Table 3.13 Assessment of gelatine.

Advantages	Disadvantages
Multifunctional (texture, surface activity, emulsifier, stabilizer, film former)	Low stability to heat
Melts at body temperature with rapid and intense release of flavor	Low gelation temperature
Unique texture, elasticity and brilliance	Slow gelation
Transparent	Soluble only at higher temperatures (exceptions: Instant gelatine and gelatine hydrolysates)
Easy to process	BSE discussion
No E-No. (food)	Animal source (vegetarians/vegans)
Preventive function in osteoarthritis and osteoporosis	Religious reservations
Protein enrichment	

advantages and a higher price, unless high temperatures or extreme pH values have to be used or there are religious or personal reasons for not using animal-based substances.

3.1.2
Dissolution Kinetics and the Rheological Behavior of a Gelatine Solution are Central to Process Optimization

When selecting a powder gelatine, the focus is frequently on parameters such as Bloom, color, clarity, or viscosity. Properties such as the degree of grinding, foam formation, setting temperature, or setting time, however, although not normally considered as important, can exert considerable influence on the production process.

Depending on the final product, the gelatine has to be processed either as a low- or high-percentage solution. Preparing such solutions with powder gelatine is technologically relatively simple compared to using other hydrocolloids. However, in practice, other problems tend to occur, e.g., the formation of lumps or foaming, if the process involved has not been adapted completely to the specific type of gelatine involved. The lumps formed comprise dry particles of gelatine that adhere to each other and that are very difficult to dissolve afterwards without using mechanical means. If these swollen fines agglomerate, they tend to incorporate other dry particles, consequently preventing them from being wetted.

3.1.2.1 Process Steps for Dissolution

The dissolution process consists of a number of process steps: dispersion of the powder gelatine, swelling of the dry gelatine particles, and their dissolution by warming. Traditionally, this takes place in a two-step process. The gelatine is stirred into cold water, allowed to swell, and then heated to form a solution. The swelling and dissolution steps can, however, take place simultaneously – and therefore more quickly – in a one-step process, whereby the gelatine is directly stirred into hot water. Providing the process parameters are selected correctly and an appropriate apparatus is used, thermal degradation of the protein chains, excess foaming, and the formation of lumps can be avoided.

3.1.2.2 Factors Influencing Dissolution – Particle Size

In the ideal dispersion process, the powder gelatine is brought into the liquid with a minimum of stirring so that each individual particle is rapidly surrounded by it. During subsequent swelling, the gelatine particles take on five to ten times their weight as water. The water diffuses from the surface into the body of the particles. The time required for this process depends on the surface area of the particles. As the surface area of a particle increases in proportion to the square of its linear dimension and the volume in proportion to its third power, small particles have a greater specific surface area than large ones, so that the cross-section of the particles to be penetrated by the water is smaller. Therefore, they swell more quickly and dissolve more rapidly upon warming.

The time required for complete dissolution is especially dependent on the degree of granulation of the gelatine. The dissolution curves of high- and low-Bloom gelatines of identical particle size are thus very similar in nature (see Fig. 3.5).

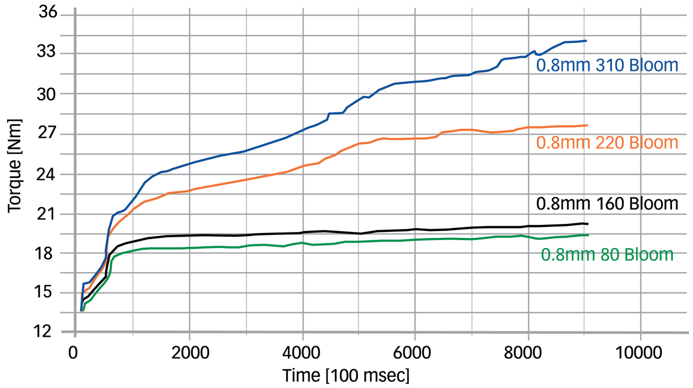

Fig. 3.5 Dissolution curves of granulated gelatine of different quality but with the same particle size.

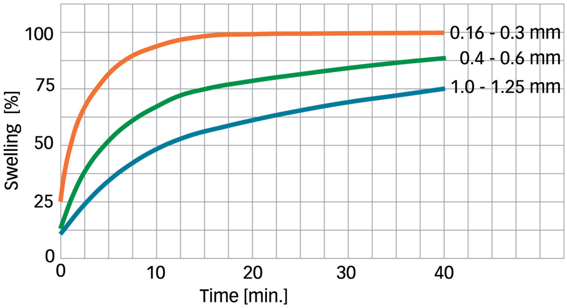

Fig. 3.6 Swelling behavior of the same powder gelatine at 18 °C as a function of particle size.

As a guideline, finely ground particles (0.1–0.3 mm) swell within a few minutes in cold water (see Fig. 3.6); medium-sized particles (0.3–0.8 mm) take about 10 min, and large particles (over 2.0 mm) require an hour to swell completely.

In the case of smaller particles, the absolute surface area increases disproportionately, so that lumps are more likely to form. To compensate for this, cold water should be used; the particles then take up water more slowly and the surfaces do not become “tacky”. Although this reduces the formation of lumps, it prolongs the process by a few minutes. Another possibility is to stir intensively. Here, however, there is a risk of excess foaming at a later point as too much air is introduced into the system. The air bubbles that are formed are difficult to remove, especially from highly concentrated solutions.

3.1.2.3 **Factors Influencing Dissolution – the Matrix**

Apart from the degree of granulation and the temperature, the composition of the surrounding liquid and the concentration of the gelatine also influence dissolution behavior.

In aqueous solutions of citric, tartaric, or acetic acid, for example, gelatine dissolves somewhat more quickly than in pure water. This effect is not utilized in practice in order to avoid loss of quality brought about by acid-induced hydrolysis of the gelatine. In contrast, concentrated sugar or salt solutions delay the dissolution process, as these substances, which have a great affinity for water, compete with the gelatine particles for the available water. This also can give rise to the formation of lumps and to undissolved gelatine particles. Furthermore, processors should initially dissolve the gelatine in water or at least subject it to preswelling before adding it to a system containing high concentrations of salt or sugar.

In addition, the gelatine particles also compete with each other for the water. Thus, the higher the concentration, the longer they take to swell. Therefore, there is a limiting concentration value up to which gelatine can be easily dissolved. This is about one part gelatine to two parts of water. Higher concentrations of gelatine are possible but are much more difficult to produce without foam because of the very high viscosities involved.

3.1.2.4 Traditional Two-step Processing versus the Modern Hot-Melt Process

In the two-step process, the cold-swollen gelatine is placed in a water bath at 60–70 °C or a in a vessel heated by an external mantle or heating coil to a similar temperature. The solution that is prepared can then be further processed. At temperatures over 50 °C, the internal structures formed within individual particles during previous drying of the gelatine are completely broken down; a disperse molecular ‘‘random coil structure’’ is formed. The ordered structures typical of gels no longer exist. At the same time, because of the lower temperature, thermal degradation is minimal, and there is no need for intensive stirring. This reduces the amount of air taken up by the solution.

The absolute dissolution time can be reduced by using processes that, in contrast to the two-step process, do not necessitate a pre-swelling step. In such a one-step hot-dissolution process, the powder gelatine is added to water at 80 °C under vigorous stirring. The gelatine immediately swells and dissolves. These one-step dissolution processes were previously recommended only for concentrations up to a maximum of 15%. Today, however, in the interest of shortening production processes, even highly concentrated solutions are prepared using the hot-melt process.

These modern methods, however, require special apparatus and processes. In the confectionery industry for example, the gelatine is dispersed in a special gelatine dissolution apparatus at 80–90 °C under vigorous stirring (see Fig. 3.7); the colloidal suspension is then pumped, together with sugar and glucose syrup, into

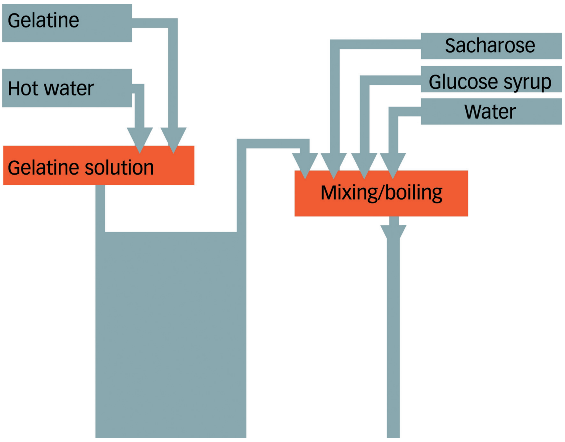

Fig. 3.7 Flow chart of a modern dissolution process for highly concentrated gelatine solutions in the confectionery industry.

a continuous sugar boiler where, if any undissolved particles of gelatine are still present, these are then dissolved completely. In the subsequent vacuum part of the equipment, any air bubbles created by the vigorous stirring are removed, and, at the same time, part of the water is evaporated off; the temperature of the solution drops as a result. The final outcome is a bubble-free solution.

Hot-melt processes, in contrast to traditional two-step processing, have the major advantage that the gelatine can be further processed within minutes – the entire swelling process becomes unnecessary. The required apparatus is expensive and the resulting solutions can be very hot. As such, they should be processed immediately, therefore avoiding the loss in quality brought about by the thermal degradation of the peptide chains.

In addition, in the one-step process, the significantly increased rapid lump formation brought about by the higher temperature must be avoided. Such lumps can be formed during dispersion if the gelatine added is too fine or if the stirring speed is too low. Thus, in the accelerated, one-step process, the use of a frequency-regulated stirrer is optimal; in this way, the stirring intensity and the particle size of the powder gelatine can be balanced optimally. Also, with such a variable stirring system, the rotation speed can be reduced in proportion to the degree of dispersion desired. This in turn reduces the amount of air taken in, and hence foaming, during the dissolution process.

If such equipment flexibility is unavailable, the degree of grinding of the powder gelatine must be optimally adapted to the conditions of the equipment being used. The rule of thumb is that, for all hot-melt processes, a powder gelatine containing a low proportion of dust is the safest material to use. Such a gelatine allows for a moderate stirring speed and the development of a lump-free solution at an acceptable processing speed. However, if high concentrations are being used, the dimensions of the stirrer also have to be taken into account. The viscosity of a dispersion of coarsely ground gelatine also increases more rapidly than that of finely ground gelatine shortly after the addition of the gelatine (see Fig. 3.8).

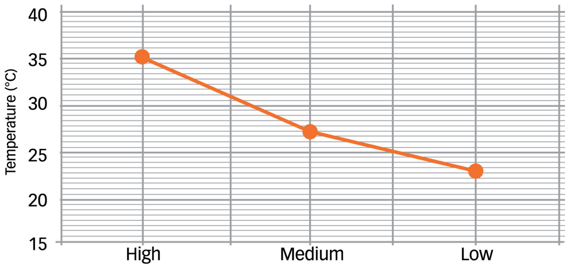

Fig. 3.8 The stirrer is subjected to maximum mechanical force shortly after addition of gelatine due to the rapid increase in viscosity of the solution.

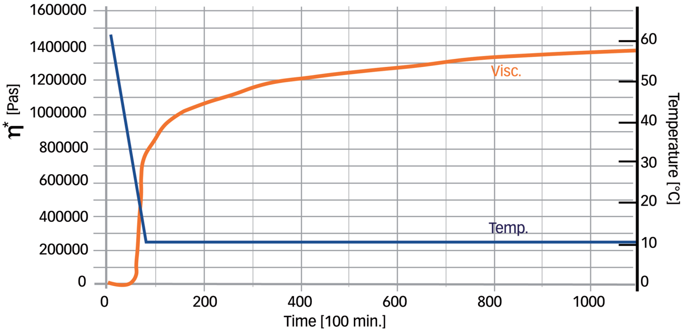

Fig. 3.9 Viscosity of a gelatine solution on cooling.

3.1.2.5 The Viscous Behavior of a Gelatine Solution During Further Processing

When a finished gelatine solution is being further processed, the viscosity is an important criterion (see Fig. 3.9). In the case of molded articles such as fruit gummies, where flowability is important for production purposes, a low-viscosity gelatine is normally used. High-viscosity gelatine on the other hand is required for creams. Low-viscosity gelatines have the disadvantages that they require setting times that are a little longer and the final product softens more at higher ambient temperature.

The viscosity of a gelatine solution is a function of the raw material, the conditioning process, the concentration, and the temperature (see Figs. 3.10 and 3.11). In solutions of identical gelling power, the viscosity of alkaline-conditioned gelatine and neutral or slightly alkaline-extracted types is 30–50% higher than that of acid-extracted gelatine from raw material that has undergone the same pretreatment. However, the viscosity of a particular gelatine solution at different concentrations cannot be precisely derived directly from the standard viscosity as provided by the manufacturer. Since there is no linear correlation, it is not possible to predict an exact value from a single-point measurement.

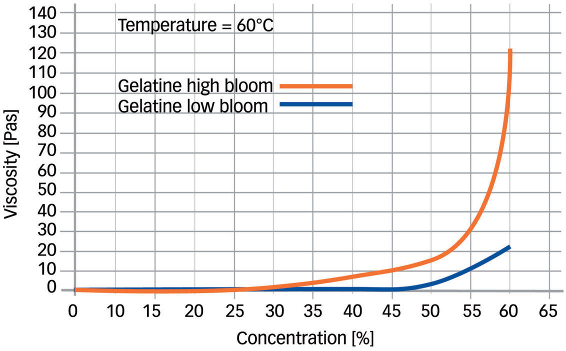

Fig. 3.10 Viscosity of a gelatine solution as a function of the Bloom value and concentration.

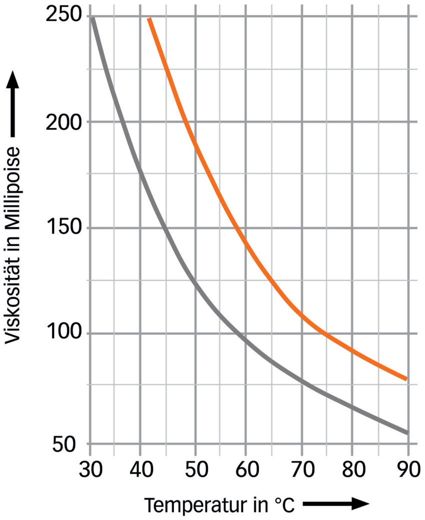

Fig. 3.11 Viscosity of different 10% solutions of gelatine as a function of temperature.

Rheological measurements have shown that at least at the concentrations normally employed in the processing of gelatine solutions in numerous applications there is almost Newtonian behavior. Structural viscosity is present only in the case of higher concentrations of high-Bloom gelatine. However, in the normal case, there will be no problems associated with the dimensions of piping, pumps or other equipment. Gelatine solutions have a high degree of shear stability and are thus easily pumped without quality loss.

3.1.2.6 Setting Temperature and Setting Time

During the course of processing products containing gelatine, they are cooled, and this results in the conversion of gelatine from the sol to the gel state. The setting time and temperature are influenced by the temperature profile during cooling, the type of gelatine employed and the composition of the aqueous system. However, in addition to the gelatine type and concentration, the interaction of gelatine with other components of the formulation and the overall water content of the system are major factors.

With increasing amounts of water, setting begins at lower temperatures. The actual sol/gel transition, however, requires less time. This can be explained by the fact that a firm gel can only be formed if the gelatine molecules are arranged in a three-dimensional network that is subsequently stabilized by hydrogen bonds and ionic and hydrophobic interactions. The more mobile the gelatine molecules are at the beginning of the cooling process in a system the more rapidly do they achieve the ideal spatial arrangement for gel formation.

In brief, if there is a lot of water in a particular system, the viscosity of the solution drops (see Fig. 3.12) and the longer gelatine molecules move more

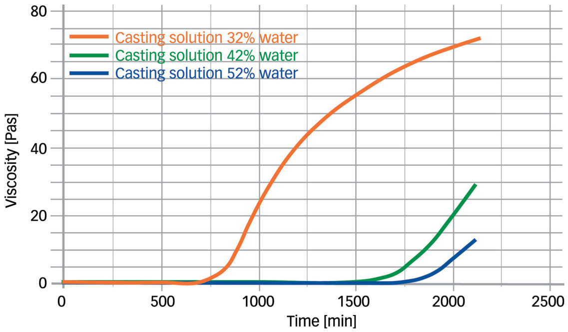

Fig. 3.12 Viscosity of a fruit gummie molding solution on cooling as a function of its water content.

easily and rapidly. This gives rise to faster solidification times, but at lower temperatures.

3.1.2.7 **Process Optimization in Practice**

In summary, the particle size distribution of the powder gelatine and its viscosity are the most important technical factors for the optimal processing of gelatine. Under certain circumstances, however, the setting behavior of the gelatine system can also be of importance, especially when processing time is an important factor.

During the manufacturing of soft shell capsules, for example, the gelatine mass on the cooling drum must set in less than one minute and on the dipping pins of the hard shell capsule machine in less than 15 s. In the preparation of photographic layers, the required setting time is even less. And even in the production of cereal bars, where gelatine hydrolysate is used as a natural "adhesive," the time required for binding through loss of water is a critical factor in the production process. For fruit gummies, in contrast, this is not the case; here, drying takes place on a bed of starch simultaneously with the gelling process. The time-limiting factor in this process is the drying process, which, with a few exceptions, is much longer than the gelling process.

For the dissolution process, the high temperatures sometimes used as well as the length of time these temperatures are held have to be taken into account to prevent the degradation of technological properties of the gelatine solution. More specifically, this is manifested by an irreversible decrease in viscosity, a loss of gelling power, an increase in the color, and inferior organoleptic properties. The extent to which these occur is a function of temperature, time, and pH.

Within the temperature range 60–70 °C, gelatine solutions can be kept for several hours without much loss of gelling power. For example, after two hours at 60 °C, a solution will retain 98% of its original gelling power (see Fig. 3.13).

A gelatine solution may even be heated to between 90 and 100 °C without much loss in gelling power provided that the temperature is maintained for only

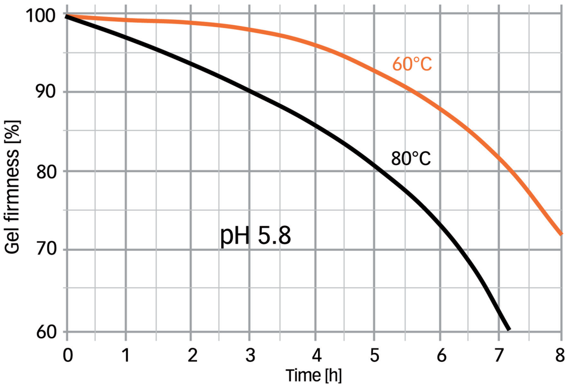

Fig. 3.13 Relative decrease in gel firmness of a gelatine solution as a function of storage temperature and storage time.

a few minutes. However, temperatures over 100 °C, e.g. as found in autoclaves or during the boiling of highly concentrated sugar solutions, should be avoided whenever possible, as in this case, the loss in gelling power can be extreme, even if the holding time is very short (see Fig. 3.14). Thus, for sterilized products, higher concentrations of gelatine must be used to compensate for anticipated losses in gelling power.

A higher degree of degradation takes place when the pH of hot gelatine solutions is within the strongly acidic or alkaline range (see Fig. 3.15). Thus, if acid or alkali has to be added, this should take place as late as possible during the process.

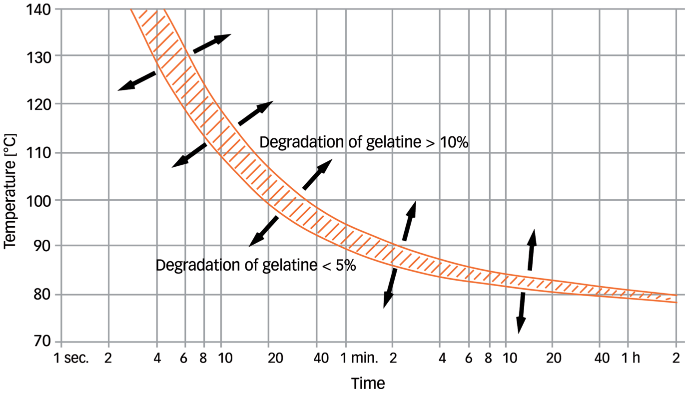

Fig. 3.14 Critical and non-critical heating/temperature conditions for the quality of gelatine solutions at pH 5.0.

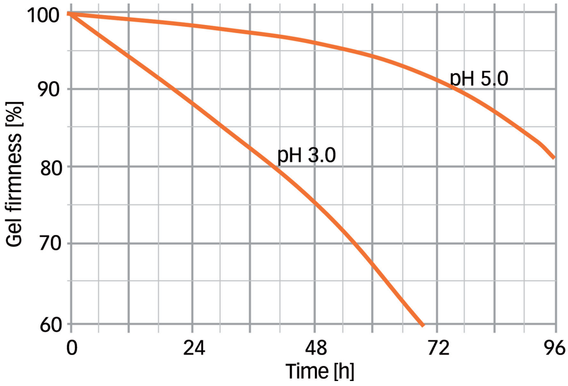

Fig. 3.15 Relative decrease in gel firmness of a 6.67% gelatine solution at 60 °C as a function of the pH and storage time.

To protect the gelatine from the effects of acid, buffer salts may be added. This enables the acidity to be increased to strengthen the flavor profile.

An additional parameter is the type of gelatine used. Pigskin gelatine, for example, is more thermally stable at slightly acidic pH than neutral or slightly alkaline-extracted ossein and hide split gelatines. Alkaline media exert the opposite effect (see Figs. 3.16 and 3.17).

Therefore, only a very detailed understanding of the dissolution and rheological behavior of the specific type of gelatine used, its interaction with other compo-

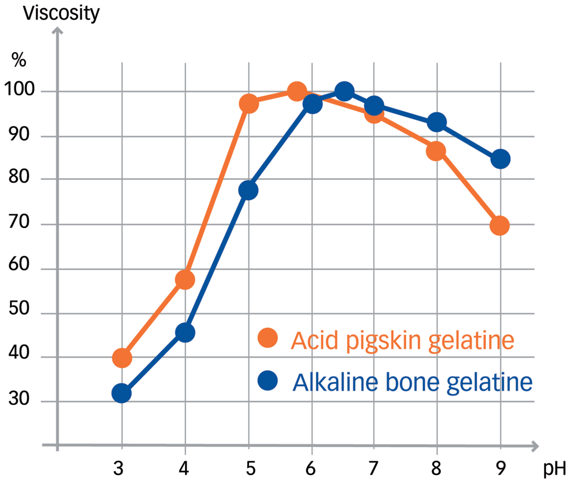

Fig. 3.16 Decrease in viscosity after 3 hours at 70 °C and different pH levels.

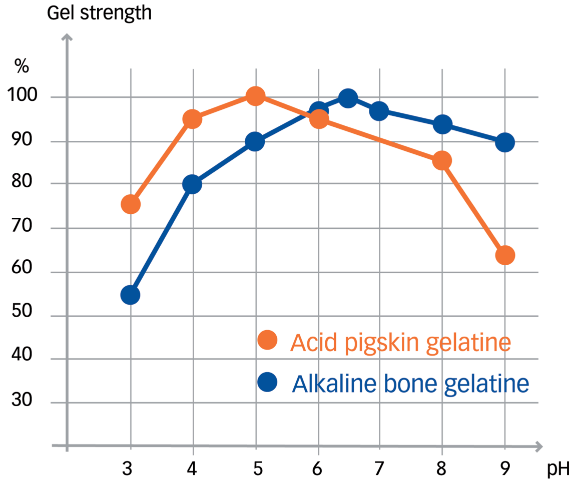

Fig. 3.17 Decrease in gel firmness after 3 hours at 70 °C and different pH levels.

nents of the formulation, and consideration of the time and temperature profiles will ensure optimal production processing. Problems such as lump formation during dissolution, excessive foaming, loss of gelling power, and quality losses during storage or additional production processes should be reduced to a minimum from the very beginning (see Table 3.14). Such optimization, within reason, is possible in cooperation with the gelatine manufacturer. This approach guarantees an efficient production process and allows for the manufacture of products of consistently high quality.

Table 3.14 Indication of a less than optimal dissolution process.

– *In the gelatine solution:*

Lump formation
Severe foaming
Very long dissolution times
Gelatine particles in the solution

– *In the product:*

Decreased degree of clarity
Varying product quality and texture
Changing viscosity
Collapsing foam
Syneresis
Increased degree of crystallization

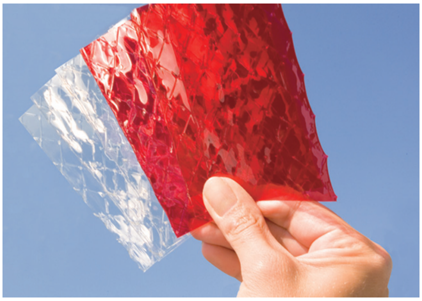

Fig. 3.18 One leaf of gelatine always produces the same gel strength.

3.1.2.8 Special: Processing Leaf Gelatine

Leaf gelatine (see Fig. 3.18) is primarily used in domestic households, the fine bakery and pastry industries and in catering. The central factor here is that one leaf of gelatine – regardless of the brand – dissolved in a given quantity of water always exhibits the same gel strength. This has been standardized by the few worldwide manufacturers of leaf gelatine. The gelling power of powder gelatine as sold in small units for domestic use is, however, not standardized, so that the amount to be used must first be determined and then weighed precisely because each brand might well have a different gelatine quality and quantity in the sachet.

For processing (see Fig. 3.19), the leaves are first placed in cold water and allowed to swell for several minutes. The swollen leaves are then removed from the water and gently squeezed.

For warm dishes, the swollen, squeezed gelatine can be added directly to the heated mixture, where it dissolves readily. Heating should then be stopped, however, as the gelatine would otherwise lose a portion of its gelling power. The same effect occurs when processing raw kiwi, pineapple, and papaya fruits. This is because these fruits contain proteolytic enzymes that decompose protein. The enzymes must be deactivated by blanching briefly prior to being processed.

For cold dishes such as creams and curds, the swollen and squeezed gelatine should first be dissolved by warming in a little liquid. Several tablespoons of the

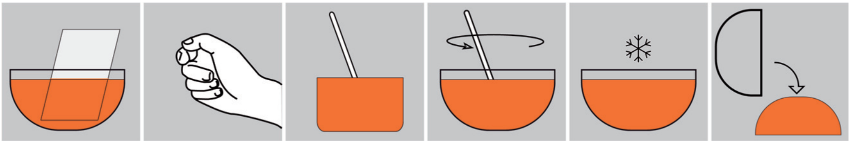

Fig. 3.19 Processing of leaf gelatine: 1) Swelling in cold water. 2) Squeezing out. 3 and 4) Dissolving in a warm fluid 5) Chilling. 6) Turning out.

cold mixture can then be stirred into the gelatine solution, followed by the rest of the mixture.

Alternatively, the gelatine, subsequent to swelling and squeezing, can be dissolved in a microwave oven and then mixed with the cold mixture in the same way.

Info Box 3.1

Practically unlimited shelf life when dry

If gelatine is stored under dry and odor-free conditions, it can be stored for a practically unlimited period without noticeable loss of quality. Its low water content protects it from microbiological decomposition.

In contrast, gelatine solutions present an excellent medium for microorganisms. For this reason, all gelatine provided to the customer is guaranteed to correspond to the highest possible microbiological quality requirements (see Section 2.3). However, should microorganisms enter the solution from the water, from the atmosphere, or from poorly cleaned equipment, they can grow exponentially within a very short period of time, with far-reaching consequences. Some microorganisms form CO_2, and the solution may suddenly begin to foam after a few hours. Others release proteolytic enzymes that can rapidly diminish the gelatine quality (see Fig. 3.20). Also, the organoleptic properties of the gelatine worsen whenever there is microbial contamination. Therefore, gelatine solutions should always be prepared under hygienic conditions and are best stored between 55 and 60 °C – the best compromise between thermal degradation and microbiological risk. It is, however, always best to conduct any additional processing without delay.

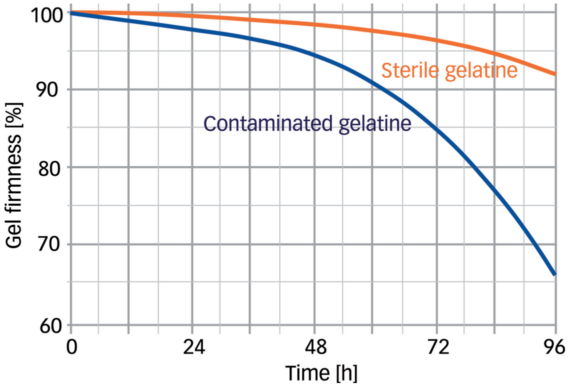

Fig. 3.20 Relative decrease in gel firmness by proteolytic enzymes brought about by microbiological activity.