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MICROBIAL POLYSACCHARIDES: NEW PRODUCTS AND THEIR COMMERCIAL APPLICATIONS

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Abstract - In the past two decades, significant progress has been made in the identification, characterization, and commercialization of microbially-derived polysaccharides. Although xanthan gum is the only commercially significant microbial polysaccharide to be used in food, industrial, and oil field applications, other new microbial polysaccharides are the main topic of this paper. Gellan gum, a microbial polysaccharide from *Pseudomonas elodea*, is sold now for use in microbiological media as a gelling agent to replace agar. Gellan gum's unique properties also appear to have great potential in structured food products. S-130, a biopolymer from a strain of *Alcaligenes* has excellent heat stability, suspending capabilities, and rheological properties which are useful in a variety of oil field applications. S-194, another biopolymer, has unusual compatibility with high levels of salts, is stable to shear, and has excellent suspending properties. S-194 is particularly useful in agricultural applications, especially suspension (liquid) fertilizers and flowable pesticides.

New applications for xanthan gum, including its use in retort pouch foods, candy, farinaceous foods, jet and foam printing will be briefly reviewed also.

It appears as if new microbial polysaccharides will continue to be discovered and some of these will undoubtedly outperform current polysaccharides in the market place.

INTRODUCTION

This paper will illustrate the wide diversity of properties found in microbial polysaccharides that have commercial applications. Currently, xanthan gum is the major significant commercial microbial product, but gellan gum, which is in its initial stages of commercialization, is currently being sold as an agar replacer for use in microbiological media (Table 1). Several pertinent reviews on microbial polysaccharides have appeared (1-11).

TABLE 1. Microbial polysaccharides of commercial interest

	Type	Microbial Source
a. Commercially Available		
Xanthan Gum	Anionic	*Xanthomonas campestris*
Gellan Gum	Anionic	*Pseudomonas elodea*
Dextran	Neutral	*Leuconostoc spp.*
b. Under Current Development		
S-130 Polysaccharide	Anionic	*Alcaligenes spp.*
S-194 Polysaccharide	Anionic	*Alcaligenes spp.*
c. Developed to Large Scale		
Scleroglucan	Neutral	*Sclerotium spp.*
Curdlan	Neutral	*Agrobacterium spp.* *Alcaligenes faecalis*
Pullulan	Neutral	*Aureobasidium pullulans*
Bakers' yeast glycan	Neutral	*Saccharomyces cerevisiae*
Bacterial alginate	Anionic	*Azotobacter vinelandii* *Pseudomonas aeruginosa*

DRIVING FORCES IN MICROBIAL POLYSACCHARIDE DEVELOPMENT

Unlike traditional gums, microbial polysaccharides can be produced uniformly and reliably by fermentation. Thus, microbial polysaccharides are not subject to variations in climatic conditions. Besides stability in supply, other factors favoring microbial polysaccharides, such as xanthan gum, include their improved and sometimes novel functionality. Often microbial polysaccharides allow superior commercial products to be formulated and in somes cases at a lower cost.

MAJOR MARKETS OF POLYSACCHARIDES

Polysaccharides are used commercially to thicken, suspend, or stabilize aqueous systems. Also they are used to produce gels and to act as flocculants, binders, film-formers, lubricants, and friction reducers.

Tables 2 lists the most important industrial markets, and Table 3 the food markets of polysaccharides, including plant, seaweed, and microbially-derived products, (1, 12-14). Traditionally, industrially useful polysaccharides have been derived from algal and plant sources, but in more recent times polysaccharides such as xanthan gum, microbially derived, have found increased usage.

TABLE 2. Polysaccharide Applications

Market and Application	Properties	Polysaccharides
ADHESIVES (also see Paper)		
- Latex	Rheology	Cellulosic derivatives
- Tile Mortars (Cement)	Fluid loss/rheology	Methylcellulose
- Wallpaper	Thickening	Algin, starch, modified starch
AGRICULTURE		
- Flowable pesticides	Suspension-drift control	Xanthan gum
- Liquid fertilizers	Suspension	Xanthan gum
- Liquid feed supplements	Suspension	Xanthan gum, guar gum,
CERAMIC, REFRACTORIES,	Slip Agent	Algin
WELDING RODS	Suspension	Xanthan Gum
CLEANERS, POLISHES	Abrasive, suspension, acid and Base stability	Xanthan Gum
DETERGENTS	Antiredeposition, antisoil	Carboxymethylcellulose
EXPLOSIVES		
- Ammonium nitrate slurries	Water resistnace	Guar gum, hydroxypropyl guar gum, xanthan gum
- Package gels	$Ca(NO_3)_2$ compatibility	Guar gum, hydroxypropyl guar gum, xanthan gum
FIRE-FIGHTING	Foam stabilization, ignition retardation	Guar gum, guar derivatives and xanthan gum
INK (FLEXO, GRAVURE, JET)	Rheology	
LITHOGRAPHY	Low-Viscosity-High-Solids	Gum arabic
METAL-WORKING		
- Refractory Coatings	Suspension	-
MINING (HEAVY MEDIA SEPARATION)	Suspension	Xanthan gum, starch, guar

Table 2 contd. on p. 881

TABLE 2. Polysaccharide Applications: cont.

Market/ Application	Properties	Polysaccharides
OILFIELD		
- Drilling Muds	Viscosity, suspension	Xanthan gum, cellulose ethers
- Enhanced Oil Recovery Polymer Flooding	Viscosity	Xanthan gum
- Fluid-loss additives	Fluid loss properties	CMC
- Slimulation Hydraulic fracturing	Suspension, fluid loss, viscosity reduction by chemical/enzymatic breakers, crosslinkable	Hydroxypropyl guar gum, Hydroxyethyl cellulose xanthan gum, Carboxymethyl cellulose
- Acidizing	Suspension, stability to strong acids at elevated temperatures	Xanthan gum
PAINT		
- Latex Trade Sales	Rheology-suspension	Hdroxyethyl cellulose methylcellulose, (microbial biopolymers)
- Maintenance Coatings		
- Industrial Coatings		
PAPER		
- Wet end binder	Formation-beater aid	Modified starch, guar derivatives, locust bean gum, and karaya gum
- Coatings	Rheology	Algin, Carboxymethylcellulose
- Surface Sizes	Film-Forming, water-loss, printing	Starch, modified starch and algin
- Particle board, corrugated board	Extend glue	
PHOTOGRAPHY	Antistatic Coating, extension	Sodium cellulose sulfate
POLYMERIZATION		
- Emulsion	Protective colloid	Hydroxyethylcellulose
- Suspension	Suspension	Xanthan gum
ROOM DEODORANT GELS	Stable gel	Carrageenan
TEXTILES		
- Warp sizing	Film forming	Starch, modified starch and CMC
- Printing	Rheology antimigrant-disperse dyes	Algin
- Batch dyeing	Same as Printing	
- Pad dyeing	Same as Printing	Algin, Karaya
- Pigment printing	Rheology-binder compatability	Modified starch, Hydroxyethyl cellulose, methyl cellulose, hydroxypropyl guar gum, guar, locust bean gum
- Jet printing	Rheology	Modified starch, Hydroxyethyl cellulose, methyl cellulose, hydroxypropyl guar gum, guar, locust bean gum
- Fabric finish	Fiber substantivity	Cellulosics

TABLE 3. Polysaccharide food markets (1)

	Dry foods	Canned foods	Glassed foods	Bakery products	Dairy products	Frozen foods	Salad dressings	Beverages	Soft drinks	Brewing	Confectionery	Pharmaceuticals	Cosmetics	Detergents	Pet foods
Microbial															
Xanthan gum	x	x	x	x	x	x	x	x			x	x	x		x
Seaweed															
Alginates	x	x	x	x	x	x	x			x	x	x	x		x
Agar						x	x				x	x	x		
Carrageenan		x			x				x		x		x		x
Plant															
Guar Gum				x	x	x						x			x
Locust Bean Gum					x							x			x
Psyllium Husks												x			
Quince Seed											x				
Gum Arabic				x				x	x	x	x	x	x		
Gum Tragacanth		x	x				x		x		x	x	x		
Gum Karaya															
Cellulosics															
CMC		x	x	x	x		x	x			x	x	x	x	x
HPC		x		x							x				
HEC				x				x							
Microcrystalline Cellulose	x											x	x		

GELLAN GUM

Source - The fermentation and isolation of gellan gum have been previously described in detail and will not be discussed further here (15-17) There are two commercial forms of gellan gum: one that forms a brittle gel and one that forms an elastic gel.

Composition/Structure - In the search for microbial polysaccharides with solution properties of commercial interest, the exocellular polysaccharide elaborated from the bacterium *Pseudomonas elodea* (14, 15) was found. This polysaccharide contains O-acetyl groups, which when removed by hot, alkaline treatment gave aqueous solutions which have low viscosity at elevated temperatures but which form strong gels on cooling in the presence of cations (17). This polysaccharide, now called gellan gum, has been shown to be composed of tetrasaccharide repeating units having the following structure. [->3)-β-D-Glcp-(1->4)-β-D-Glcp A-(1->4)-β-D-Glcp-(1->4)-α-L-Rhap-(1->] (18-19). NMR indicates that the position of the O-acetyl group(s) is on the C-6 position of one of the glucose units.

Properties - Brittle gellan gum gels are similar to carrageenan gels and like carrageenan, gellan gum requires cations for gelation (20) (Table 4). Like agar, brittle gellan gum gels exhibit marked melting/setting hysteresis. Figure 1 illustrates that maximum gel strengths are achieved with lower divalent cation levels than with monovalent cations.

TABLE 4. Gellan gum gel properties: comparison with Carrageenan and Agar

	Gel Nature	Melting Point (°C)	Setting Point (°C)	Hysteresis (°C)
Gellan Gum	Brittle	90	40	45-60
Kappa Carrageenan	Brittle	40-95	25-75	12-20
Agar	Brittle	60-97	32-39	<65

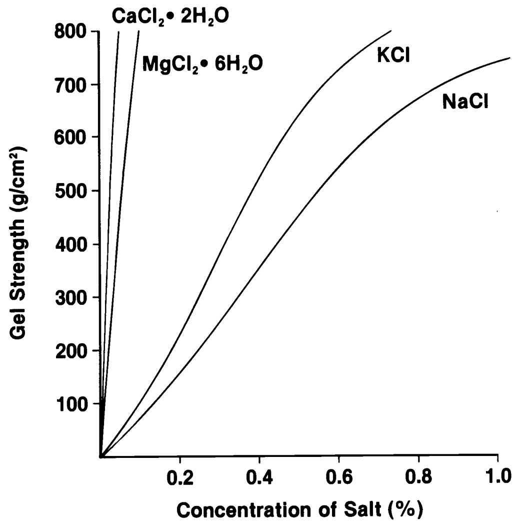


Fig. 1

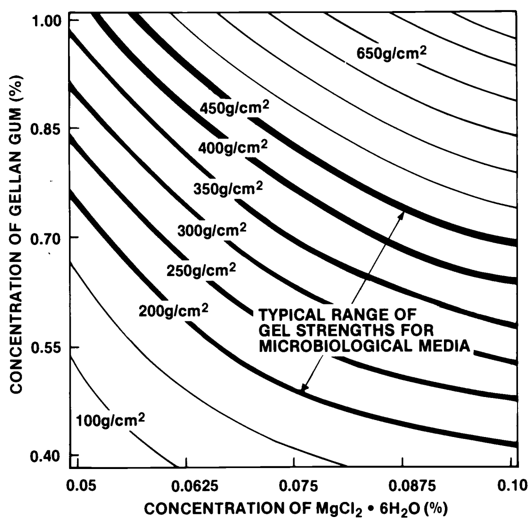


Fig. 2

Fig. 1. Effect of cations on the gel strength of gellan gum (Gelrite™).

Fig. 2. Gel strength of gellan gum (Gelrite™) as a function of gellan gum and Mg^{++} concentrations.

Microbiological Media - Currently a gellan gum product with excellent clarity is being sold under a trade name of GELRITE™ as a gelling agent for the preparation of microbiological media (22-23). In this application, GELRITE forms high gel strength gels that are stable to multiple autoclavings, chemically inert to most biological growth media additives, generally resistant to enzymatic degradation, and melt/set reversibly like agar. Figure 2 shows the effect of gellan gum and magnesium (Mg^{++}) concentration on gel strength. By adjusting the concentration of gellan gum or magnesium ions, a large range of gel strengths is available. Typically, the gel strength of microbiological media is between 200-400 g/cm^2. Three apparent advantages of GELRITE over agar are 1) improved clarity, 2) equivalent gel strength at about 1/3 to 1/2 the use level, and 3) reduced toxicity to sensitive microorganisms and plant tissue cultures. A recent study (23) also indicates that GELRITE is superior to agar as a gelling agent in media for the growth of thermophilic microorganisms (Table 5). Most gels formed by heating and cooling gellan gum remelt on heating.

TABLE 5. Comparative growth of thermophiles on media solidified with GELRITE™ or agar (23)

Organism	Basal medium	Gelling Agent	Gelling Aid	Incubation Temp (°C)	Incubation Time (h)	Gel St. (g/cm^2)	Med. Appear. after Inc	CFU[a] (mean ±SD)
B. acidocaldarius	Bacillus medium	2% Agar		55	24	550	Cloudy	15 ± 2
	Bacillus medium	0.55% GELRITE	0.057% $CaCl_2.2H_2O$	55	24	470	Clear	780±163
B. stearothermophilus	Nutrient broth	2% Agar		55	24	402	Cloudy	1,216±27
	Nutrient broth	0.8% GELRITE	0.1% $MgCl_2.6H_2O$	55	24	620	Clear	446±30
	Nutrient broth	2% Agar	0.1% $MgCl_2.6H_2O$	55	24	-	Cloudy	536±26
T. thermophilus	Thermus medium	3.0% Agar		70	48	1,150	Cloudy semigel	0±0
	Thermus medium	1.1% GELRITE	0.1% $CaCl_2.2H_2O$	70	48	910	Clear; intact gel	792±30
T. aquaticus	Castenholz TYE medium	1.5% Agar		70	48	275	Cloudy; bubbles	16±1
	Castenholz TYE medium	0.8% GELRITE		70	48	455	Clear; no bubbles	767±13

[a] For each organism similar inoculum levels were used for all media, CFU = Colony Forming Units.

TABLE 6. Typical potential food applications of Gellan Gum

Major food area	Typical Products	Function of Gellan Gum
Confectionery	Starch jellies, pectin jellies, fillings, marshmallow	Provide structure/texture, reduce set time
Jams and jellies	Reduced-calorie jams, imitation jams, bakery fillings, jellies	Provide consistency/gel, reduce syneresis
Fabricated foods	Fabricated fruits, vegetables, meats	Gel matrix, freeze/thaw stability
Water-based gels	Dessert gels, aspics	Good mouth feel, gelatin replacer
Pie fillings and puddings	Instant desserts, canned puddings, precooked puddings, pie fillings	Starch replacer, eliminate syneresis
Pet foods	Canned meat chunks, gelled pet foods	Provide structure/shape
Icings and frostings	Bakery icings, canned frostings	Prevent moisture loss, cracking, sugar crystallizing, agar replacer
Diary products	Ice cream, gelled milk, yogurt, milkshakes	Gel structure

Food Systems - Properties such as those described above make gellan gum suitable for use in food systems (24-26). Gellan gum has not yet been cleared by FDA for use in food. Table 6 shows typical food applications where gellan gum has potential. Particularly attractive are the gel melting temperatures that gellan gum offers. Some food products may be required to melt for reprocessing, while others may require a gel structure that is stable to heat treatment (e.g., frying). The setting temperature is usually between 30° to 45°C while the melting temperature can be either above or below 100°C, depending on conditions of formation such as types and amounts of cations. In some products, desirable texture, body and mouthfeel can be achieved by using gellan gum in combination with other food hydrocolloids such as xanthan gum, locust bean gum, guar gum, carboxymethylcellulose (CMC), modified starches, agar, carrageenan, gelatin, algin, or pectin.

Microencapsulation - Gellan gum forms rigid coacervate gels in the presence of gelatin. These coacervate gels have been found to be suitable for use in microencapsulation (27). Above 60°C, gellan gum forms a fluid low viscosity coacervate with gelatin, while at 25°C it produces a high strength coacevate gel. Gellan gum/gelatin coacervates are stable over a wide pH range and in the presence of soluble salts. Gellan gum coacervate gels contain carboxyl groups that are available for chemical crosslinking.

Industrial Gels - Both aqueous and glycol (ethylene glycol, propylene glycol, glycerol) gels have industrial uses (28). For example, air freshener gels can be made and the rate of evaporation can be varied by varying the glycol content.

S-130 POLYSACCHARIDE

Source - S-130 polysaccharide, produced by an *Alcaligenes* species in an aerobic submerged fermentation, is described in U.S. Patent 4,342,866 (29).

Composition/Structure - Initial data indicates that the S-130 polysaccharide is composed of glucose: rhamnose: glucuronic acid in the ratios of 2:2:1 with varying amounts of mannose (~1 part).

Outstanding Properties - Besides having high viscosity at low concentrations, excellent suspending properties, pseudoplastic rheological properties (shear thinning), and excellent stability towards pH (2-12) and shear, polysaccharide S-130 has the outstanding property of unusual and excellent viscosity retention at temperatures up to 150°C (~300°F). In Figure 3 the viscosity-temperature profiles of S-130, xanthan gum, and hydroxyethylcellulose (HEC) are compared, demonstrating that the viscosity of S-130 is more stable at high temperatures than either HEC or xanthan gum. Table 7 compares the viscosity half lives of these three gums at various temperatures. Again S-130 can be seen to have excellent viscosity stability at high temperatures, suggesting that S-130 will have potential in applications where viscosity at temperature is required. One such application would be drilling fluids used to drill deep, and hence hot, wells.

S-130 is an excellent suspending agent. Whether the solids are cuttings, weighting material, bridging particles, fracturing sand, or gravel for packs, S-130 suspends better than other polymers used in oil field applications such as HEC or hydroxypropyl guar (See Figure 4).

S-130 develops high viscosity in most saline waters (e.g., 3% KCl, seawater, brackish waters, saturated NaCl and $CaCl_2$ up to 20%), although it is not recommended for use in saturated heavy brines above a density of 1.3 (eg. saturated $CaCl_2$, $CaBr_2$). The viscosity of S-130 is relatively stable to pH changes, although viscosity loss does occur at pH values above 11.0 in the presence of elevated levels of Ca^{++}.

S-130's rheological characteristics, however, are ideal for a low-solids drilling mud and for other aqueous oil field fluids at high temperature in the deeper oil wells.

TABLE 7. Viscosity half-lives at temperature

	Half-lives (minutes) at Temperature					
Product	225°F	250°F	265°F	275°F	300°F	325°F
Hydroxyethyl Cellulose	65	10	0	0	0	0
Xanthan Gum	428	273	100	0	0	0
S-130	N.D.	N.D.	N.D.	900	50	2.5

Viscosity of 0.4% gum in 3% KCl with 300 ppm Na_2SO_3, measured with Fann 50C viscometer at 100 sec^{-1}.

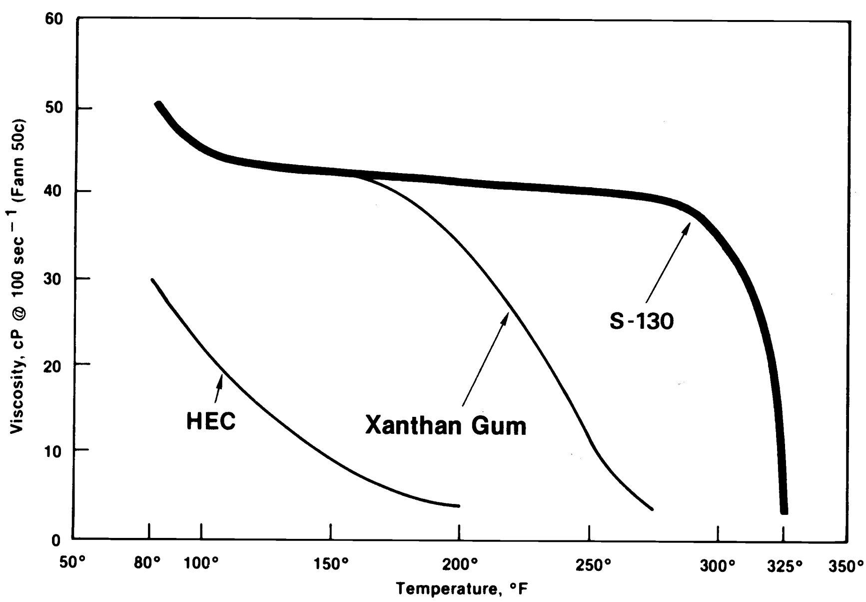


Fig. 3. Viscosity versus temperature curves. Comparsion of S-130 with hydroxyethylcellulose (HEC) and xanthan gum (KELZAN XC®).

S-194 POLYSACCHARIDE

Source - S-194 polysaccharide, produced by an Alcaligenes species in an aerobic fermentation process, is described in U.S. Patent 4,401,760 (30). After growth on a medium with glucose as a carbon source, the polysaccharide is recovered by alcohol precipitation, dried, and milled.

Composition - S-194 is composed of glucuronic acid, glucose, and rhamnose in the approximate ratios of 1:4:1 and also contains O-acyl groups (4% as acetyl). The structure of S-194 is not currently known.

Outstanding Properties - S-194's key features are its compatibility with high levels of salt and its ability to suspend components of suspension fertilizers (31). Like S-130, S-194 provides high viscosity at low concentrations and low shear rates. The viscosity of S-194 solutions is not affected by high temperatures even at 100°C (see Figure 5). Figure 6 shows that S-194 has pseudoplastic rheology (shear thinning) much like xanthan gum.

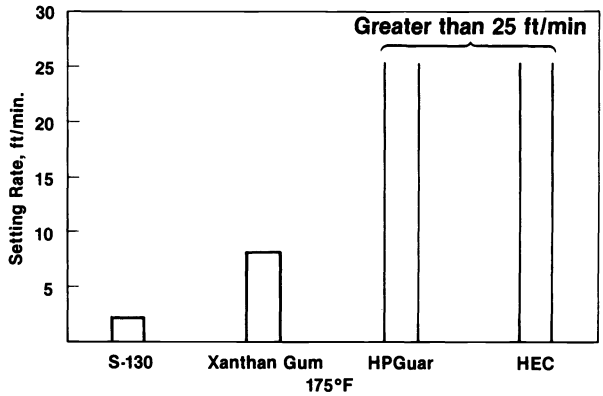
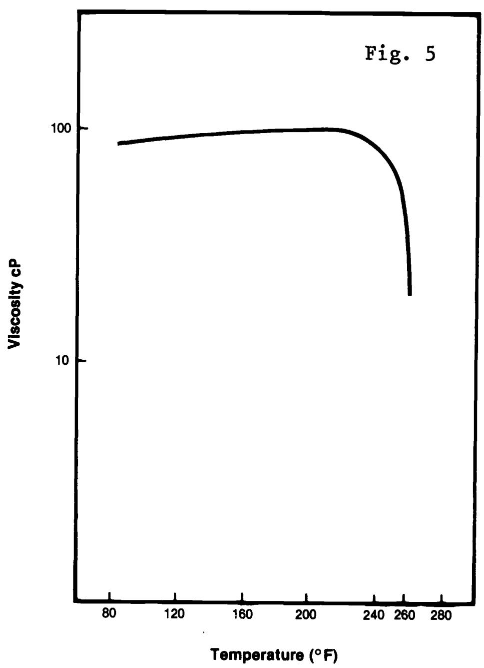


Fig. 4. Suspension capabilities of S-130 using 10-20 mesh sand: Comparsion with xanthan gum (KELZAN XC®), hydroxypropyl guar (HP Guar), and hydroxyethylcellulose (HEC). Conditions: 1 pound gum/barrel; 3% KCl; 175°F; 10-20 mesh sand.



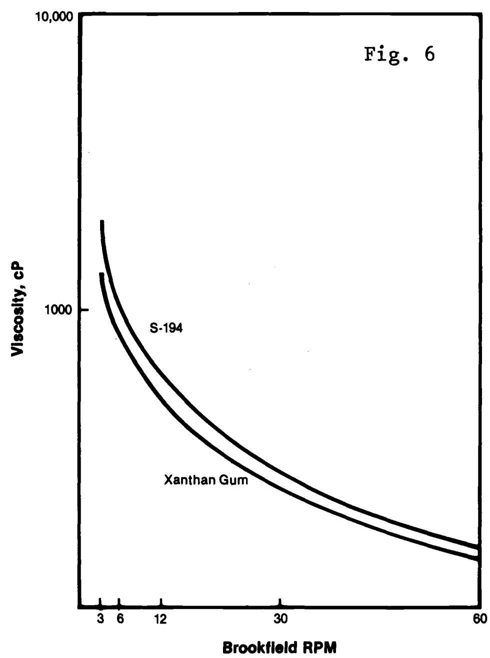
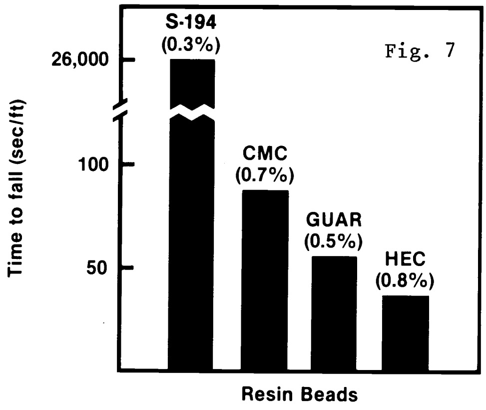


Fig. 5. Viscosity of S-194 versus temperature. Conditions: 0.5% S-194: Fann 50 c viscometer, 100 sec^{-1}.

Fig. 6. Viscosity versus shear rate of S-194 and xanthan gum. Brookfield LVF viscometer, appropriate spindle, 25°C; gum concentration, 0.25%.

Suspension fertilizers have become popular because lower production costs are achieved by use of lower grades of materials, grades of higher analysis than normal liquids are possible, especially higher percentages of potassium, and micronutrients can be uniformly distributed. Although most polysaccharide suspending agents are usually incompatible (e.g., salt out) with the high concentrations of ammonium polysphosphate or orthophosphate used in suspension fertilizers, S-194 has excellent suspension capabilities and salt compatibility and formulation of a wide variety of suspension fertilizers (See Figures 7 and 8).



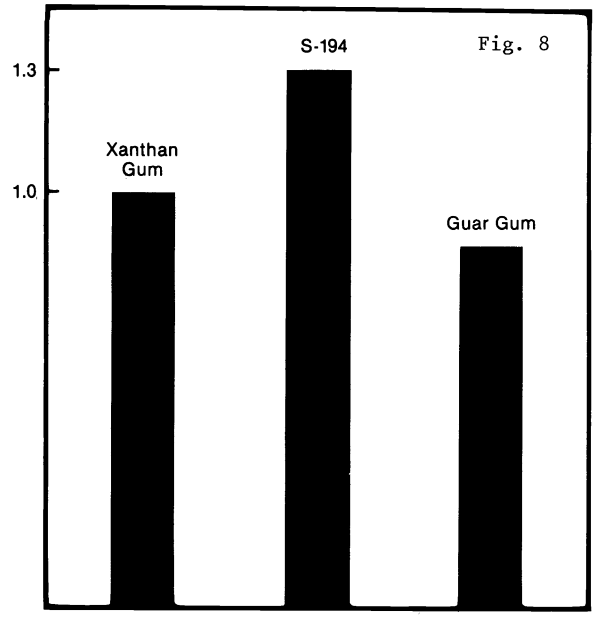


Fig. 7. Suspension capabilities of S-194 and other gums using resin beads. All solutions were adjusted to 200 cP (Brookfield LVF, spindle No. 2, 60 rpm, 25°C). The beads were ~5 mm in diameter and had a density of 1.25 g/cc. CMC = carboxymethylcellulose, HEC = hydroxyethylcellulose, GUAR = guar gum.

Fig. 8. Relative compatibility of S-194, xanthan gum and guar gum with ammonium polyphoshate (10-34-0). S-194 will accomodate more ammonium polyphosphate without salting out.

TABLE 8. Major food and industrial applications of xanthan gum

FOOD
- Dressings (high oil, low oil, no oil)
- Relishes and sauces
- Syrups and toppings
- Starch-based products (canned desserts, sauces, fillings, retort pouches)
- Dry mix products (desserts, gravies, beverages, sauces, dressings)
- Farinaceous foods (cakes)
- Beverages
- Dairy products (ice cream, shakes, processed cheese spread, cottage cheese)
- Confectionery

INDUSTRIAL
- Flowable pesticides
- Liquid feed supplements
- Cleaners, abrasives, and polishes
- Metal-working
- Ceramics
- Foundry coatings
- Texturized coatings
- Slurry explosives
- Dye and pigment suspensions

OIL FIELD
- Drilling fluids (muds)
- Workover and completion fluids
- Stimulation - hydraulic fracturing
  - acidizing
- Enhanced oil recovery - polymer flooding

Commonly use levels of about 0.1% of S-194 can replace 1-3% attapulgite clay, the suspending agent frequently used.

Another outstanding property of S-194 is its stability towards shear. In the preparation of flowable pesticides it is standard practice to grind the active ingredient to a fine particle size (e.g., <5μm). Often used is a Dyno Mill that uses glass beads as the grinding medium and imparts such intense shear that the viscosity of most polymer solutions is irreversibly lost. Figure 9 shows that S-194 is very stable to shear in a Dyno Mill.

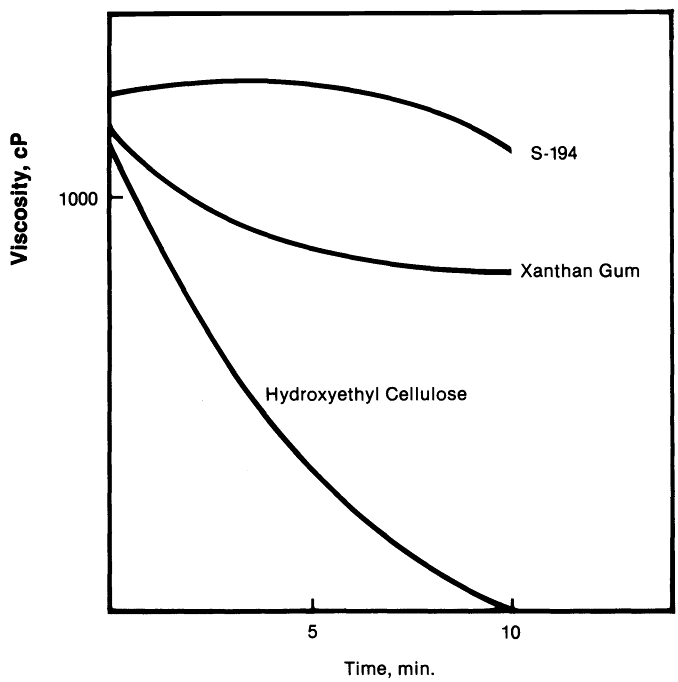


Fig. 9. Effect of DYNO-MILL treatment on the viscosity (Brookfield LVF Viscometer, 3 rpm, 25°C, appropriate spindle) of S-194, xanthan gum and hydroxyethylcellulose (HEC). Glass beads are the grinding medium.

NEW APPLICATIONS FOR XANTHAN GUM

Since xanthan gum is the only microbial polysaccharide used extensively in food and industrial applications, a few new uses of xanthan gum will be mentioned briefly. Xanthan gum has been successfully used in various commercial applications since the 1960's and its use in food and industrial applications is due to its remarkable properties that include 1) high viscosity at low concentration, 2) high pseudoplasticity (shear thinning), 3) yield value/ suspending power, and 4) stable viscosity towards salts and a wide range of temperature and pH.

Although Table 8 lists the major commercial applications of xanthan gum, I would like to highlight a few of the most recently identified applications (32).

Retort Pouch Foods (33) - An alternative to the conventional cans, jars and foil trays, retort pouches are finding increased usage for foods because the resulting foods have better color, firmer texture, and fresher flavor as a consequence of reduced sterilization times in retorts. Xanthan gum is being used in retort pouch foods to maintain filling consistency, improve heat penetration, replace (partial) starch, and provide a clean, non-pasty mouthfeel.

Starch-jelly Confections (34) - Combinations of xanthan gum and locust bean gum (KELGUM®) form a useful thermally-reversible gelling system that provides accelerated gelling to reduce set time, extended shelf life, improved water control and retention, and clean mouthfeel without pastiness.

Farinaceous Foods/Cakes (35) - In these products, the subtle interactions of xanthan gum with other ingredients (such as starch and protein) can result in increased moisture binding and retention, improved volume with less fragility, better rheological control of batters during mixing, pumping, and baking, improved cell structure in the finished cake, due to foam/air cell stabilization, better suspension of fruits or nuts during processing, and improved tolerance to variation in production conditions and ingredient quality.

Fig. 10. Retort pouch sauce.

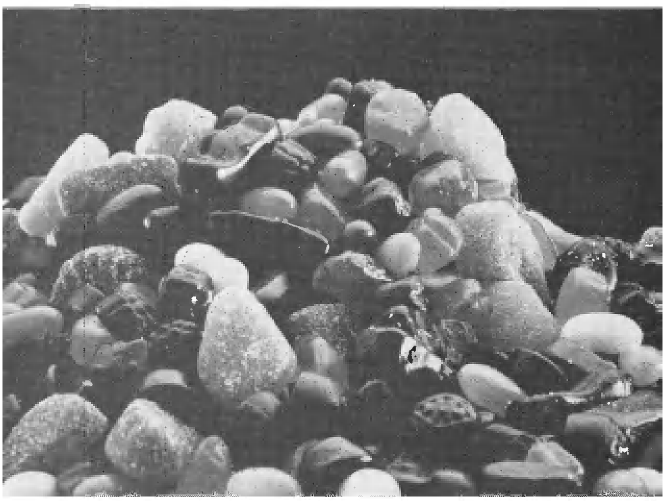


Fig. 11. Candy with xanthan gum.

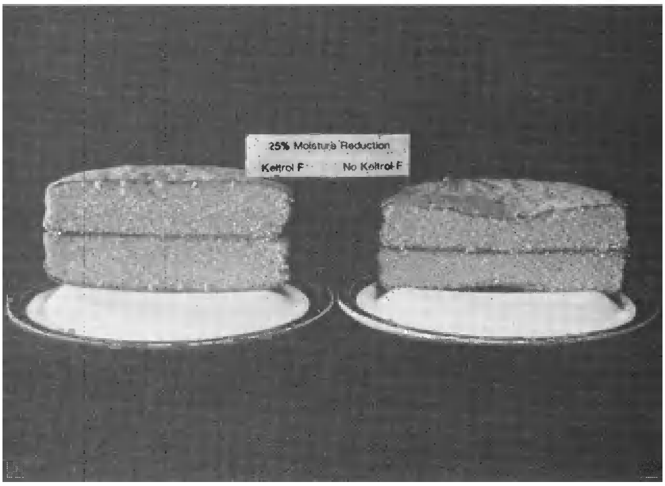


Fig. 12. Cake with (left) and without (right) xanthan gum.

Jet Printing (36) - Computer-injection or jet printing was developed in the mid-seventies and is used primarily for carpet and upholstery printing. Xanthan gum provides stability to shear, and high temperatures, pseudoplastic flow, rapid solubility, and compatibility with most acids and disperse dyestuffs, making it suitable for both nylon and polyester printing.

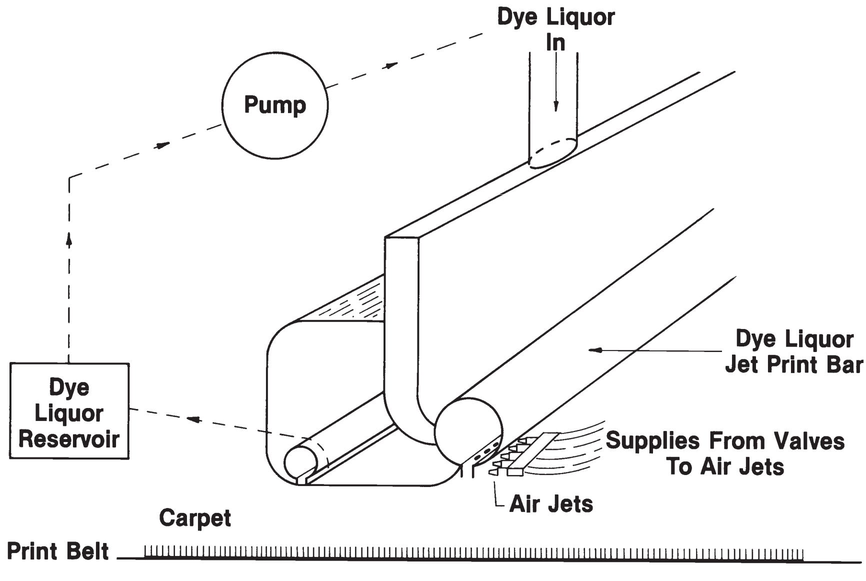


Fig. 13. Carpet jet printer.

Foam Printing (37) - Textile printing and dyeing has recently turned to foam media printing. Essentially, color application involves foaming the print paste and applying it to the fabric substrate. The foam is collapsed mechanically, thermally, or chemically, and allows recyling of the foamed print paste/dye. Xanthan gum can be used to increase the foam stability, provide uniform bubble size, distribution and collapse rate, and control migration of the aqueous phase on the substrate (textile) after the foam has collapsed.

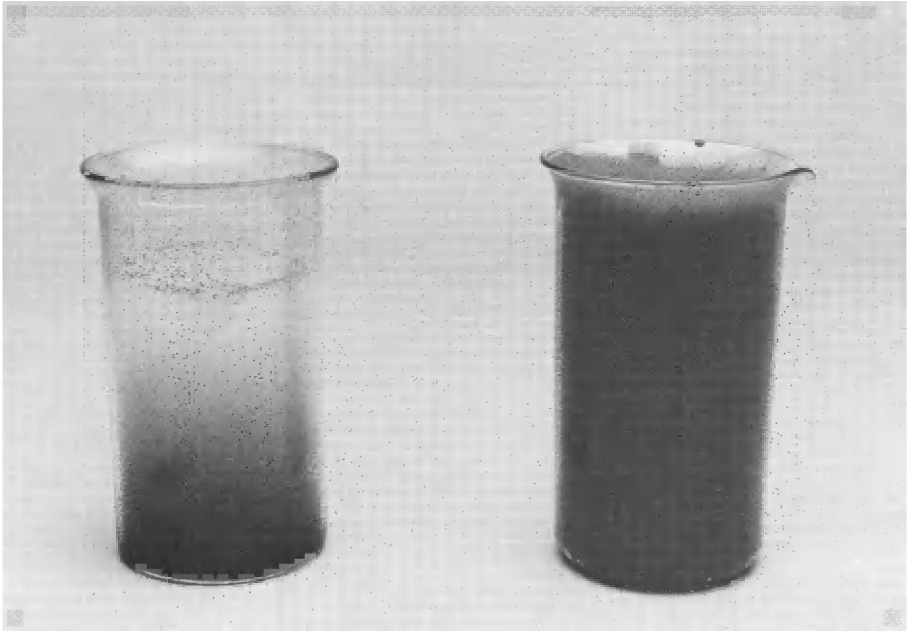


Fig. 14. Printing foams. Left, no xanthan gum added; Right, foam stabilized with xanthan gum.

SUMMARY

The purpose of this paper has been to illustrate that microbial polysaccharides have a wide diversity of properties and potential/new uses. It is anticipated that industry's trend towards water-based thickeners, foaming and gelling agents, industry's continual seeking for lower cost and higher functional products, and the need for new and improved polymers will allow microbial biopolymers to capture markets traditionally occupied by traditional gums.

REFERENCES

1. P. A. Sandford, and J. Baird, "Industrial Utilization of Polysaccharides", The Polysaccharides 2, p. 411-490, Academic Press, New York (1983).

2. J. K. Baird, P. A. Sandford, and I. W. Cottrell, Bio/Technology 778-783 (1983).

3. K. S. Kang, G. T. Veeder, and I. W. Cottrell, "Some Novel Bacterial Polysaccharides of Recent Development, "Progress in Industrial Microbiology 18, p. 231-253, Elsevier, New York (1983).

4. P. A. Sandford, Adv. Carbohydr. Chem. 36, 265-313 (1979).

5. P. A. Sandford, Polysaccharides in Food, p. 251-262, Butterworth, London (1979).

6. D. J. Pettitt, Polysaccharides in Food, p. 263-282, Butterworth, London (1979).

7. I. W. Cottrell and J. K. Baird, Kirk-Othmer Encycl. Technol., 3rd Ed. 12, 45-66 (1980).

8. K. S. Kang and I. W. Cottrell, Microbiol. Technol. 1, 417-481 (1979).

9. I. W. Cottrell, K. S. Kang, and P. Kovacs, "Xanthan Gum", Handbook of Water-Soluble Gums and Resins, McGraw-Hill, New York, 24-1 to 24-31 (1980).

10. P. A. Sandford and A. Laskin, eds., Extracellular Microbial Polysaccharides, ACS Sympo. Ser. 45, Am. Chem. Soc., Washington (1977).

11. R. L. Whistler and J. N. BeMiller, eds., Industrial Gums, Academic Press, New York (1973)

12. Anon., Thickening Agents: Consumer Products, Charles H. Kline & Co., Fairfield, New Jersey (1975).

13. Anon., Thickening and Sizing Agents: Industrial Products, Charles H. Kline & Co., Fairfield, New Jersey (1975).

14. Anon., Paper Industry, 4th ed., Charles H. Kline & Co., Fairfield, New Jersey (1980).

15. K. S. Kang and G. T. Veeder, U.S. Pat. 4,377,636 (1983).

16. K. S. Kang and G. T. Veeder, U.S. Pat. 4,326,053 (1982).

17. K. S. Kang, G. T. Colegrove, and G. T. Veeder, U.S. Pat. 4,326,052 (1982).

18. P.-E. Jansson, B. Lindberg, and P. A. Sandford, Carbohydr. Res. 124, 135-139 (1983).

19. M. A. O'Neil, R. R. Selvendran, and V. J. Morris, Carbohydr. Res. 124, 123-133 (1983).

20. R. Moorhouse, G. T. Colegrove, P. A. Sandford, J. K. Baird, and K. S. Kang, Am. Soc. Soc. Symp. Ser. 150, 111-124 (1981).

21. K. S. Kang, G. T. Veeder, P. J. Mirrasoul, T. Kaneko, and I. W. Cottrell, Appl. Environ. Microbiol 43, 1086-1091 (1982).

22. D. Shungu, M. Valiant, V. Tutlane, E. Weinburg, B. Weisberger, L. Koupal, H. Gadebusch, and E. Stapley, Appl. Environ. Microbiol. 46, 840-845 (1983).

23. C. C. Lin and L. E. Casida, Jr., Appl. Environ. Microbiol. 47, 427-429 (1984).

24. I. W. Cottrell, "Industrial Potential of Fungal & Bacterial Polysaccharides," Fungal Polysaccharides, ACS Symp. Serv. 126, Am. Chem. Soc., Washington, 251-270 (1980).

25. Anon., Food Eng. 55, 52-53 (1983).

26. G. R. Sanderson and R. C. Clark, Food Technol. 37, 63-70 (1983).

27. Anon., "Gellan Gum in Micro-encapsulation", Commercial Development Bulletin CD-31, Kelco Div. of Merck & Co., Inc., San Diego, CA. (1983).

28. Anon., "K9A50 for Use in Aqueous Gel systems", Commercial Development Bulletin CD-30, Kelco Div. of Merck & Co., Inc., San Diego, CA. (1983).

29. K. S. Kang and G. T. Veeder, U.S. Pat. 4,342,866 (1982).

30. J. A. Peik, S. M. Steenbergen, and H. R. Hayden, U.S. Pat. 4,401,760 (1983).

31. G. T. Colegrove, Ind. Eng. Chem. Prod. Res. Dev. 22, 456-460 (1983).

32. M. Lawson and E. E. Fitzgerald, Abstr. 185th Am. Chem. Soc. Meeting, Carb. , Seattle, WA (1983).

33. Anon., "KELTROL® Xanthan Gum for Use in Foods Packaged in Retort Pouches", Technical Bulletin F-79, Kelco Div. of Merck & Co., Inc., San Diego, CA. (1980).

34. Anon., "KELTROL® Xanthan Gum With Locust Bean Gum in Starch Jelly Candies", Technical Bulletin F-79, Kelco Div. of Merck & Co., Inc., San Diego, CA. (1981).

35. Anon., "KELTROL® and KELTROL® F Food Grade Xanthan Gums for Farinaceous Foods", Technical Bulletin F-78, Kelco Div. of Merck & Co., Inc., San Diego, CA. (1982).

36. G. C. Varner, U.S. Pat. 4,170,883 (1979).

37. Anon., "KELZAN® Xanthan Gum as a Foam Stabilizing Agent in Textile Applications", Technical Bulletin TX-12, Kelco Div. of Merck & Co., Inc., San Diego, CA. (1982).