given to the product were no longer prevented from growing by the reduced a_w (see Section 7.5.5).

4.1.5 Spoilage of Canned Foods

If a canned food contains viable micro-organisms capable of growing in the product at ambient temperatures, then it will spoil. Organisms may be present as a result of an inadequate heat process, underprocessing, or of post process contamination through container leakage. Spoilage by a single spore former is often diagnostic of underprocessing since rarely would such a failure be so severe that vegetative organisms would survive.

A normal sound can will either be under vacuum with slightly concave ends or have flat ends in those cases where the container is brimful. Spoilage often manifests itself through microbial gas production which causes the ends to distend and a number of different terms are used to describe the extent to which this has occurred (Table 4.6). The spore-forming anaerobes *Clostridium* can be either predominantly proteolytic or saccharolytic but both activities are normally accompanied by gas production causing the can to swell. Cans may sometimes swell as a result of chemical action. Defects in the protective lacquer on the inside of the can may allow the contents to attack the metal releasing hydrogen. These hydrogen swells can often be distinguished from microbiological spoilage since the appearance of swelling occurs after long periods of storage and the rate at which the can swells is usually very slow.

In cases where microbial growth occurs without gas production, spoilage will only be apparent once the pack has been opened. *Bacillus* species, with the exceptions of *B. macerans* and *B. polymyxa*, usually break down carbohydrates to produce acid but no gas giving a type of spoilage known as a 'flat sour', which describes the characteristics of both the can and the food.

The heat process a product receives is determined largely by its acidity: the more acidic a product is, the milder the heat process applied.

Table 4.6 *Description of blown cans*

Name	*Description*
Flat	No evidence of swelling.
Hard swell	Both ends of the can are permanently and firmly bulged and do not yield readily to thumb pressure.
Soft swell	Both ends bulged but not tightly; they yield to thumb pressure.
Springer	One end flat, the other bulged. When the bulged end is pressed in then the flat one springs out.
Flipper	A can with a normal appearance which when brought down sharply on a flat surface causes a flat end to flip out. The bulged end can be forced back by very slight pressure.

Although more complex schemes have been described, the essential classification of canned foods is into low acid (pH > 4.5, or 4.6 in the United States) and acid foods (pH < 4.5 or 4.6). We have already seen how this is applied to assure safety with the requirement that products with a pH > 4.5 must undergo a botulinum cook to ensure 12 decimal reductions of *C. botulinum* spores. This is not a concern in acid foods as *C. botulinum* cannot grow and the F_0 applied to products with a pH in the range 4.0–4.5 such as canned tomatoes and some canned fruits is generally 0.5–3.0. In higher acidity products such as canned citrus fruits (pH < 3.7) the heat process is equivalent only to a pasteurization.

A product's acidity also determines the type of spoilage that may result from underprocessing since it can prevent the growth of some spoilage organisms. At normal ambient temperatures (< 38 °C) only mesophilic species will grow. Typical examples would be *C. botulinum*, *C. sporogenes* and *B. subtilis* in low acid products and *C. butyricum* and *C. pasteurianum* in products with a pH below 4.5.

Cans are cooled rapidly after processing to prevent spoilage by thermophiles. Thermophilic spores are more likely to survive the normal heat process but would not normally pose a problem. If however a large assemblage of cans is allowed to cool down naturally after retorting, the process will be slow and the cans will spend some time passing through the thermophilic growth range. Under these conditions surviving thermophilic spores may be able to germinate and grow, spoiling the product before it cools. This may also occur if cans are stored at abnormally high ambient temperatures (>40 °C) and canned foods destined for very hot climates may receive a more stringent process to reduce thermophilic spoilage.

Thermophilic organisms commonly associated with spoilage of low acid canned foods are the saccharolytic organism *C. thermosaccharolyticum, B. stearothermophilus* and *Desulfotomaculum nigrificans*. The last of these causes a type of spoilage known as 'sulfur stinker'. It produces hydrogen sulfide which does not usually distend the can but does give the product an objectionable smell and reacts with iron from the can to cause blackening.

Leakage is the most common cause of microbiological spoilage in canned foods. Cans are the most common containers used for retorted products, although glass jars, rigid plastic containers and soft pouches are also sometimes used. Cans are usually made of two or three parts: the three-part can consists of a base, body and lid while in two part cans the body and base are made from a single piece of metal. In a three-part can the body seam is electrically welded but the lid on all cans is held in place by a double seam (Figure 4.7). The correct formation and integrity of this seam are crucial to preventing leakage and monitoring seam integrity is an important aspect of quality control procedures in canning.