Correct handling of foods, ingredients and packaging materials from suppliers, through the production process, and during distribution to the consumer is essential to optimise product quality and to minimise costs. Improvements in materials handling have led to substantial increases in production efficiencies, and are used at all stages in a manufacturing process, including:

- harvest and transportation to raw material stores
- preparation procedures (Chapter 3) and movement of food within the factory or through a process
- collection and disposal of process wastes
- packaging, collation of packaged foods and movement to finished product warehouses
- distribution to wholesalers and retailers
- presentation of products for sale.

Until recently, materials handling has received relatively little attention, compared with optimisation of process design, packaging developments, marketing, etc., but advances in computer software which optimise the use of warehouse space and vehicle loads, together with developments in bulk handling systems and increasing energy costs, have led to substantial improvements to the efficiency of handling during the last decade. Other examples in which computer programs are used to optimise purchasing and processing choices to reduce costs are described in Chapter 2.

Waste materials are produced by most food processing operations and their handling and disposal are a significantly increasing cost to manufacturers. Legislative requirements for control of food quality, especially for ‘high risk’ foods, have also increased the costs of storage and distribution. At each production stage, it is therefore necessary to optimise the methods used to handle both foods and wastes to reduce costs. In this chapter, an outline of handling methods that are used to handle solid and liquid materials is given, together with recent advances in storage and distribution of foods, and waste management and disposal.
26.1 Materials handling

Efficient materials handling is ‘the organised movement of materials in the correct quantities, to and from the correct place, accomplished with a minimum of time, labour, wastage and expenditure, and with maximum safety’. Some advantages of correct materials handling are summarised in Table 26.1.

The important techniques identified in Table 26.1 are:

- a systems approach to planning a handling scheme
- the use of unit loads and bulk handling
- continuous methods of handling
- automation (described in Chapter 2).

When establishing methods for materials handling, a systems approach that covers raw materials and ingredients, in-process stock and distribution of finished products to consumers is needed. This creates optimum flows of materials, in the correct sequence throughout the production process, and avoids bottlenecks or shortages. This area is known as production planning and detailed descriptions are beyond the scope of this book. Further details are given by Eilon (1970), Magee and Boodman (1967), Tersine (1994) and Shafer and Meredith (1998). In summary, correct production planning should ensure that:

- raw materials, ingredients and packaging materials are scheduled to arrive at the factory at the correct time, in the correct quantities and in the required condition
- storage facilities are sufficient for the anticipated stocks of materials and are suitable to maintain the quality of materials for the required time
- handling equipment has sufficient capacity to move materials in the required amounts
- staff levels are adequate to handle the required amounts of materials
- processing and packaging equipment is selected to provide the required production throughput

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Methods of achieving efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Savings in storage and operating space</td>
<td>Only move materials when necessary and minimise all movements by placing related activities close together</td>
</tr>
<tr>
<td>Better stock control</td>
<td>Handle materials in bulk</td>
</tr>
<tr>
<td>Improved working conditions</td>
<td>Package or group materials for easier handling</td>
</tr>
<tr>
<td>Improved product quality</td>
<td>Use continuous handling techniques and minimise manual handling</td>
</tr>
<tr>
<td>Lower risk of accidents</td>
<td>Automate where possible</td>
</tr>
<tr>
<td>Reduced processing time</td>
<td>Combine operations to eliminate handling between them</td>
</tr>
<tr>
<td>Lower costs of production</td>
<td>Use a systems approach to optimise material flows and make paths as direct as possible</td>
</tr>
<tr>
<td>Less wastage of materials and operator time</td>
<td>Use all layers of a building’s height</td>
</tr>
<tr>
<td></td>
<td>Use handling equipment that can be adapted to different applications</td>
</tr>
<tr>
<td></td>
<td>Use gravity wherever possible</td>
</tr>
</tbody>
</table>
• finished product warehousing is sufficient to accommodate stock levels, taking into account both production and sales volumes
• distribution vehicles are sufficient in number and capacity, and journeys are scheduled to optimise fuel consumption and drivers’ time, particularly minimising journeys with empty vehicles.

Aspects of production planning that relate to materials handling are discussed in more detail below and storage facilities, finished product warehousing and distribution are described in Section 26.3. Important questions to be asked when designing a materials handling system are listed by Farrall (1979) for different areas of a food factory and detailed information on materials handling is given by Ingram (1979) and Brennan et al. (1990). Sidebottom (1985) describes advances in the control of materials handling in processing and warehousing.

26.1.1 Handling equipment for raw materials and ingredients
The bulk movement of particulate, powdered and liquid food ingredients by road or rail tanker, and storage in large silos, has been common practice in large plants for many years. More recent advances in microelectronics are now applied to monitoring and control of storage silos (fill-level, humidity and temperature) and multi-ingredient batch weighing and metering systems, using PLC based logic controllers (Chapter 2). Additionally, within the last few years increasing use has been made of large (1 tonne or more) intermediate bulk containers (IBCs) for movement of foods. Examples include ‘Combi’ bins and woven polypropylene bags which are used to both ship ingredients and to move food within a production line. Large bulk packaging made from eight-layer corrugated outer card and an inner food grade membrane are increasingly replacing metal drums as shipping containers (details are given in Chapter 24).

Mechanised handling systems for fresh crops and other raw materials for processing have developed from, for example, the pea viners and combine harvesters that have been in common use for several decades. Mobile crop washing, destoning and grading equipment, gentle-flow box tippers that transport and unload crops with minimal damage, and automatic cascade fillers for large boxes and ‘jumbo’ bags are now routinely used to produce washed and graded crops for processors and retailers. Further details of raw material preparation are given in Chapter 3.

Batch weighing and metering systems are an integral part of ingredient or raw materials handling and there are a number of different systems: for example, sensors can be used to detect the loss in weight from a storage tank or silo as it is emptied and calculate the weight of ingredient used. Alternatively sensors on a mixing vessel can detect the increase in weight as different ingredients are added. The information from sensors is used by PLCs to control pumps, create pre-programmed recipe formulations and record data for production costing and stock control. Further details are given in Chapters 2 and 25.

26.1.2 Handling equipment for processing
The pattern of movement of materials during processing should be as simple as possible to avoid the risk of contamination of processed foods by raw foods and to attain the other benefits described in Table 26.1. Cross-contamination is a major concern for all food processors, but especially for those that produce ‘high-risk’ foods. Further details of
special procedures for these foods are described in Chapters 19 and 20. There is no single ‘model’ layout for plant and equipment, but five patterns are commonly used:

1. straight line – for relatively simple processes containing few pieces of equipment
2. serpentine (or ‘zig-zag’) – where the production line is increased for a given floor area by ‘bending back’ on itself
3. U-shaped – used when a process is required to place the finished product in the same general area as the starting point
4. circular – used when a part-processed or finished product is required in exactly the same place where it started
5. odd-angle – where there is no recognisable pattern, but where short flow lines are needed between a group of related operations, where handling is mechanised or where space limitations will not permit another layout.

Examples of factory layouts that are correctly and incorrectly designed for materials handling are shown in Figs 26.1(a) and (b).

It is important that all equipment which is used to handle foods is designed to be easily cleaned, to reduce the risk of product contamination. Hygienic design of equipment is described by Holm (1980) and Romney (1988). The principles of sanitary equipment design are incorporated into good practice guides (for example Anon., 1967). These can be summarised as follows:

- equipment surfaces that are in contact with food should be inert to the food being processed and must not migrate to, or be absorbed by, the food
- surfaces should be smooth and non-porous to prevent accumulations of food and bacteria
- surfaces should either be accessible for cleaning and inspection, or able to be easily disassembled for manual cleaning and inspection. If cleaned without disassembly, it should be demonstrated that results are similar to manual cleaning

![Fig. 26.1](image)

**Fig. 26.1** Examples of factory layouts for materials handling: (a) correctly designed and (b) incorrectly designed: 1, cleaning; 2, peeling and preparation; 3, inspection; 4, packaging; 5, freezing; 6, cold store; 7, office; 8, overflow cold store; 9, raw material cold store. Note the following faults in design (a): A, raw material, partly processed product and finished product in same cold store; B, adjacent inspection of prepared food and washing of raw material; C, confused and excessive materials handling.
• equipment should be self-draining and have a minimum number of internal crevices or ‘dead spaces’ where food or micro-organisms could collect
• equipment should protect food from external contamination.

Continuous handling equipment is an essential component of continuous processes and it also improves the efficiency of batch processing. The most important types of materials handling equipment used in food processing are

• conveyors and elevators
• pumps.

Other types of equipment, including chutes, cranes and trucks are described by Brennan et al. (1990) and are summarised in Table 26.2.

**Conveyors and elevators**
Conveyors are widely used in all food processing industries for the movement of solid materials, both within unit operations, between operations and for inspection of foods

<table>
<thead>
<tr>
<th>Table 26.2 Applications of materials-handling equipment</th>
</tr>
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<tbody>
<tr>
<td>Direction</td>
</tr>
<tr>
<td>Vertical up</td>
</tr>
<tr>
<td>Vertical down</td>
</tr>
<tr>
<td>Incline up</td>
</tr>
<tr>
<td>Incline down</td>
</tr>
<tr>
<td>Horizontal</td>
</tr>
<tr>
<td>Direction</td>
</tr>
<tr>
<td>Vertical up</td>
</tr>
<tr>
<td>Vertical down</td>
</tr>
<tr>
<td>Frequency</td>
</tr>
<tr>
<td>Location served</td>
</tr>
<tr>
<td>Point</td>
</tr>
<tr>
<td>Path</td>
</tr>
<tr>
<td>Limited area</td>
</tr>
<tr>
<td>Unlimited area</td>
</tr>
<tr>
<td>Height</td>
</tr>
<tr>
<td>Overhead</td>
</tr>
<tr>
<td>Working height</td>
</tr>
<tr>
<td>Floor level</td>
</tr>
<tr>
<td>Underfloor</td>
</tr>
<tr>
<td>Materials</td>
</tr>
<tr>
<td>Packed</td>
</tr>
<tr>
<td>Bulk</td>
</tr>
<tr>
<td>Solid</td>
</tr>
<tr>
<td>Liquid</td>
</tr>
<tr>
<td>Service</td>
</tr>
<tr>
<td>Permanent</td>
</tr>
<tr>
<td>Temporary</td>
</tr>
</tbody>
</table>

From Brennan et al. (1990).
There are a large number of conveyor designs, produced to meet specific applications, but all types can only cover a fixed path of operation. Their operation, and the development of ‘intelligent’ conveyors, is reviewed by Perera and Rahman (1997). Common types include belt conveyors – an endless belt which is held under tension between two rollers, one of which is driven. The belts may be stainless steel mesh or wire, synthetic rubber, or a composite material made of canvass, steel and polyurethane or polyester. They are described in detail by Brown (1983). Flat belts are used to carry packed foods, and trough-shaped belts are used for loose materials. Flat belts may be inclined up to 45°, if they are fitted with cross slats or raised chevrons to prevent the product from slipping.

Roller conveyors and skate wheel conveyors are usually unpowered, but roller conveyors may also be powered. The rollers or wheels are either horizontal, to allow packed foods to be pushed along, or slightly inclined (e.g. a fall of 10 cm in a length of 3 m) to allow packs to roll under gravity. Rollers are stronger than wheels and therefore able to carry heavier loads, but their greater inertia means that they are more difficult to start and stop, and they are more difficult to use around corners. Additionally, the build up of materials on the rollers and bearings causes increased friction, which increases power consumption and maintenance costs. ‘Air-cushioned’ conveyors overcome these problems by carrying materials on a film of air blown into tubular trough sections by a small fan.

Chain conveyors are used to move churns, barrels, crates and similar bulk containers by placing them directly over a driven chain, which has protruding lugs at floor level. Monorail conveyors are used for moving meat carcasses or boxed poultry carcasses on an overhead track. Screw conveyors comprise a rotating helical screw inside a metal trough. They are used to move bulk foods such as flour and sugar, or small-particulate foods including peas and grain. The main advantages are the uniform, easily controlled flow rate, the compact cross-section without a return conveyor and total enclosure to prevent contamination. They may be horizontal or inclined, but are generally limited to a maximum length of 6 m as above this, high friction forces result in excessive power consumption. Vibratory conveyors cause a small vertical movement to food to raise it a few millimetres off the conveyor, and forward movement to transport it along the conveyor (Fig. 26.2). The amplitude of vibration is adjusted to control the speed and direction of movement and this precise control makes vibratory conveyors useful as feed mechanisms for processing equipment.

Pneumatic conveyors consist of a system of pipes through which powders or small-particulate foods, such as salt, flour, peas, sugar, milk powder, coffee beans, etc., are suspended in recirculated air and transported at up to 20–35 m s⁻¹. The air velocity is...
Fig. 26.3 Different types of pneumatic conveying.
(Courtesy of NEU Ltd.)
**Dilute or Lean Phase - Vacuum**

Suction created so that pipeline operates below atmospheric pressure. Product cannot escape into environment. Dust-free product introduction. Pick up from single or multi-source simplified.

**Dilute or Lean Phase - Pressure**

Material carried by aerodynamic force with comparatively high air velocities (30-35 m/s), but low pressures (max. opposite 1 bar). Simplest, most economical blowing system. Ideal for conveying free flowing product from source to one or especially more than one destination.

**Discontinuous Dense Phase**

Product is conveyed in an in-atmosphere mode of pressures usually in the region of 2-6 bar. Velocities are in the range of 15-20 m/s and high product throughput is achieved. Material feed is normally on a batch basis from a storage vessel or a bulk storage arrangement. Low pressure too results in minimum power consumption and air requirement, leading to smaller pipes and receiving equipment. Ideal for cohesive, dusty, dense or granular products, but other bulk properties can also be handled.

**Neuphase or Continuous Dense Phase**

Product is transferred very slowly at a fraction of the speed of other systems. Velocities are restricted to 4-8 m/s along the whole route. Very high product flow rates (kg/h) in excess of 180 t can be obtained, resulting in low air consumption. Ideal means of conveying fragile or abrasive products. Twin biowheels are the traditional method of product introduction, but the Neu HDF Rotary Valve is a highly efficient alternative. Advantages include continuous operation, compact size and product conservation.

**Conveying Velocity**

Minimum conveying velocity means minimum product damage and system wear, especially important with fragile or abrasive products. Achieved by selecting correct velocity and most applicable conveying technique for each product.

**Stepped Pipelines**

Applicable to all systems. As the pressure along a constant diameter conveying pipe gradually decreases as the velocity increases. To maintain a velocity within ±10% of design, the pipeline is progressively expanded in steps, reducing pipeline wear, product damage and energy consumption.
critical; if it is too low, the solids settle out and block the pipe, whereas if it is too high, there is a risk of abrasion damage to the internal pipe surfaces. The calculation of air velocity needed to suspend foods is described in Chapter 1. Different types of pneumatic conveying are described in Fig. 26.3, together with various methods of introducing materials into the pneumatic conveyor and removing them after conveying. Similar equipment is used to classify foods (Chapter 3), and when heated air is used, to dry foods (Chapter 15). Generation of static electricity by movement of foods is a potential problem that could result in a dust explosion when conveying powders, and is prevented by earthing the equipment, venting, or explosion containment and suppression techniques. Pneumatic conveyors cannot be overloaded, have few moving parts, low maintenance costs and require only a vacuum pump or a supply of compressed air at around \(700 \times 10^3\) Pa. Details of new developments in conveying are given by Sharp (1998).

Conveying foods in water using shallow inclined troughs (or flumes) and pipes finds application for the simultaneous washing and transporting of small particulate foods, such as peas, sweetcorn, etc. The main advantage is reduced power consumption as water flows under gravity, especially at factory sites located on hillsides. Water is recirculated to reduce costs and is filtered and chlorinated to prevent a build up of micro-organisms.

There are many designs of elevator, but two common types are bucket and magnetic elevators: bucket elevators consist of metal or plastic buckets fixed between two endless chains. They have a high capacity for moving free-flowing powders and particulate foods. The shape and spacing of the buckets and the speed of the conveyor (15–100 m min\(^{-1}\)) control the flow rate of materials. Magnetic elevators are used for conveying cans within canneries (Chapter 12). They have a positive action to hold the cans in place, and are thus able to invert empty cans for washing, and they produce minimal noise.

In general, conveyors and elevators are best suited to high-volume movement, where the direction of flow of materials is fixed and relatively constant. They can also be used as a reservoir of work-in-progress.

### Pumps and valves

Pumps, valves and associated pipework are the usual method of handling liquid foods, cleaning fluids, etc., and there is a very wide range of designs that are available, often for specific applications. Centrifugal pumps are widely used in food processing and the selection of a particular pump is based on the following requirements:

- type of product, particularly its viscosity
- product flowrate, pressure and temperature
- type of impeller
- motor size (determined by the required flowrate and impeller diameter) and speed
- type of seal on motor shaft and pump body
- type of pipework couplings and other fittings (e.g. motor shroud, number of legs, lifting handle and mounting brackets).

In some applications, high pressure piston pumps, positive displacement pumps, vacuum pumps, or rotary pumps for gentle product handling or special hygiene conditions may be required. Further details are given by Hogholt (1998).

There are a large number of different types of valves that are used in food processing pipelines, each of which is suitable for easy cleaning-in-place (CIP) to prevent contamination of the product and can be operated either manually or, more commonly, automatically using compressed air and/or electricity.
• **Butterfly valves** contain a pivoting disc that can be closed against a food grade seal. They are suitable for pressures up to 1 MPa.

• **Single and double seat valves** contain a stainless steel ball that is moved into a corresponding seat using an actuator. They are suitable for process pressures of up to 0.5 MPa. The double seat type enables two fluid streams to pass through the valve without mixing and thus finds application in CIP (Fig. 26.4).

• **Diaphragm valves** consist of an elastomer membrane or stainless steel bellows that prevent the product from having contact with the valve shaft. They are used for sterile applications up to product pressures of 0.4 MPa.

**Fig. 26.4** Double seat type valve in an application for cleaning in place (CIP).

(Courtesy of APV Fluid Handling Ltd.)
Other types of valve include:

- **safety valves** to prevent excess pressure in pressure vessels
- **vacuum valves** to protect vessels or tanks from collapse under unwanted vacuums
- **modulating valves** to permit the exact control of product throughputs
- **non-return (or 'check') valves**, and **sampling valves** to allow bacteriologically safe samples to be taken from a production line without the risk of contaminating the product.

All valves can be fitted with proximity switches to detect and transmit their position, and pneumatic or electro-pneumatic actuators to position the valve accurately. Further details of the use of valves in process control are given in Chapter 2.

### 26.2 Waste management and disposal

With the exception of a few processes (for example baking or grain milling), solid wastes and liquid effluents are produced in large quantities by food processing (Table 26.3). They arise due to cleaning and preparation of raw materials (Chapter 3), spillages and cleaning of equipment and floors, and change-overs to different products.

Adequate cleaning routines in food plants are part of good manufacturing practice (GMP) (Anon., 1998a) and form an integral part of management systems needed to implement quality assurance and HACCP programmes (Chapter 1). Software to assist managers to devise adequate cleaning schedules to meet HACCP requirements is described by Dillon and Griffith (1999). Detailed information on plant cleaning is also available in a number of texts including Quartly-Watson (1998), Marriott (1989), Tamplin (1980), Guthrie (1988) and Dillon and Griffith (1999).

The nature of wastes varies according to the type of food being processed: fruit and vegetable processing, for example, produces effluents that have high concentrations of sugars, starch and solid matter such as peelings, whereas meat and dairy processing effluents contain a higher proportion of fats and proteins. Nearly all processors also produce dilute waste water from washing equipment, and solid wastes from discarded packaging materials, office paper, etc. Sources of production of effluents and their

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Volume (litres per unit)</th>
<th>BOD (mg/l)</th>
<th>Suspended solids (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fruit products</td>
<td>90–450</td>
<td>1 000–5 000</td>
<td>100–2 000</td>
</tr>
<tr>
<td>Meat packing</td>
<td>9 000–36 300</td>
<td>600–1 600</td>
<td>400–720</td>
</tr>
<tr>
<td>Milk processing</td>
<td>12–23</td>
<td>20–650</td>
<td>30–360</td>
</tr>
<tr>
<td>Mushrooms</td>
<td>30 000</td>
<td>80–850</td>
<td>50–240</td>
</tr>
<tr>
<td>Potato chips</td>
<td>18 000</td>
<td>730–1 800</td>
<td>800–2 000</td>
</tr>
<tr>
<td>Poultry packing</td>
<td>6.8</td>
<td>725–1 150</td>
<td>770–1 750</td>
</tr>
<tr>
<td>Sauerkraut</td>
<td>14–80</td>
<td>1 400–6 300</td>
<td>60–630</td>
</tr>
<tr>
<td>Vegetable products</td>
<td>90–1 260</td>
<td>500–11 000</td>
<td>30–4 000</td>
</tr>
</tbody>
</table>

1 Per case of product (data from apples, apricots, citrus, pumpkin and tomatoes).
2 Per ton of product.
3 Per litre of milk.
4 Per chicken.
5 Per case of product (data from beans, carrots, corn, peas, peppers, spinach).

Data adapted from Guthrie (1988), Potter (1986) and Dalzell (1994).
treatment methods are described by Tebbutt (1992) and Brennan et al. (1990). Wheatley (1994) describes the composition of typical food industry wastes and methods that can be used to minimise waste production. Anon. (1996) describe methods for auditing wastes and reducing their costs.

In large processing plants or those located in unpopulated areas, effluent treatment can be carried out on-site in purpose-built facilities, but the effluent from most food factories is treated by municipal authorities or private water utilities. The cost of effluent treatment is based on a combination of the volume of effluent and its polluting potential, as measured by both chemical oxidation demand (COD) and the amount of suspended solids (in mg l\(^{-1}\)). High concentrations of sugars, starches and oils have very high polluting potential (CODs from 500–4000 mg l\(^{-1}\) compared to domestic sewage at 200–500 mg l\(^{-1}\)) because as micro-organisms utilise these materials, they remove dissolved oxygen from water, which may kill fish and aquatic plants. Charges are therefore considerably higher for treatment of these effluents. The cost of effluent treatment in the UK is calculated using the Mogden formula (Anon., 1998b):

\[
C = R + (V \text{ or } VB \text{ or } VM \text{ or } M) + B(O_t/O_s) + S(S_t/S_s)
\]

where \(C\) = total charge per m\(^3\) of trade effluent, \(R\) = reception and transport charge per m\(^3\), \(V\) = volumetric and primary treatment charge per m\(^3\) in effluent treatment works that do not have biological treatment, \(VB\) = volumetric and primary treatment charge per m\(^3\) in effluent treatment works that have biological treatment, \(VM\) = treatment and disposal charge per m\(^3\) at non-designated sea outfalls, \(M\) = treatment and disposal charge per m\(^3\) at designated sea outfalls, \(O_t = \text{COD (mg l}^{-1}\text{)}\) of trade effluent after 1 h settlement, \(B = \text{biological oxidation charge per m}^3\text{ of settled sewage, } S_t = \text{total suspended solids (mg l}^{-1}\text{), } S_s = \text{mean suspended solids at treatment works (currently 395 mg l}^{-1}\text{) (Anon., 1998b).}

This formula is important for calculating the cost of effluent treatment as, together with water purchase, this is steadily increasing and now comprises a major cost to food businesses. In many processes it is possible to reduce treatment costs by separating concentrated waste streams from more dilute ones (for example, washings from boiling pans in confectionery or jam production can be isolated from general factory washwater). Effluents that contain a relatively high percentage of sugars, starch or pectic materials have been used in some instances as growth media for yeasts or moulds (Fellows and Worgan, 1987a and 1987b) to produce saleable animal feeds and thus reduce the costs of treatment (Forage, 1978; Hang, 1980 and Jarl, 1969). Other means of reducing both polluting potential and waste treatment charges include:

- recycling water
- recovering fats and oils by aeration flotation for sale as by-products
- storing concentrated effluents and blending them over a period of time with dilute wastes to produce a consistent moderately dilute effluent
- removing solids using screens and discharging them as solid waste to commercial waste disposal companies or for composting

1. COD is a measure of chemical oxidation using boiling potassium dichromate and concentrated sulphuric acid. BOD (biological oxidation demand) is a measure of the oxygen requirement by microorganisms when breaking down organic matter, but is no longer used to calculate effluent treatment charges.
floculating suspended solids using a chemical coagulant (for example lime or ferrous sulphate) or removing suspended solids directly by sedimentation, filtration or centrifugation (Chapter 6) and disposing of them as solid waste

• treating effluents using a biological method such as a trickling filter, activated sludge processes, lagoons, pond, oxidation ditches, spray irrigation or anaerobic digesters

• fermenting waste materials to produce more valuable products (e.g. organic acids, vitamins, etc.).

Descriptions of the methods used to treat effluents and details of the advantages and limitations of these treatment methods are given by Tebbutt (1992) and Brennan et al. (1990).

Solid wastes, packaging and office waste materials are collected in some countries by municipal authorities and in others by private waste management and recycling companies. They are usually disposed of in landfill sites, but increasing shortages of suitable sites and steadily increasing costs of collection have stimulated incentives and opportunities for recycling and re-use, especially for paper, metals and some types of plastics. These developments are described in Chapter 24.

### 26.3 Storage

Storage of raw materials, ingredients and products can take place under ambient conditions or under controlled conditions of temperature, humidity or atmospheric composition. Storage of chilled and frozen foods is described in Chapters 19 and 21 respectively and controlled or modified atmosphere storage is described in Chapter 20. Storage of packaging materials is discussed in Chapter 24. In this section, storage under ambient conditions is described for a range of representative foods.

In general, manufacturers reduce the amount of stored ingredients and products to a minimum for the following reasons:

• financial – money is tied up in materials that have been paid for, or in final products that have incurred the costs of production. Large amounts of stored materials may adversely affect the cashflow of a company.

• loss of quality – chemical or biochemical changes to foods and deterioration of some types of packaging materials may occur during storage which reduce their quality and value, or render them unusable.

• risk of pilferage for some high value products

• high cost of warehousing and storage space.

However, because of the seasonality of supply for some raw materials and, for some products a seasonal demand, it is necessary for processors to maintain stocks of ingredients, packaging materials and final products. The ‘just-in-time’ methodologies of materials supply that are found in some other industries (Johnson et al., 1997) are less common in the food processing sector. Stored goods (or inventory) may be classified into raw materials, work-in-progress and finished goods. However, they can be categorised more usefully by their role in the production system (Johnson et al., 1997) as follows:

• buffer (or safety) inventory, to compensate for uncertainties in supply or demand

• cycle inventory – this occurs because a processor chooses to produce in batches that are greater than the immediate demand
• anticipation inventory – this is created where seasonal demand or supply fluctuations are significant but predictable. It is used especially for supply of seasonal fruits and vegetables, or for products that have a specific seasonal demand (for example Easter eggs and Christmas cakes)
• pipeline (or in-transit) inventory, for materials that are in the process of being moved from a point of supply to a point of demand.

Decisions on the size of stocks of different materials that are held in storage depend on the balance between two sets of costs: the cost of buying and the cost of storage. For example one strategy is to hold a small stock and only buy materials as they are needed. This has little effect on the cashflow of a business but may be more expensive in having to make frequent orders and not obtaining discounts from bulk purchases. Conversely, ordering large amounts of materials infrequently may benefit a company by achieving a discounted price and reduced administration, but incurs higher storage costs. One way of controlling inventory costs is to rank individual materials by their usage value (their rate of usage multiplied by their individual value) into three classes (Johnson et al., 1997):

1. Class A – the 20% of high value materials that account for 80% of the total usage value
2. Class B – the next 30% of medium value materials which account for 10% of the usage value
3. Class C – the lowest value materials that are stocked, comprising 50% of the total, which account for 10% of the usage value.

Class A products are then given inventory preference over Class B and in turn over Class C.

The physical conditions of storage are an important aspect that may be given less attention than other areas of processing and as a result, causes problems of contamination and financial losses. It is important that there is a similar level of control over hygiene and storage conditions in warehouses and distribution vehicles to that given to processing operations. The main causes of spoilage of stored foods and ingredients are as follows:

• contamination by rodents, birds, insects and micro-organisms
• contamination by dust or foreign bodies
• respiratory activity of fresh foods, or enzyme activity leading to development of rancidity or browning
• losses from spillage, bursting of containers, etc.
• incorrect storage conditions such as exposure to sunlight, heat and moisture.

Correct storage and prevention of spoilage are particularly important for finished products, because the expenditure that has already been made during processing makes losses at this stage very damaging financially.

Storerooms, warehouses and distribution vehicles should therefore be constructed to prevent access by rodents, insects and birds, and carefully inspected on a regular basis to ensure that preventative measures are effective. Details of materials used for construction of storerooms are given by Brennan et al. (1990). Windows are screened against insects, drainage channels and power cable ducting are fitted with devices to prevent entry by rodents, the structure of the roof and walls is designed to prevent insects, rodents and birds from gaining entry. Doors are fitted with screens or air curtains and rooms are equipped with insect electrocutors. Floors are covered with vinyl based coatings to prevent cracks that could harbour insects and micro-organisms.
For ambient temperature storage, the store-room should be cool with good ventilation to maintain a flow of air. Fresh foods are only stored for short periods, but the storeroom temperature should be low and humidity sufficiently high to prevent wilting or drying out (see Chapter 20). Ingredients such as sugar, salt and powdered flavourings or colourants can pick up moisture from the atmosphere. Where this is likely to result in loss of quality or function, the humidity in a storeroom should be controlled to equal the equilibrium relative humidity (ERH) (see Chapters 1 and 15) of the stored product. For example, white sugar which has an ERH of 60% will form a cake if it picks up moisture, and it is therefore stored below 60% humidity. Fats and oils are particularly susceptible to odour pickup, and spices are likely to contaminate other ingredients with their odour. Both types of ingredient are therefore stored separately from other foods.

Most foods are packaged for protection and convenience of handling. Packages which are grouped into larger (or ‘unitised’) loads require less handling when they are moved through storage and distribution networks. Wooden pallets are commonly used to move unitised loads of cases or sacks by fork-lift or stacker trucks. A development of this method uses fibreboard slipsheets to reduce the volume occupied by pallets in vehicles and warehouses (Spreen and Ellis, 1983). Products are secured onto the pallet or slipsheet by shrink-film or stretch-film (Chapters 24 and 25).

Working procedures in storerooms and warehouses ensure that sacks or cartons of food are stored on pallets or racks to keep them off the floor, with space to clean behind the stack. They should be carefully stacked to the recommended height to prevent crushing or collapse and injury to operators. Lighting should be as bright as possible and at a high level to reduce shadowing caused by stacked pallets. Warehouse management systems are increasingly computer controlled (Chapter 2) and are used to monitor material movements into and out of the stores, check stock levels, stock rotation, the use of materials in the process and the destinations for delivery of products. Daily cleaning routines are used as part of a HACCP plan (Chapter 1) to prevent dust or spilled food accumulating which would encourage insects or rodents.

Large warehouses use computerised truck-routing systems, which store information on stock levels, their location in a warehouse and warehouse layout. Computers that control automated guided vehicles (AGVs) have been used for a number of years. The AGVs follow fixed routes guided either by wires buried in the warehouse floor or coloured lines painted onto the floor. These are now being replaced by ‘free-path’ AGVs in which the computer assigns an optimum route for each vehicle. Packaged goods are palletised and each pack and pallet is coded with a bar code that is read by a microprocessor. The coded stock is allocated a storage location by the computer, which compiles both a map of the warehouse and current stock levels in its memory. The progress of each AGV in retrieving or replacing stock is monitored and controlled using information transmitted by an odometer in the vehicle and by bar-code directions that are displayed throughout the warehouse, which are read by a laser mounted on the truck. Developments in robotic handling and picking in warehouses and other areas of food processing are described by Murphy (1997a, 1997b).

### 26.4 Distribution

The link between harvesting and production of a processed food and purchase by the customer is known as the distribution chain (for example Fig. 26.5) and the different...
systems involved in distribution are termed ‘logistics’. The main factors that are involved in an efficient distribution chain are:

- providing the consumer with products at the right place, at the right time and in the right amount
- reducing the cost to a minimum (distribution is an expense but does not add value to a product)
- maintaining the product quality throughout the distribution chain.

Further details are given by Rushton and Oxley (1989) and a case study that describes the handling and distribution of peas from harvest to sale of frozen product is described by Chambers and Helander (1997).

Within the last decade, consumers have demanded foods having better quality, freshness, availability, and a greater variety. This consumer pressure has resulted in a substantial increase in the volume and range of foods that are handled by the major food retailers, together with higher standards for temperature control of some foods (Chapter 19). This in turn has caused retailers to change their methods of storage and distribution,
and these companies now dominate food distribution. Previously, products from a food manufacturer were transported to a relatively large number of small distribution depots that each handled a single product. Delivery volumes were low and it was not economic to deliver every day. In addition, foods that required temperature-controlled transport had to be carried on separate vehicles, some of which were owned by contractors who operated their own distribution policies and delivery schedules. Each of these aspects increased the cost of distribution and reduced both quality and efficiency.

These problems caused retailers to change their strategy for food distribution, and use mathematical models and simulations to improve the logistics of food supply to reduce costs and distribution times as a result of:

- combining distribution streams of various suppliers
- combining transport of fresh food, frozen food and dry foods
- changing the method and frequency of ordering
- redesigning and reorganising warehouses

Koster (undated).

These developments resulted in a smaller number of large ‘composite’ distribution depots that can handle a wide range of products. Each composite depot, which may cover 23 000 square metres (250 000 square feet), can typically handle more than 30 million cases of food per year and serve up to 50 retail outlets. The depot is divided into five temperature zones (ambient, semi-ambient (+10ºC), chill (+5ºC), chilled (0ºC) and frozen (−25ºC)) to handle the range of short- and long-shelf life products found in most large stores (Harrison, 1997). Delivery vehicles use insulated trailers that are fitted with movable bulkheads and refrigeration units to create three different temperature zones. Short shelf life products are received into distribution depots during the afternoon and evening, and are delivered to retail stores before trading starts the next day (termed the ‘first wave’ delivery). Longer shelf life and ambient products are taken from stock and formed into orders for each retail store over a 24-hour period, and are delivered in a ‘second wave’ between 8 am and 8 pm at scheduled times that are agreed with each store. Many larger retailers now use electronic data interchange (EDI) to automatically order replacement products, directly in response to consumer purchases (also Chapter 24, Section 24.3.1). This results in more frequent deliveries of smaller amounts of product, in order to minimise stock levels in stores. Further details are given by Krcmar et al. (1995) and O’Callaghan and Turner (1995). However, these developments have caused a dramatic increase in distribution and handling costs for processors. Many smaller- and medium-scale processors now co-operate in logistics, to gain cost savings and more efficient distribution from the larger volumes that are handled. In addition, co-operation and sharing of costs enables these processors to invest in automatic order picking systems that would be unaffordable for individual companies (Koster, undated).

Managers in processing factories use forecasts of demand for foods and actual orders to inform computer-based systems, known as material requirement planning (MRPI) systems which co-ordinate decisions on ordering, stock levels, work-in-progress, storage and distribution of finished products. This enables them to calculate the amounts of materials that are needed at a particular time to manufacture products to meet customer demand. The software is also used to generate customer orders and sales forecasts, the physical distribution routes for products, records of available stocks and inventory. The information can then be used to produce purchase orders for raw materials, work orders and material plans (Johnson et al., 1997).
The concept of MRPI has expanded during the last 20 years to integrate other parts of the business and has become Manufacturing Resource Planning (MRPII). This is a single integrated system, containing a database that can be accessed by all parts of the company, including engineering departments, sales and marketing departments, finance and accounting departments as well as production managers. Information from sales can therefore be used directly in, for example, production scheduling, buying and plant maintenance. Details of computerised systems for management and process control are described in Chapter 2 and further information is given by Orlicky (1975) and Tersine (1994).

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26.6 References
