6

Xanthan gum

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6.1 Introduction

Xanthan gum is an extracellular polysaccharide secreted by the micro-organism *Xanthomonas campestris*. Xanthan gum is soluble in cold water and solutions exhibit highly pseudoplastic flow. Its viscosity has excellent stability over a wide pH and temperature range and the polysaccharide is resistant to enzymatic degradation. Xanthan gum exhibits a synergistic interaction with the galactomannans guar gum and locust bean gum (LBG) and the glucomannan konjac mannan. This results in enhanced viscosity with guar gum and at low concentrations with LBG. At higher concentrations soft, elastic, thermally reversible gels are formed with locust bean gum and konjac mannan.

6.2 Manufacture

The bacterium *Xanthomonas campestris* produces the polysaccharide at the cell wall surface during its normal life cycle by a complex enzymatic process.[1] In nature the bacteria are found on the leaves of the *Brassica* vegetables such as cabbage. Commercially, xanthan gum is produced from a pure culture of the bacterium by an aerobic, submerged fermentation process. The bacteria are cultured in a well-aerated medium containing glucose, a nitrogen source and various trace elements. To provide seed for the final fermentation stage, the process of inoculum build-up is carried out in several stages. When the final fermentation has finished the broth is pasteurised to kill the bacteria and the xanthan gum is recovered by precipitation with isopropyl alcohol. Finally, the product is dried, milled and packaged.

6.3 Structure

The primary structure of xanthan gum shown in Fig. 6.1, is a linear $(1 \rightarrow 4)$ linked β-D-glucose backbone (as in cellulose) with a trisaccharide side chain on every other glucose
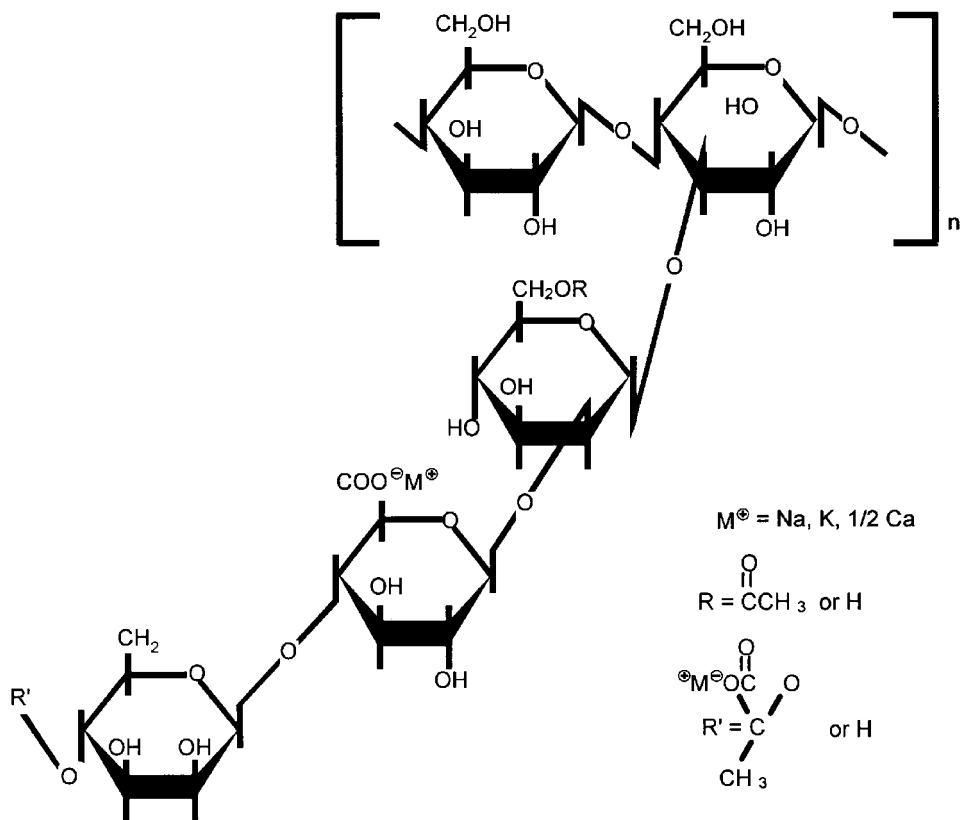
Fig. 6.1   Primary structure of xanthan gum.

at C-3, containing a glucuronic acid residue linked $(1 \rightarrow 4)$ to a terminal mannose unit and $(1 \rightarrow 2)$ to a second mannose that connects to the backbone.[2,3] Approximately 50% of the terminal mannose residues are pyruvated and the non-terminal residue usually carries an acetyl group at C-6. X-ray diffraction studies on orientated xanthan gum fibres identified the molecular conformation as a right-handed, five-fold helix with a rise per backbone disaccharide residue of 0.94nm, i.e. a five-fold helix with a pitch of 4.7nm.[4] In this conformation the trisaccharide side chain is aligned with the backbone and stabilises the overall conformation by non-covalent interactions, principally hydrogen bonding. In solution the side chains wrap around the backbone thereby protecting the labile β-$(1 \rightarrow 4)$ linkages from attack. It is thought that this protection is responsible for the stability of the gum under adverse conditions.

Xanthan gum solutions at low ionic strength undergo a thermal transition. This was first observed as a sigmoidal change in viscosity of 1% salt-free solutions.[5] Subsequent studies using optical rotation and circular dichroism show transitions coincident with the viscosity change.[6,7] These results are consistent with a helix coil transition. It has been proposed that the xanthan helix in solution should be considered as a rigid rod. The transition is thermally reversible with the structure returning to its original state upon cooling. The transition temperature increases with increasing salt concentration as shown in Fig. 6.2. Xanthan gum in solution is also able to form intermolecular associations that result in the formation of a complex network of weakly bound molecules.
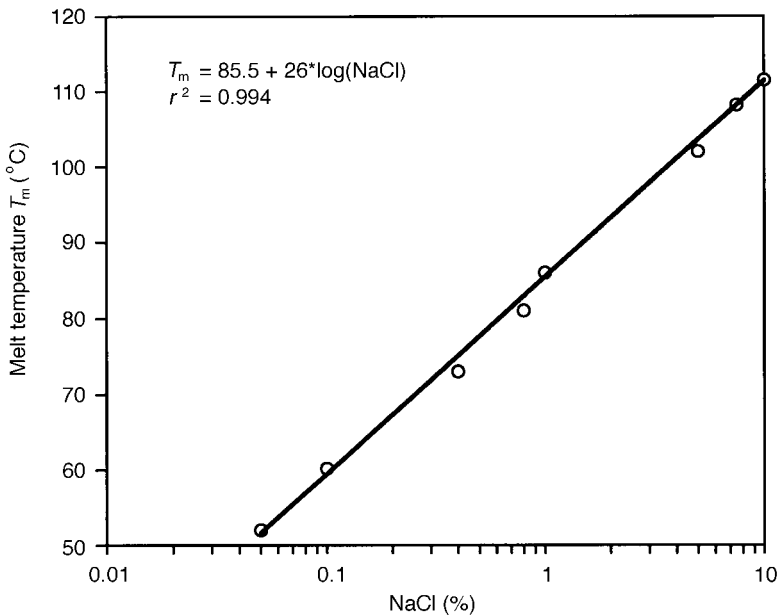
The figure shows a plot with axis label "Melt temperature T_m (°C)" on the y-axis (ranging 50 to 120) and "NaCl (%)" on the x-axis (0.01 to 10, logarithmic). The fitted equation is:

$$T_m = 85.5 + 26 * \log(\text{NaCl})$$
$$r^2 = 0.994$$

Fig. 6.2   Melting temperature of 1.0% xanthan gum solutions as a function of sodium chloride concentration.

6.4   Technical data

The functionality of xanthan gum is dependent upon the correct preparation of the gum solution. Poor solution preparation can lead to poor functionality in the final application. Therefore, before discussing the properties of xanthan gum in more detail, it is important to understand how to prepare a gum solution correctly.

6.4.1   Preparing xanthan gum solutions

To obtain optimum functionality, xanthan gum must be properly hydrated before use. Hydration depends on four factors:

1.   dispersion
2.   agitation rate of the solvent
3.   composition of the solvent
4.   particle size.

To hydrate properly the gum particles must be well dispersed. Poor dispersion leads to clumping of particles during mixing which results in formation of swollen lumps (sometimes called 'fisheyes'). Severe lumping prevents complete hydration and reduced functionality.

The ideal way to disperse xanthan gum is through the use of a dispersion funnel and mixing eductor (Fig. 6.3). Using this apparatus may eliminate the need for high shear mixing equipment. Before xanthan is added, the tank should be filled with sufficient water to cover the mixer blades when a vortex is developed. In small tanks, the water may be run through the eductor. Larger tanks may be filled faster directly. When enough water has been added, the agitator is turned on, and water flow is started in the eductor at a rate of 80–120 litres per minute. Dry xanthan gum powder is poured into the funnel attached
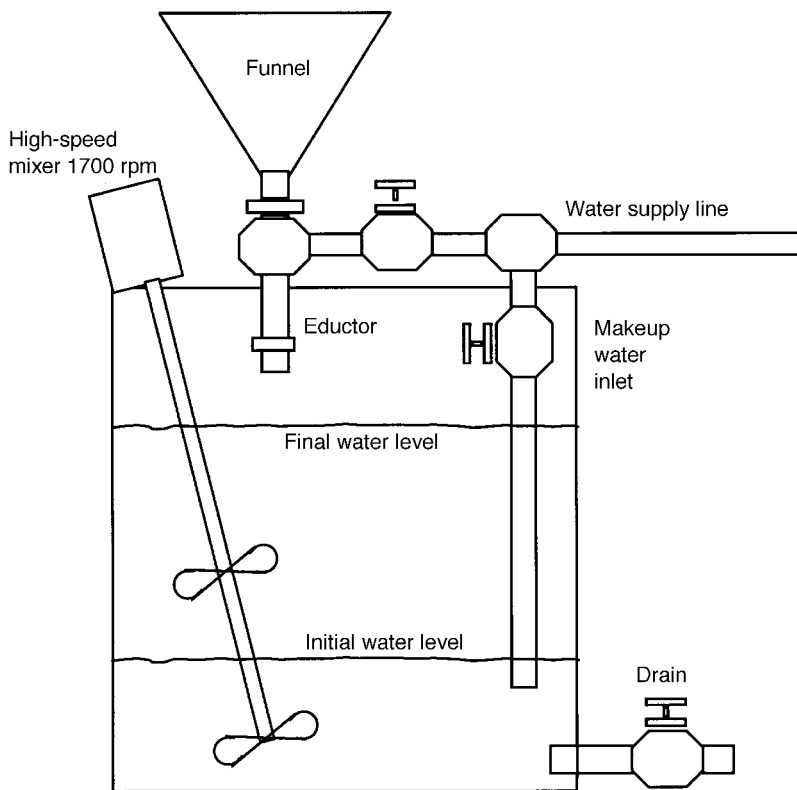
Fig. 6.3   Diagram of dispersion funnel and mixing eductor.

to the top of the eductor. While xanthan gum is being added, and until it is completely dissolved, the liquid must be stirred continuously to prevent settling of dispersed granules. A minimum water pressure of 50psi is required. If water pressure exceeds 100psi, flow will be too fast, and particles will lump.

An alternative method of dispersion is to blend the xanthan gum with other ingredients in the formulation such as sugar or starch. In this case the gum particles are kept separated by the dispersant and the blend can be added directly to the vortex created by an agitator. An ideal blend ratio is approximately 10:1 dispersant:xanthan. Dispersion can also be improved by separating the xanthan gum particles with non-solvents such as miscible, non-aqueous liquids (alcohol or glycol), or non-miscible liquids (vegetable or mineral oil). The xanthan gum can be slurried in the non-aqueous liquid and poured into water that is being agitated. Glycol dispersions should be used within a few minutes of being prepared because xanthan gum tends to solvate and swell in these liquids.

In some applications the use of a stock paste may be desirable. Xanthan gum pastes of at least 6% solids can be prepared and, with the addition of a preservative, stored indefinitely at room temperature. When needed, the appropriate amount of paste can be weighed into a container equipped with an agitator and dilution water added slowly with agitation. Note that addition of stock paste to the water results in poor dispersion and hydration.

Several grades of xanthan are specifically processed for ease of dispersion. These can be used where only relatively low shear mixing equipment is available. Examples are
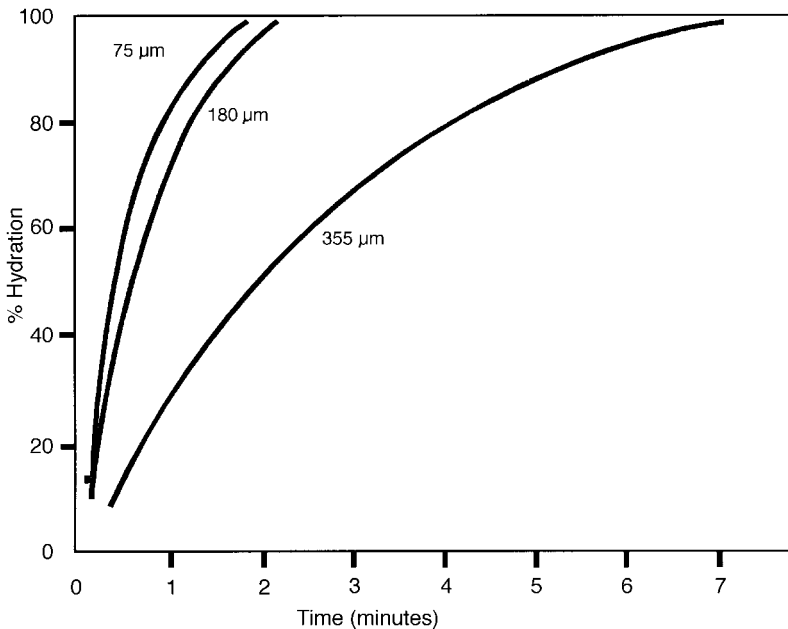
Fig. 6.4   Effect of particle size (μm) on the viscosity development profile of xanthan gum.

KELTROL® RHD and KELTROL® RD xanthan gum. Where dispersion and mixing conditions are good, fine particle size food grades of xanthan such as KELTROL® F and KELTROL® TF are available. When the dry powder particles are dispersed correctly a solution can be achieved in a few minutes with the hydration rate being dependent on the particle size as shown in Fig. 6.4.

6.4.2   Rheology of xanthan gum solutions

Present knowledge of the structure and conformation of xanthan gum explains many of its unique solution properties. The relationship between the structure of xanthan gum and its properties is summarised in Table 6.1. Xanthan gum solutions are highly pseudoplastic. When shear stress is increased, viscosity is progressively reduced. Upon the removal of shear, the initial viscosity is recovered almost instantaneously. This behaviour results from the ability of xanthan molecules, in solution, to form aggregates

Table 6.1   Structure/property relationship for xanthan gum

| Structural features	Properties
Complex aggregates, with weak intermolecular forces	High viscosity at low shear rates (suspension stabilising properties) High viscosity at low concentrations High elastic modulus Pseudoplastic rheology
Rigid helical conformation, hydrogen bonded complexes, anionic charge on side chains	Temperature insensitivity and salt compatibility
Backbone protected by large overlapping side chains	Stability to acids, alkalis and enzymes
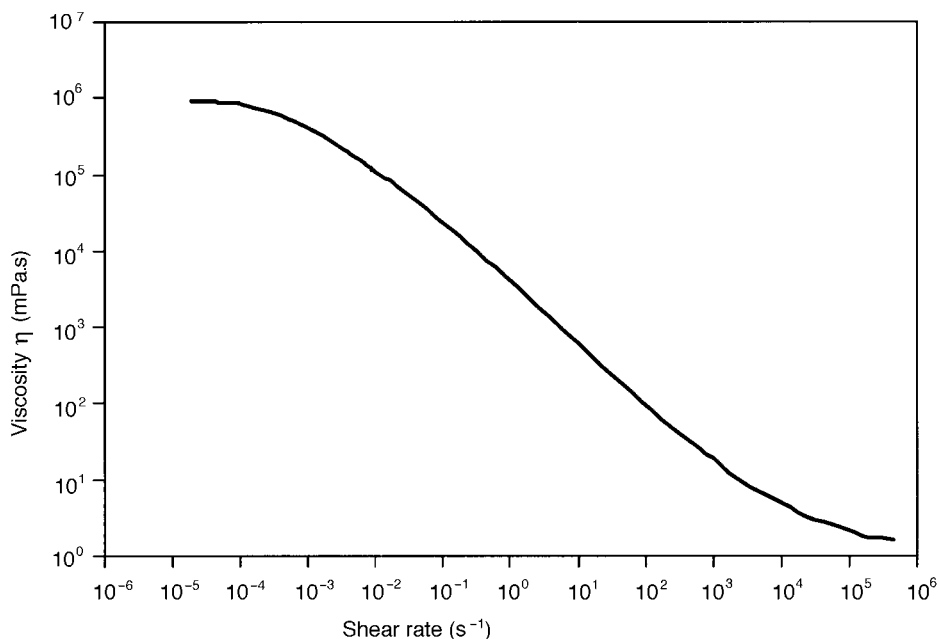
Fig. 6.5   Flow curve of 0.5% xanthan gum solution in standardised tap water. Standardised tap water is prepared by dissolving 1.00g NaCl and 0.15g $CaCl_2.2H_2O$ in 1 litre of deionised water.

through hydrogen bonding and polymer entanglement. This highly ordered network of entangled, stiff molecules results in high viscosity at low shear rates, and in practical terms, accounts for the outstanding suspending properties of xanthan gum solutions. These aggregates are progressively disrupted under the influence of applied shear, hence the highly pseudoplastic flow characteristics of xanthan gum solutions.[8] Figure 6.5 shows the effect of shear rate on a 0.5% xanthan gum solution. Eleven orders of magnitude are covered, and xanthan gum shows pseudoplastic properties over most of the range. This solution varies in viscosity from 1 million mPa.s at low rates of shear to about 1.7 mPa.s at the highest rates of shear. At both the highest and lowest shear rates there is evidence of a levelling off of the viscosity. These regions are known respectively as the upper and lower Newtonian regions.

   Solutions of xanthan gum at 1% or higher concentration appear almost gel-like at rest yet these same solutions pour readily and have low resistance to mixing and pumping. These same qualities are observed at typical use levels of about 0.1–0.3%. The high viscosity of xanthan gum solutions at low shear rates accounts for their ability to provide long-term stability to colloidal systems. The reduction in viscosity in response to increasing shear is important to the pouring properties of suspensions and emulsions and to the efficacy of xanthan gum as a processing aid.

   In Fig. 6.6, the viscosity of some common gums is compared over a range of shear rates relating to specific functions or processes. At low shear rates, solutions of xanthan gum have approximately 15 times the viscosity of guar gum and significantly more viscosity than carboxymethylcellulose (CMC) or sodium alginate which accounts for its superior performance in stabilising suspensions. At a shear rate of approximately $100s^{-1}$ all the hydrocolloids have similar viscosity. Above $100s^{-1}$, however, the viscosity of xanthan gum solutions drops sharply compared to the other gums making it easy to pour, pump or spray.
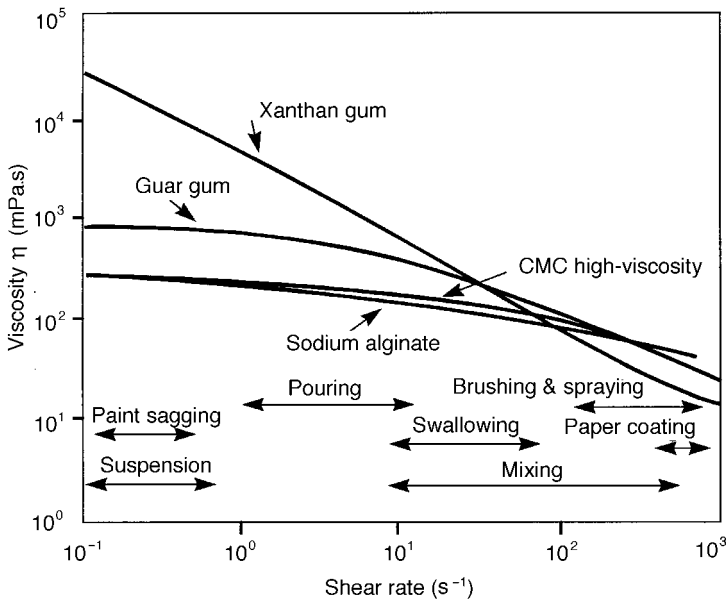
Fig. 6.6   Comparison of the flow behaviour of xanthan gum to other hydrocolloid solutions (0.5% concentration).

Effect of salts on viscosity
How salts affect viscosity depends on the concentration of xanthan gum in solution. At or below about 0.25% gum concentration, monovalent salts such as sodium chloride cause a slight decrease in viscosity. At higher gum concentrations, viscosity increases with added salt. At a sodium chloride level of 0.1%, a viscosity plateau is reached, and further addition of salt has little effect on viscosity. Many divalent metal salts, including those of calcium and magnesium, have a similar impact on viscosity. To develop optimal rheological and uniform solution properties, some type of salt should be present; usually the salts found naturally in tap water are sufficient to generate these effects. Salt concentrations of greater than 1–2% in the water can slow down the hydration of xanthan gum and it is therefore recommended to hydrate the gum in the absence of excess salt. Once hydrated, additional salt can be added without adverse effects. Special grades of xanthan gum such as KELTROL® BT are available that are able to hydrate in up to 20% salt solutions.

Effect of pH on viscosity
Generally, pH has little effect on the viscosity of xanthan gum solutions over the range encountered in food systems. Uniform and high viscosity is maintained over the pH range 2–12, with some reduction at extreme pH values. However, differences in viscosity are more evident at low concentrations of xanthan gum. The solutions have excellent stability at low pH over long time periods.

    Xanthan gum hydrates in many acidic solutions. For example, it is directly soluble in 5% acetic acid, 5% sulfuric acid, 5% nitric acid and 25% phosphoric acid. Additionally, xanthan gum will hydrate in up to 5% sodium hydroxide. Hydration rate, however, is improved when it is dissolved in water before adding the acid or alkali. In the presence of most organic acids, stability is excellent. At elevated temperatures, however, acid hydrolysis of the polysaccharide is accelerated and a reduction in viscosity will occur.

Table 6.2   Stability of xanthan gum solutions to acid at ambient temperatures

Acid	Acid concentration (%)	Xanthan gum concentration (%)	Viscosity retained after 90 days
Acetic acid	20	2	100
Citric acid	20	1	75
Hydrochloric acid	5	2	80
Phosphoric acid	40	2	100
Sulfuric acid	10	2	80
Tartaric acid	20	1	75

Table 6.2 shows the stability of xanthan gum in several organic and mineral acids at ambient temperatures.

Effect of temperature on viscosity
Xanthan gum solutions are unique in their ability to retain their viscosity until a definite 'melting temperature' is reached. At this temperature, the viscosity drops sharply due to a reversible molecular conformation change. The melting temperature is dependent on the ionic strength of the solution as shown in Fig. 6.2. Above approximately 5% NaCl the melting temperature is greater than 100ºC. The viscosity loss is reversible and upon cooling the original high viscosity is recovered.

6.4.3   Compatibility of xanthan gum
Alcohol
While xanthan gum will not dissolve directly into alcohol, solutions of xanthan gum are compatible with alcohol. Products containing alcohol can be formulated, to contain up to 60% water-miscible solvents such as ethanol. This enables its use as a thickener in alcohol-based products such as cocktails and chocolate liqueurs.

Enzymes
Most hydrocolloids are degraded to some extent by enzymes normally present in some foodstuffs. Enzymes commonly encountered in food systems such as proteases, cellulases, pectinases and amylases, however, do not degrade the xanthan gum molecule. It is thought that this enzyme resistance is due to the arrangement of the side chains attached to the backbone. This arrangement prevents the enzymes from attacking the β-$(1\rightarrow4)$ linkages in the backbone, thereby preventing depolymerisation by enzymes, acid and alkali. In practice the enzyme resistance of xanthan gum is exploited in food systems such as pineapple products, starch-based systems, spice mixes and many other products containing active enzymes.

6.4.4   Interaction with galactomannans/glucomannans
A synergistic interaction occurs between xanthan gum and galactomannans such as guar gum, locust bean gum and cassia gum and glucomannans such as konjac mannan. This interaction results in enhanced viscosity or gelation.

    Galactomannans are hydrocolloids in which the mannose backbone is partially substituted by single-unit galactose side chains.[9,10,11] The degree and pattern of

substitution varies between the galactomannans and this strongly influences the extent of interaction with xanthan gum. Galactomannans with fewer galactose side chains and more unsubstituted regions react more strongly. Thus locust bean gum, which has a mannose to galactose ratio of around 3.5:1, reacts more strongly with xanthan than does guar gum, which has a mannose to galactose ratio of slightly less than 2:1. Although there is still much debate as to the exact nature of this interaction, it is generally accepted that the xanthan gum interacts with the unsubstituted 'smooth' regions of the galactomannan molecules. Xanthan/guar mixtures exhibit a synergistic increase in viscosity as do low concentration mixtures with locust bean gum (< 0.03%) At higher concentrations soft, elastic gels are formed with LBG. Xanthan gum/LBG gels are thermally reversible setting and melting at approximately 55–60°C. Solutions of xanthan/guar mixtures can be prepared at room temperature using the guidelines outlined in Section 6.4.1. However, heating of the solutions above the transition temperature of the xanthan gum does result in a greater synergistic interaction. Mixtures of xanthan and LBG require heating to approximately 90°C to 95°C to fully hydrate the LBG and maximise the synergistic interaction.

The interaction of xanthan gum with galactomannans is dependent on the ratio of the mixture, pH and ionic environment. Optimum gum ratios are approximately 80:20 guar gum:xanthan gum (Fig. 6.7) and 50:50 for LBG:xanthan gum (Fig. 6.8). Generally, the synergistic interaction with galactomannans is at its maximum in deionised water at neutral pH and is reduced at high salt concentrations and low pH.
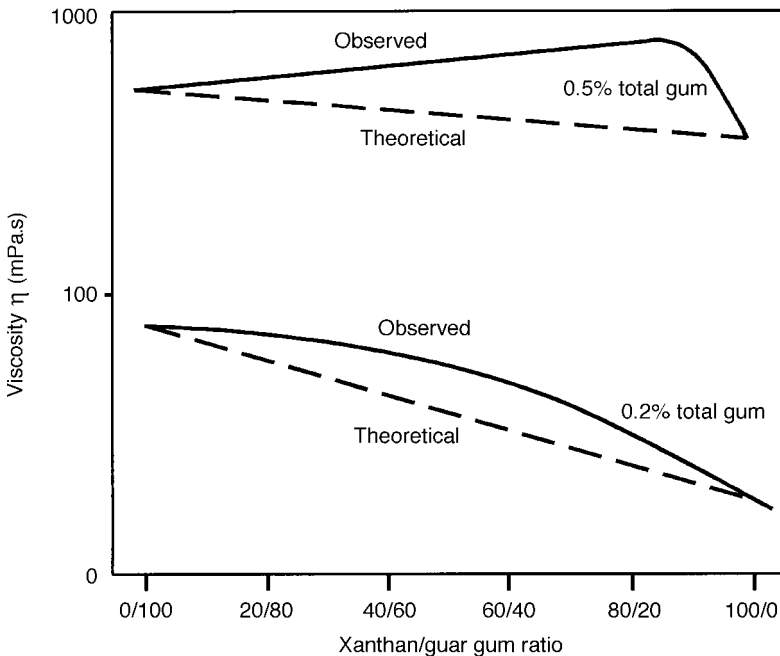

Fig. 6.7   Theoretical (dashed line) and observed (solid line) viscosities for blends of guar and xanthan gum. Data were collected with a Brookfield LVT viscometer at 60rpm at 25°C. The theoretical viscosity line is calculated on the assumption that non-interacting hydrocolloids will obey the log mean blending relationship.
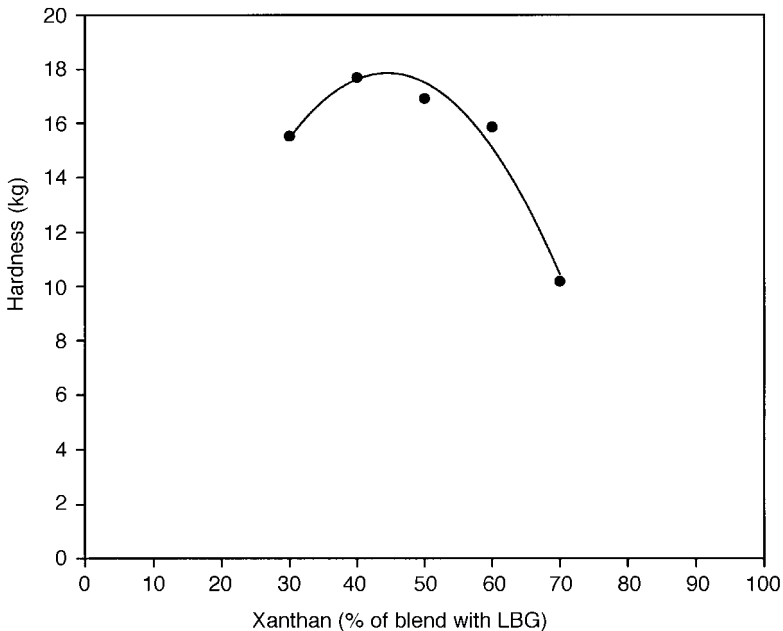
Fig. 6.8   Effect of gum ratio on the hardness (force required to break the gel) of xanthan/locust bean gum gels (1% total gum in 0.05M NaCl).

6.5   Uses and applications

The following is a summary of the many applications for xanthan gum or blends of xanthan gum and galactomannans and their related functions and benefits.

6.5.1   Batters

In wet prepared batters, xanthan gum reduces flour sedimentation; improves gas retention; imparts enzyme, shear and freeze-thaw stability; and provides uniform coating and good cling. In pre-dusts, xanthan gum improves adhesion and controls moisture migration during frying. In pancake batters, xanthan gum improves spread control, volume and air retention.

Xanthan gum is used in batter coatings for onion rings where inconsistent adhesion, caused by the waxy coating found in onion rings, can be eliminated. Variations in waxiness between varieties and seasons occur and can increase this problem. Cling properties associated with the high at-rest viscosity of xanthan gum solutions contribute to the increased adhesion of the batter. Use levels of approximately 0.15% of the batter weight are effective in this application. Batters for fish can be stabilised with 0.06% xanthan gum whereas 0.1–0.15% is recommended for thin batters such as those used with shrimps (tempura). Xanthan can also be used in batters for frozen products such as chicken, shrimp or fish.

6.5.2   Baked goods, bakery and pie fillings

Xanthan gum contributes smoothness, air incorporation and retention, and recipe tolerance to batters for cakes, muffins, biscuits and bread mixes. Baked goods have

increased volume and moisture, higher crumb strength, less crumbling and greater resistance to shipping damage. Xanthan gum improves volume, texture and moisture retention in refrigerated dough, reduced calorie baked goods and gluten-free breads.

Moisture control is essential at all stages of cake production and also when formulating a dry cake mix. Improper moisture control can result in lumpy cake batters and uneven mixing, giving poor structure which results in collapsed cakes during or after baking. The overall quality of the finished cake, particularly after storage, can be affected by poor hydration characteristics of the dry ingredients. For example, volume can be reduced and texture may be non-uniform or fragile when moisture is not evenly distributed throughout the cake. Xanthan gum blended with the other dry cake ingredients, hydrates rapidly and evenly to aid in preventing lumping during the critical initial mixing stage. This even hydration aids in the uniform distribution of moisture in the batters, which in turn helps stabilise the fine air cells formed during the mixing process. The stabilisation of air cells improves volume and symmetry in the finished cake. Xanthan can be added to the cake batter at 0.05% (total batter weight) without the need for any other formulation change.

Adding xanthan gum to either cold or hot processed bakery and fruit pie fillings improves texture and flavour release. The added benefits in cream and fruit fillings are extended shelf stability, freeze-thaw stability and syneresis control.

6.5.3   Dairy products

Blends of xanthan gum, carrageenan and galactomannans are excellent stabilisers for a range of frozen and chilled dairy products such as ice cream, sherbet, sour cream, sterile whipping cream and recombined milk. These economical blends are available pre-prepared and provide optimal viscosity, long-term stability, improved heat transfer during processing, heat shock protection and ice crystal control.

6.5.4   Dressings

This is arguably the largest single application of xanthan gum in the food industry. Xanthan gum's stability to acid and salt, effectiveness at low concentrations and highly pseudoplastic rheology make it the ideal stabiliser for pourable, no-oil, low-oil and regular salad dressings. Dressings with xanthan gum have excellent long-term stability and a relatively constant viscosity over a wide temperature range. They pour easily but cling well to the salad. Use level is typically between 0.2–0.4% xanthan depending on the oil content. Generally, as the oil content of the dressing increases less xanthan gum is required for stabilisation and a guide to use levels is given in Table 6.3. Dressings can be formulated over a wide range of oil contents as shown in Formulation 6.1.

Table 6.3   Suggested stabiliser level for salad dressing formulation

% Oil used	10	20	30	40
% Starch	2.0	2.0	1.5	1.5
% Xanthan gum	0.35	0.3	0.25	0.25

Formulation 6.1   Recipe for salad dressings using KELTROL® T xanthan gum.

Ingredients	(%)
Water	to 100.0
Distilled malt vinegar	15.0
Vegetable oil	see Table 6.3
Sugar	10.0
Egg yolk powder	1.35
Salt	1.0
Mustard powder	0.8
Lemon juice	0.8
Potassium sorbate	0.1
Waxy maize starch	see Table 6.3
Xanthan gum	see Table 6.3

Preparation
1. Slurry the xanthan and starch in a little of the oil. Use approximately 2 parts oil to 1 part gum. This will help to disperse the gum easily into the water without lumping.
2. Add the slurry to the water and continue mixing with a high shear mixer until a smooth, lump free solution is obtained.
3. Pre-blend the other dry ingredients and dissolve them into the gum solution.
4. Slowly add the oil using vigorous agitation to achieve an homogeneous emulsion.
5. Slowly add the distilled malt vinegar and lemon juice whilst stirring.
6. Homogenise at 105kg/cm^2 (1500psi) and fill into bottles.

6.5.5   Dry mixes
Fine particle size xanthan gum provides rapid, high viscosity development in cold or hot systems and yields excellent texture and flavour release. It also permits easy preparation of desserts, salad dressings, dips, soups, milkshakes, sauces, gravies and beverages. In dry mix beverages, xanthan gum provides enhanced body and quality to the reconstituted drink. In addition, it uniformly suspends fruit pulp in prepared drinks to improve product appearance and texture.

6.5.6   Frozen foods
Stability, syneresis control and consistent viscosity during freeze-thaw cycles and heating are achieved by adding xanthan gum to a variety of frozen products such as whipped toppings, sauces, gravies, batters, entrées and soufflés.

6.5.7   Retorted products
Although xanthan gum provides stable, high viscosity over a range of temperatures, this viscosity is temporarily reduced at retort temperatures, ensuring good thermal penetration in retorted foods. At the same time the ability of xanthan gum to recover its viscosity upon cooling, provides a uniform, high-quality product. In retort pouch products, xanthan gum also improves filling and reduces splashing and fouling of the critical heat-seal area of the pouch. Xanthan gum can be used to partially replace starch in this application. This results in improved heat stability and a cleaner, less pasty mouthfeel. Typically, xanthan is used at 0.1–0.2% concentration.

6.5.8   Sauces and gravies

Low levels of xanthan gum provide high viscosity in sauces and gravies at both acid and neutral pH. Viscosity is also stable to temperature changes and is maintained under a variety of long-term storage conditions. Sauces and gravies containing xanthan gum cling to hot foods.

6.5.9   Syrups and toppings

Xanthan gum promotes ease of pouring and excellent cling to ice cream, fruits and pancakes. Under refrigerated storage, syrups and toppings retain uniform consistency. Cocoa powder in chocolate syrups remains suspended. Frozen non-dairy whipped toppings and frozen whipped topping concentrates have firm texture, high overrun and excellent freeze-thaw stability.

6.6   Regulatory status

Xanthan gum is recognised as a food additive under the provisions of the US Food and Drug Administration regulations (21 CFT 172.695) for use as a stabiliser, thickener or emulsifier. Xanthan gum is designated by the European Union as E415 with a non-specified acceptable daily intake (ADI). KELTROL® and KELTROL® F xanthan gum are approved for Kosher use.

6.7   References

1. HARDING, N. E., IELPI, L. and CLEARY, J. M. (1995) 'Genetics and biochemistry xanthan gum production by *Xanthomonas campestris*' in *Food Biotechnology Microorganisms*, eds Y. H. Hui and G. C. Khachatourians. VCH Publishers, New York, pp. 495–514.
2. JANSSON, P. E., KENNE, L. and LINDBERG, B. (1975) 'Structure of the exocellular polysaccharide from *Xanthomonas campestris*' *Carbohydr. Res.* **45**, 275–82.
3. MELTON, L. D., MINDT, L., REES, D. A. and SANDERSON, G. R. (1976) 'Covalent structure of the polysaccharide from *Xanthomonas campestris*: evidence from partial hydrolysis studies' *Carbohydr. Res.* **46**, 245–57.
4. MOORHOUSE, R., WALKINSHAW, M. D. and ARNOTT, S. (1977) 'Xanthan gum-molecular conformation and interactions' in *Extracellular Microbial Polysaccharides*, ed. P. A Sandford. ACS symposium series no. 45, American Chemical Society, Washington, DC, pp. 90–102.
5. JEANES, A., PITTSLEY, J. E. and SENTI, F. R. (1961) 'Polysaccharide B-1459: a new hydrocolloid polyelectrolyte produced from glucose from bacterial fermentation' *J. App. Polym. Sci.*, **5**, 519–26.
6. MORRIS, E. R., REES, D. A., YOUNG, G., WALKINSHAW, M. D. and DARKE, A. (1977) 'Order-disorder transition for a bacterial polysaccharide in solution: a role for polysaccharide conformation in recognition between *Xanthomonas* pathogen and its plant host' *J. Mol. Biol*, **110**, 1–16.
7. KAWAKAMI, K., OKABE, Y. and NORISOYE, T. (1991) 'Dissociation of dimerized xanthan in aqueous solution' *Carbohydr. Polym.*, **14**, 189–203.
8. OVIATT, H.W. and BRANT, D. A. (1993) 'Thermal treatment of semi-dilute xanthan solutions yields weak gels with properties resembling hyaluronic acid' *Int. J. of Biol. Macromol.*, **15**, 3–10.
9. BAKER, C. W. and WHISTLER, R. L. (1975) 'Distribution of D-galactosyl groups in guar and locust bean gum' *Carbohydr. Res*., **45**, 237–43.
10. COURTOIS, J. E. and LEDIZET, P. (1966) 'Action de α-galactosidase du café sur quelques galactomannaes' *Carbohydr. Res*., **3**, 141–51.
11. COURTOIS, J. E. and LEDIZET, P. (1970) 'Recherches sur les galactomannanes. VI Action de quelques mannase sur diverses galactomannanes' *Société de Chemie Biologique, Paris, Bulletin* **52**, 15–22.