying conditions for individual foods. Examples of commercially important dried foods are coffee, milk, raisins and other fruits, pasta, flours, beans, pulses, nuts, breakfast cereals, tea and spices. Examples of important dried ingredients that are used by manufacturers include egg powder, flavorings and colorings, lactose, sucrose or fructose powder, enzymes and yeasts. There are basically three big families of processes very different in technological aspects. The first ones, the most used in the industrial reality, are all of those sets of processes involving heating the food through hot air streams or heated surfaces. The second category is formed by all of those processes that use the dielectric (microwave and infrared) heating and finally the third and last family is based on a different principle that use cold to extract water from foods through sublimation. In the following section of this essay all of those three family will be briefly explained evaluating pros and cons.

Heat drying processes using hot air and surfaces

In this kind of processes the moisture in the food is removed either by an hot stream of air blown through the food or by hot surfaces on which the food is laid.

Hot air drying processes

In this family of processes there are three inter-related factors that control the capacity of air to remove moisture from a food: the amount of water vapor already carried by the airthe air temperaturethe amount of air that passes over the food. The amount of water vapor in air is expressed as either absolute humidity (termed moisture content in Fig. 1) or relative humidity (RH) (in per cent). Psychrometry is the study of inter-related properties of air–water vapor systems. These properties are conveniently represented on a psychrometric chart (Fig. 1) which easily gives information about the physical and thermodynamic properties of air–water mixtures. Heat from drying air is absorbed by food and provides the latent heat needed to evaporate water from the surface. The temperature of the air, measured by a thermometer bulb, is called the dry-bulb temperature. If the thermometer bulb is surrounded by a wet cloth, heat is removed by evaporation of water from the cloth and the temperature falls. This lower temperature is called the wet-bulb temperature. The difference between this two temperatures is used to find the relative humidity of air on the psychrometric chart. An increase in air temperature, or reduction in RH, causes water to evaporate more rapidly from a wet surface and therefore produces a greater fall in temperature. The dew point is the temperature at which air becomes saturated with moisture (100% RH) and any further cooling from this point results in condensation of the water from the air. Adiabatic cooling lines are the parallel straight lines sloping across the chart, which show how absolute humidity decreases as the air temperature increases. The third factor that controls the rate of drying, in addition to air temperature and humidity, is the air velocity. When hot air is blown over a wet food, water vapor diffuses through a boundary film of air surrounding the food and is carried away by the moving air (Fig. 2). A water vapor pressure gradient is established from the moist interior of the food to the dry air. This gradient provides the ‘ driving force’ for water removal from the food. Water moves from the interior of the food to the surface by the following mechanisms: liquid movement by capillary forces, particularly in porous foodsdiffusion of liquids, caused by differences in the concentration of solutes at the surface and in the interior of the fooddiffusion of liquids which are adsorbed in layers at the surfaces of solid components of the foodwater vapor diffusion in air spaces within the food caused by vapor pressure gradients. Other factors which influence the rate of drying include: The composition and structure of the food has an influence on the mechanism of moisture removal. For example, the orientation of fibers in vegetables (e. g. celery) and protein strands in meat allow more rapid moisture movement along their length than across the structure. Similarly, moisture is removed more easily from intercellular spaces than from within cells. Rupturing cells by blanching or size reduction increases the rate of drying but may adversely affect the texture of the rehydrated product. Additionally, high concentrations of solutes such as sugars, salts, gums, starches, etc., increase the viscosity and lower the water activity and thus reduce the rate of moisture movement. The amount of food placed into a drier in relation to its capacity (in a given drier, faster drying is achieved with smaller quantities of food). In practice, the rate at which foods dry may differ from theFigureFigure 2

Heated surfaces drying processes

In this kind of processes food is deposited on a heated steel drum. Heat is conducted from the hot surface, through the food, and moisture is evaporated from the exposed surface. The main resistance to heat transfer is the thermal conductivity of the food. Additional resistance arises if the partly dried food lifts off the hot surface, forming a barrier layer of air between the food and the drum. Knowledge of the rheological (i. e. the study of the flow of matter) properties of the food is therefore necessary to determine the thickness of the layer and the way in which it is applied to the heated surface. Driers in which heat is supplied to the food by conduction have two main advantages over hot-air drying: It is not necessary to heat large volumes of air before drying commences and the thermal efficiency is therefore high. Drying may be carried out in the absence of oxygen to protect components of foods that are easily oxidized. Typically heat consumption is 2000–3000 kJ per kilogram of water evaporated compared with 4000–10 000 kJ per kilogram of water evaporated for hot-air driers. However, foods have a low thermal conductivity which becomes lower as the food dries and a thin layer of food is therefore needed to conduct heat rapidly, without causing heat damage. Both of this family of processes includes many kind of method that will be the matter of the next session of the essay. Right now, however, it’s important to analyze the theory behind the other two families of drying processes to understand the pros and cons in terms of quality of finished goods, costs and energy consumption.

Other drying technology

Dielectric drying

Dielectric (microwave and radio frequency) is a form of electromagnetic energy that is transmitted as waves, which penetrate food and are then absorbed and converted to heat. In contrast, ohmic (or resistance) heating uses the electrical resistance of foods to directly convert electricity to heat. The majority of foods contain a a big quantity of water. The molecular structure of water consists of a negatively charged oxygen atom, separated from positively charged hydrogen atoms and this forms an electric dipole. When a microwave or radio frequency electric field interact with a food, dipoles in the water attempt to orient themselves to the field (like a compass in a magnetic field). Since the rapidly oscillating electric field changes from positive to negative and back again several million times per second, the dipoles attempt to follow and these rapid changes create frictional heat. The increase in temperature of water molecules heats the rest of the food by conduction and/or convection. It is the distribution of water (and also salt that is a dipole similar to water) within a food that has the major effect on the amount of heating (although differences also occur in the rate of heating as a result of the shape of the food, at its edges etc.). The depth of penetration of both microwaves and radio frequency energy is determined by the dielectric constant and the loss factor of the food. These properties have been recorded for some foods (Table 1). They vary with the moisture content and temperature of the food and the frequency of the electric field. In general, the lower the loss factor (i. e. greater transparency to microwaves) and the lower the frequency, the greater the penetration depth. It is possible to choose a frequency from the permitted bands that will give a suitable electric field strength for a given loss factor. Because most foods have a high moisture content and therefore a high loss factor, they readily absorb microwave and radio frequency energy and flash-over (a near-simultaneous ignition of most of the directly exposed combustible material in an enclosed area) is not a problem. However, care is needed when selecting equipment for drying low moisture foods to prevent the electric field strength from exceeding a level at which flash-over would take place. Radio frequency energy is mostly used to heat or evaporate moisture from a product, whereas higher frequency microwaves are used for defrosting and low pressure drying. MaterialDielectric constant (Fm-1)Loss factorPenetration depth (cm)Banana (raw)62170. 93Beef (raw)51160. 87Bread40. 0051170Brine (5%)67750. 25Butter30. 130. 5Carrot (cooked)71180. 93Cooking oil2. 60. 219. 5Distilled water779. 21. 7Fish (cooked)46. 5121. 1Glass60. 140Ham85670. 3Ice3. 20. 0031162Paper40. 150Polyester tray40. 2195Potato (raw)6216. 70. 93Table 1 Dielectric properties of materials at 20-

25°C and 2450MHzMicrowave equipment consists of a microwave generator (termed a magnetron) (Fig. 3), aluminum tubes named wave guides, and a metal chamber for batch operation, or a tunnel fitted with a conveyor belt for continuous operation. Because microwaves heat all biological tissues, there is a risk of leaking radiation causing injury to operators, particularly to eyes which have insufficient blood flow to provide sufficient cooling. Chambers and tunnels are therefore sealed to prevent the escape of microwaves. The magnetron is a cylindrical diode (‘ di’ meaning two and ‘ electrode’), which consists of a sealed copper tube with a vacuum inside. The tube contains copper plates pointing towards the center like spokes on a wheel. This assembly is termed the " anode" and has a spiral wire filament (the cathode) at the center (Fig. 3). When a high voltage (e. g. 4000 V) is applied, the cathode produces free electrons, which give up their energy to produce rapidly oscillating microwaves, which are then directed to the waveguide by electromagnets. The waveguide reflects the electric field internally and thus transfers it to the heating chamber. It is important that the electric field is evenly distributed inside the heating chamber to enable uniform heating of the food. In batch equipment a rotating antenna or fan is used to distribute the energy, or the food may be rotated on a turntable. Both methods reduce shadowing (areas of food which are not exposed to the microwaves). In continuous tunnels a different design of antennae is used to direct a beam of energy over the food as it passes on a conveyor. It is important that the power output from the magnetron is matched to the size of the heating chamber to prevent flashover. Power outputs of continuous industrial equipment range from 30 to 120 kW. Figure 3The main disadvantages of hot-air drying are: low rates of heat transfer, caused by the low thermal conductivity of dry foodsdamage to sensory characteristics and nutritional properties caused by long drying times and overheating at the surfaceoxidation of pigments and vitamins by hot aircase hardening. Microwaves and radio frequency energy overcome the barrier to heat transfer caused by the low thermal conductivity. This prevents damage to the surface, improves moisture transfer during the later stages of drying and eliminates case hardening. The radiation selectively heats moist areas while leaving dry areas unaffected. It is not necessary to heat large volumes of air, and oxidation by atmospheric oxygen is minimized. However, the higher cost of microwaves and radio frequency units, together with the smaller scale of operation, compared with traditional methods of dehydration, restrict microwave drying to ‘ finishing’ (removing the final moisture) of partly dried or low-moisture foods (Fig. 4). Figure 4For example, in pasta drying the fresh pasta is pre-dried in hot air to 18% moisture and then in a combined hot air and microwave drier to lower the moisture content to 13%. Drying times are reduced from 8 h to 90 min, bacterial counts are 15 times lower, there is a reduction in energy consumption of 20–25%, the drying tunnel is reduced from 36–48m to 8 m, clean-up time is reduced from 24 to 6 person-hours and there is no case hardening. In grain finish drying, microwaves are cheaper, more energy efficient and quieter than conventional methods and do not cause dust pollution. The lower drying temperature also improves grain germination rates. In conventional freeze drying, the low rate of heat transfer to the sublimation front limits the rate of drying. Microwave freeze drying overcomes this problem because heat is supplied directly to the ice front. However, careful control over drying conditions is necessary to prevent localized melting of the ice. Any water produced in the drying food heats rapidly, owing to the higher loss factor, and causes a chain reaction, leading to widespread melting and an end to sublimation.

Freeze drying

The heat used to dry removes water and therefore preserves the food by a reduction in water activity. However, the heat also causes a loss of sensory characteristics and nutritional qualities. In freeze drying a similar preservative effect is achieved by reduction in water activity without heating the food, and as a result nutritional qualities and sensory characteristics are better retained. However, this kind of method is slower than conventional dehydration. Energy costs for refrigeration are high and the production of a high vacuum is an additional expense. This, together with a relatively high capital investment, results in high production costs for freeze-dried. Freeze drying is used to dry expensive foods which have delicate aromas or textures (for example coffee, mushrooms, herbs and spices, fruit juices, meat, sea foods, vegetables and complete meals for military rations or expeditions) for which consumers are willing to pay higher prices for superior quality. In addition, microbial cultures for use in food processing are freeze dried for long-term storage prior to inoculum generation. The main differences between freeze drying and conventional hot air drying are shown in Table 2. Conventional dryingFreeze dryingSuccessful for easily dried foods (vegetables and grains)Meat generally unsatisfactoryTemperature range 37–93ºCAtmospheric pressuresEvaporation of water from surface of foodMovement of solutes and sometimes case hardeningStresses in solid foods cause structural damage and shrinkageSlow, incomplete rehydrationSolid or porous dried particles often having a higher density than the original foodOdor and flavor frequently abnormalColor frequently darkerReduced nutritional valueCosts generally lowSuccessful for most foods but limited to those that are difficult to dry by other methodsSuccessful with cooked and raw meatsTemperatures below freezing pointReduced pressures (27–133 Pa)Sublimation of water from ice frontMinimal solute movementMinimal structural changes or shrinkageRapid complete rehydrationPorous dried particles having a lower density thanoriginal foodOdor and flavor usually normalColor usually normalNutrients largely retainedCosts generally high, up to four times those of conventional dryingTable 2 Differences between conventional drying and freeze dryingThe first stage of freeze drying is to freeze the food in conventional freezing equipment. Small pieces of food are frozen rapidly to produce small ice crystals and to reduce damage to the cell structure of the food. In liquid foods, slow freezing is used to form an ice crystal lattice, which provides channels for the movement of water vapor. The next stage is to remove water during subsequent drying and hence dry the food. If the water vapor pressure of a food is held below 4. 58 Torr (610. 5 Pa) and the water is frozen, when the food is heated the solid ice sublimes directly to vapor without melting (Fig. 5). The water vapor is continuously removed from the food by keeping the pressure in the freeze drier cabinet below the vapor pressure at the surface of the ice, removing vapor with a vacuum pump and condensing it on refrigeration coils. As drying proceeds a sublimation front moves into the frozen food, leaving partly dried food behind it. Figure 5The heat needed to drive the sublimation front (the latent heat of sublimation) is either conducted through the food or produced in the food by microwaves. Water vapor travels out of the food through channels formed by the sublimed ice and is removed. Foods are dried in two stages: first by sublimation to approximately 15% moisture content and then by evaporative drying (desorption) of unfrozen water to 2% moisture content. Desorption is achieved by raising the temperature in the drier to near ambient temperature whilst retaining the low pressure. In some liquid foods (for example fruit juices and concentrated coffee extract), the formation of a glassy vitreous state on freezing causes difficulties in vapor transfer. Therefore the liquid is either frozen as a foam (vacuum puff freeze drying), or the juice is dried together with the pulp. Both methods produce channels through the food for the vapor to escape. In a third method, frozen juice is ground to produce granules, which both dry faster and allow better control over the particle size of the dried food. The rate of drying depends mostly on the resistance of the food to heat transfer and to a lesser extent on the resistances to vapor flow (mass transfer) from the sublimation front. Freeze driers consist of a vacuum chamber which contains trays to hold the food during drying, and heaters to supply latent heat of sublimation. Refrigeration coils are used to condense the vapors directly to ice (i. e. reverse sublimation). They are fitted with automatic defrosting devices to keep the maximum area of coils free of ice for vapor condensation. This is necessary because the major part of the energy input is used in refrigeration of the condensers, and the economics of freeze drying are therefore determined by the efficiency of the condenser: Vacuum pumps remove non condensable vapors. Different types of drier are characterized by the method used to supply heat to the surface of the food. Conduction and radiation types are used commercially (convection heating is not important in the partial vacuum of the freeze drier cabinet) and microwave freeze drying is also now used. Both batch and continuous versions are found for each type of drier. In batch drying, the product is sealed into the drying chamber, the heater temperature is maintained at 100–120°C for initial drying and then gradually reduced over a drying period of 6–8 hours. The precise drying conditions are determined for individual foods, but the surface temperature of the food does not exceed 60°C. In continuous freeze drying, trays of food enter and leave the drier through vacuum locks. A stack of trays, interspersed by heater plates is moved on guide rails through heating zones in a long vacuum chamber. Heater temperatures and product residence times in each zone are pre-programmed for individual foods, and microprocessors are used to monitor and control process time, temperature and pressure in the chamber, and the temperature at the product surface. It’s worth mention few industrial freeze drying processes: Figure 6

Contact (or conduction) freeze driers

Food is placed onto ribbed trays which rest on heater plates (Fig. 6(a)). This type of equipment dries more slowly than other designs because heat is transferred by conduction to only one side of the food. There is uneven contact between the frozen food and the heated surface, which further reduces the rate of heat transfer. There is also a pressure drop through the food which results in differences between the drying rates of the top and bottom layers. The vapor velocity is of the order of 3 ms-1 and fine particles of product may be carried over in the vapor and lost. However, contact freeze driers have higher capacity than other types.

Accelerated freeze driers

In this equipment, food is held between two layers of expanded metal mesh and subjected to a slight pressure on both sides (Fig. 6(b)). Heating is by conduction, but heat is transferred more rapidly into food by the mesh than by solid plates, and vapor escapes more easily from the surface of the food. Both mechanisms cause a reduction in drying times compared with contact methods.

Radiation freeze driers

Infrared radiation from radiant heaters is used to heat shallow layers of food on flat trays (Fig. 6(c)). Heating is more uniform than in conduction types, because surface irregularities on the food have a smaller effect on the rate of heat transfer. There is no pressure drop through the food and constant drying conditions are therefore created. Vapor movement is approximately 1 ms-1 and there is little risk of product carryover. Close contact between the food and heaters is not necessary and flat trays are used, which are cheaper and easier to clean.

Microwave and dielectric freeze driers

Radio frequency heaters have potential use in freeze drying but are not widely used on a commercial scale. They are difficult to control because water has a higher loss factor than ice and any local melting of the ice causes ‘ runaway’ overheating in a chain reaction. A modification of freeze drying is named reversible freeze-dried compression. Food is freeze dried to remove 90% of the moisture and it is then compressed into bars using a pressure of 69 000 kPa. The residual moisture keeps the food elastic during compression, and the food is then vacuum dried. When packaged in inert gas these foods are reported to have a shelf life of five years. They are used in military rations (for example a meal consisting of separate bars of pepperoni, stew, granola dessert and an orange drink). The bars reconstitute rapidly, during which time the compressed food ‘ groans, rumbles, quivers and eventually assumes its normal shape and size’ (Unger, 1982).

Drying by direct heat methods

As said before, drying through direct heating is the method most used in the food industry. In this section we will review the most important machineries involved in this kind of processes, explaining how they operate and trying to give a quantitative comparison about costs, energy consumption and outputs.

Hot air driers

The cost of fuel for heating air is the main economic factor affecting drying operations and commercial driers have a number of features that are designed to reduce heat losses or save energy like: insulation of cabinets and ductingrecirculation of exhaust air through the drying chamber, only if an higher temperature can be tolerated by the product and the reduction in evaporative capacity is acceptablerecovering heat from the exhaust air to heat incoming air using heat exchangers or thermal wheels or pre-warming the feed materialuse of direct flame heating by natural gas and low nitrogen oxide burners to reduce product contamination by the products of combustiondrying in two stages (e. g. fluidized beds followed by bin drying or spray drying followed again by fluidized bed drying)pre-concentrating liquid foods to the highest solids content possible using multiple effect evaporation. Energy use per unit mass of water removed in evaporators can be several orders of magnitude less than that required for dehydrationautomatic control of air humidity by computer control. The criteria for selection of drying equipment and potential applications are described in Table 3. here goes table 3 which is made in excel and then will be exported

Bin driers

Bin driers are large, cylindrical or rectangular containers fitted with a mesh base. Hot air passes up through a bed of food at relatively low velocities (for example 0. 5ms-1 per square meter of bin area). They have a high capacity and low capital and running costs, and are mainly used for " finishing" (to 3–6% moisture content) after initial drying in other types of driers. The deep bed of food permits variations in moisture content to be equalized and acts as a store to smooth out fluctuations in the product flow between drying and packaging operations. The driers may be several meters high and it is therefore important that foods are sufficiently strong to withstand compression and thus retain spaces between the pieces to permit the passage of hot air through the bed. There are basically two types of bin dryers: small scale dryers for vegetables drying in the agricultural industry. This type comes at a fairly low price depending on the capacity. It’s often needed human interaction for the load/unload procedure and the control of the drying parameters. In Table 4 there are the specification of an average small scale bin dryerbig scale dryers used mainly in the production of grain or other cereal. The costs are higher the ones before but, of course, capacity is higher as well as this king kind of machinery can be quite massive (12 - 14 meters). This kind of dryers are also highly automatized both in the control of the drying parameters and in the physical procedures. In Table 4 there are the specification for an average dryer but it’s worth mention that this kind of machinery are often customized by the client so this figures may not be entirely accurate. Small scale bin dryerBig scale bin dryerCost ($)3000 – 700040000 – 150000Power (kW)5-640-120Drying capacity (kgh-1)50-602000-16000Table 4 Comparison between small and big scale bin dryers

Cabinet driers (tray driers)

These consist of an insulated cabinet fitted with shallow mesh or perforated trays, each of which contains a thin (2 – 6 cm deep) layer of food. Hot air is blown at 0. 5 – 5ms-1 through a system of ducts and baffles to promote uniform air distribution over and/or through each tray. Additional heaters may be placed above or alongside the trays to increase the rate of drying. Tray driers are used for small-scale production (1 – 20 tday-1) or for pilot-scale work. They have low capital and maintenance costs and are flexible in operation for different foods. However, they have relatively poor control and produce more variable product quality as food dries more rapidly on trays nearest to the heat source. A low cost, semi-continuous mechanism which overcomes this problem by periodically replacing the lowest tray in the stack has been developed by Intermediate Technology Development Group (Axtell and Bush, 1991 and Axtell and Russell, 2000), this kind of automatic solution it’s also useful to reduce labor costs. Average figures of this machinery are showed in Table 5. Cost ($)2000 – 20000Power (kW)0. 45 – 1. 9Drying capacity (kgh-1)25 – 400Table 5 Costs, energy consumption and drying capacity of cabinet dryers

Tunnel driers

Layers of food are dried on trays, which are stacked on trucks programmed to move semi continuously through an insulated tunnel. Food is finished in bin driers. Typically a 20m tunnel contains 12–15 trucks with a total capacity of 5000 kg of food. This ability to dry large quantities of food in a relatively short time made tunnel drying widely used, especially in the USA. However, the method has now been largely superseded by conveyor drying and fluidized bed drying as a result of their higher energy efficiency, reduced labor costs and better product quality.

Conveyor driers (belt driers)

Continuous conveyor driers are up to 20m long and 3m wide. Food is dried on a mesh belt in beds 5–15 cm deep. The air flow is initially directed upwards through the bed of food and then downwards in later stages to prevent dried food from blowing out of the bed. Two- or three-stage driers (Fig. 15. 4) mix and re-pile the partly dried food into deeper beds (to 15–25 cm and then 250–900 cm in three-stage driers). This improves uniformity of drying and saves floor space. Foods are dried to 10–15% moisture content and then finished in bin driers. This equipment has good control over drying conditions and high production rates. It is used for large scale drying of foods (for example up to 5. 5 t h_1). Driers may have computer controlled independent drying zones and automatic loading and unloading to reduce labour costs. A second application of conveyor driers is foam mat drying in which liquid foods are formed into a stable foam by the addition of a stabiliser (Appendix C) and aeration with nitrogen or air. The foam is spread on a perforated belt to a depth of 2–3mm and dried rapidly in two stages by parallel and then counter-current air flows (Table 15. 3). Foam mat drying is approximately three times faster than drying a similar thickness of liquid. The thin porous mat of dried food is then ground to a free-flowing powder which has good rehydration properties. Rapid drying and low product temperatures result in a high-quality product, but a large surface area is required for high production rates, and capitalcosts are therefore high. A further variation is trough driers (or belt-trough driers) in which small, uniform pieces of food are dried in a mesh conveyor belt which hangs freely between rollers, to form the shape of a trough. Hot air is blown through the bed of food, and the movement of the conveyor mixes and turns the food to bring new surfaces continually into contact with the drying air. The mixing action also moves food away from the drying air, and this allows time for moisture to move from inside the pieces to the dry surfaces. The surface moisture is then rapidly evaporated when the food again contacts the hot air. These driers have high drying rates (for example 55 min for diced vegetables, compared with 5 h in a tunnel drier), high energy efficiencies, good control and minimal heat damage to the product. They operate in two stages, to 50–60% moisture and then to 15–20% moisture before finishing in bin driers.

Fluidized-bed driers

The main features of a fluidised-bed drier are a distributor to evenly distribute the air at a uniform velocity around the bed of material; a plenum chamber below the distributor to produce an homogenous region of air and prevent localised high velocities; and a disengagement or ‘ freeboard’ region above the bed to allow disentrainment of particles thrown up by the air. Air from the fluidised bed is usually fed into cyclones to separate out fine particles, which are then added back to the product or agglomerated (Bahu, 1997). Above the distributor, mesh trays contain a bed of particulate foods up to 15 cm deep. Hot air is blown through the bed, causing the food to become suspended and vigorously agitated (fluidised), exposing the maximum surface area of food for drying (Fig. 15. 5). A sample calculation of the air velocity needed for fluidisation is described in Chapter 1 (Sample problem 1. 6). These driers are compact and have good control over drying conditions and high drying rates. In batch operation, the product is thoroughly mixed by fluidisation and this leads to a uniform moisture content. In continuous operation the trays vibrate to move the food under gravity from one tray to the next. There is a greater range of moisture contents in the dried product, and bin driers are used for finishing. The main applications are for small, particulate foods that are capable of being fluidised without excessive mechanical damage, including yeast, desiccated coconut, grain, herbs, instant coffee, sugar and tea (Bahu, 1997). In a development of the fluidised-bed drier, named the ‘ Torbed’ drier, a fluidised bed of particles is made to rotate around a torus-shaped chamber by hot air blown directly from a burner (Fig. 15. 6). The drier has very high rates of heat and mass transfer and substantially reduced drying times. Larger pieces require a period of moisture equilibration before final drying. The drier has microprocessor control and is suitable for agglomeration and puff drying in addition to roasting, cooking and coating applications. Another development of the fluidised bed principle is the Spin-flash drier in which a drying chamber is fitted with a rotor at the base. Hot air enters tangentially and this, together with the action of the rotor, causes a turbulent rotating flow of air up through the chamber. Food pieces, such as crab meat paste, cocoa cake or gums, enter the chamber and become coated in dry powder. The lumps fall to the base where they are fluidised by the air and rotated by the rotor. As they dry the lumps break up and release powder, which is carried up the wall of the chamber and removed through a classification orifice that is changeable for different product particle size ranges. In the centrifugal fluidised-bed drier particulate food is filled into a drying chamber which rotates at high speed. Hot air is forced through the bed of food at a velocity that is high enough to overcome the centrifugal force and fluidise theparticles. This higher air velocity increases the rate of drying (Cohen and Yang, 1995). Further details of the different types of fluidised-bed driers are given by Bahu (1997).

Kiln driers

These are two-storey buildings in which a drying room with a slatted floor is located above a furnace. Hot air and the products of combustion from the furnace pass through a bed of food up to 20 cm deep. They have been used traditionally for drying apple rings in the USA and hops in Europe, but there is limited control over drying conditions and drying times are relatively long.

High labour costs are also incurred by the need to turn the product regularly, and by manual loading and unloading. However the driers have a large capacity and are easily constructed and maintained at low cost.

Pneumatic driers

In these driers, moist powders or particulate foods, usually less than 40% moisture and particle size ranges of 10–500 _m, are metered into metal ducting and suspended in hot air. In vertical driers the air-flow is adjusted so that lighter and smaller particles, which dry more rapidly, are carried to a cyclone separator more rapidly than are heavier and wetter particles, which remain suspended to receive the additional drying required. For products that require longer residence times, the ducting is formed into a continuous loop (pneumatic ring driers) and the product is recirculated until it is adequately dried. High temperature short-time ring driers (or flash driers) are used to expand the starch in potatoes or carrots to give a rigid, porous structure, which improves both subsequent conventional drying and rehydration rates. Drying takes place within 2–10 s and these driers are therefore suitable for foods that lose moisture rapidly from the surface. Evaporative cooling of the particles prevents heat damage to give high quality products. Pneumatic driers have relatively low capital and maintenance costs, high drying rates and close control over drying conditions, which make them suitable for heat sensitive foods. Outputs range from 10 kg h_1 to 25 t h_1 (Barr and Baker, 1997). They are oftenused after spray drying to produce foods which have a lower moisture content than normal (for example special milk or egg powders and potato granules). In some applications the simultaneous transportation and drying of the food may be a useful method of materials handling (Chapter 26).

Rotary driers

A slightly inclined (up to 5º) rotating metal cylinder is fitted internally with flights to cause the food to cascade through a stream of parallel or counter-current (Table 15. 3) hot air as it moves through the drier. The large surface area of food exposed to the air produces high drying rates and a uniformly dried product. The method is especially suitable for foods that tend to mat or stick together in belt or tray driers. However, the damage caused by impact and abrasion in the drier restricts this method to relatively few foods (for example nuts and cocoa beans). To overcome this problem, a variation of the design, named a Rotary louvre drier, in which longitudinal louvres are positioned to form an inner drum, has been introduced. The food particles form a partially fluidised rolling bed on the base of this drum and hot air passes through the louvres and the food (Barr and Baker, 1997).

Spray driers

A fine dispersion of pre-concentrated food (40–60% moisture) is first ‘ atomised’ to form fine droplets and then sprayed into a co- or counter-current flow of heated air (Table 15. 3) at 150–300ºC in a large drying chamber. One of the following types of atomiser is used: Centrifugal atomiser. Liquid is fed to the centre of a rotating disc or bowl having a peripheral velocity of 90–200ms_1. Droplets, 50–60 _m in diameter, are flung from the edge to form a uniform spray. Pressure nozzle atomiser. Liquid is forced at a high pressure (700–2000_103 Pa) through a small aperture to form droplet sizes of 180–250 _m. Grooves on the inside of the nozzle cause the spray to form into a cone shape and therefore to use the full volume of the drying chamber. Two-fluid nozzle atomiser. Compressed air creates turbulence which atomises the liquid. The operating pressure is lower than the pressure nozzle, but a wider range of droplet sizes is produced. Ultrasonic nozzle atomiser. A two-stage atomiser in which liquid is first atomised by a nozzle atomiser and then using ultrasonic energy to induce further cavitation. Nozzle atomisers are susceptible to blockage by particulate foods, and abrasive foods gradually widen the apertures and increase the average droplet size. Studies of droplet drying, including methods for calculating changes in size, density and trajectory of the droplets are described by Charm (1978), Kerkhof and Schoeber (1974) and Masters (1972). Rapid drying (1–10 s) takes place because of the very large surface area of the droplets. The feed rate is controlled to produce an outlet air temperature of 90–100ºC, which corresponds to a wet-bulb temperature (and product temperature) of 40–50ºC to produce little heat damage to the food. The dry powder is collected at the base of the drier and removed by a screw conveyor or a pneumatic system with a cyclone separator. There are a large number of designs of atomiser, drying chamber, air heating and powder collecting systems which arise from the different requirements of the very large variety offood materials that are spray dried (for example milk, egg, coffee, cocoa, tea, potato, ice cream mix, butter, cream, yoghurt and cheese powder, coffee whitener, fruit juices, meat and yeast extracts, encapsulated flavours (Heath, 1985) and wheat and corn starch products). Detailed designs are described by Masters (1972), Masters (1997) andKjaergaard (1974). Spray driers may also be fitted with fluidised bed facilities to finish powders taken from the drying chamber. Spray driers vary in size from small pilot-scale models for low-volume high-value products such as enzymes and flavours, to large commercial models capable of producing 10 000 kg of dried milk per hour (Byrne, 1986). The main advantages are rapid drying, large-scale continuous production, low labour costs and relatively simple operation and maintenance. The major limitations are high capital costs and the requirement for a relatively high-feed moisture content to ensure that the food can be pumped to the atomiser. This results in higher energy costs (to remove the moisture) and higher volatile losses. Conveyor-band driers and fluidised-bed driers are beginning to replace spray driers as they are more compact and energy efficient (Ashworth, 1981). Development work with ultrasonic drying has indicated a potential alternative to spray drying. Small droplets are first produced in a liquid by ultrasound (Chapter 4) and then heated to remove the water. Drying takes place very rapidly (sometimes within seconds) and the dried residue is collected. The process works well with low-fat solutions, but less well with oily or fatty foods, which do not dry easily (Cohen and Yang, 1995).

Sun and solar drying

Sun drying (without drying equipment) is the most widely practised agricultural processing operation in the world; more than 250 000 000 t of fruits and grains are dried by solar energy per annum. In some countries, foods are simply laid out in fields or on roofs or other flat surfaces and turned regularly until dry. More sophisticated methods(solar drying) collect solar energy and heat air, which in turn is used for drying. Solar driers are classified into: direct natural-circulation driers (a combined collector and drying chamber)direct driers with a separate collectorindirect forced-convection driers (separate collector and drying chamber). Both solar and sun drying are simple inexpensive technologies, in terms of both capital input and operating costs. Energy inputs and skilled labour are not required and in sun drying, very large amounts of crop can be dried at low cost. The major disadvantages are relatively poor control over drying conditions and lower drying rates than those found inartificial driers, which results in products that have lower quality and greater variability. In addition, drying is dependent on the weather and the time of day and requires a larger labour force than other methods. There are a large number of different designs of solar driers, described in detail by Brenndorfer et al. (1985) and Imrie (1997). Small solar driers have been investigated at research institutions, particularly in developing countries, for many years but their often low capacity (Table 15. 2) and insignificant improvement to drying rates and product quality, compared to hygienic sun drying, have restricted their commercial use to only three or four applications worldwide. Larger solar driers with photo-voltaic powered fans and having a capacity of 200–400 kg/batch, have been developed by Hohenheim University to a commercial scale of operation. Several hundred driers are now in use in Mediterranean countries to dry fruit to export standards for European markets (Axtell and Russell, 2000). Potential developments using solar energyare likely to include their use in pre-heating air to gain reductions in energy consumption in fuel-fired driers.