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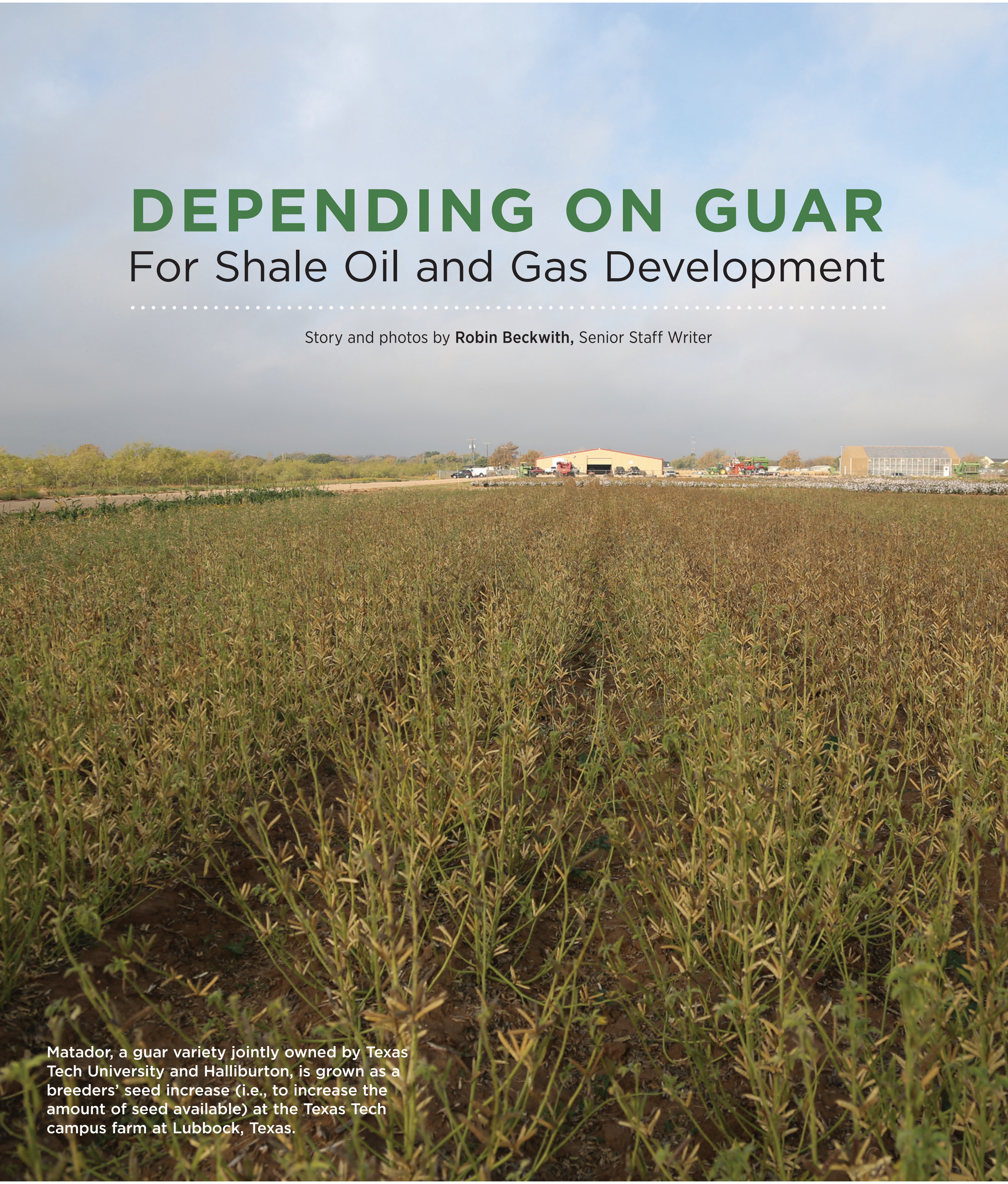
DEPENDING ON GUAR

For Shale Oil and Gas Development

Story and photos by **Robin Beckwith,** Senior Staff Writer



Matador, a guar variety jointly owned by Texas Tech University and Halliburton, is grown as a breeders' seed increase (i.e., to increase the amount of seed available) at the Texas Tech campus farm at Lubbock, Texas.

Guar is a modest-looking shrubby plant. Primarily grown in India and Pakistan, it is known there as a "poor-man's crop," according to Calvin Trostle, associate professor and extension agronomist, Texas A&M AgriLife Research & Extension Center in Lubbock, Texas.

This stepchild crop has risen in importance during the last few years as the source of an important ingredient that makes high-viscosity (as opposed to slickwater) hydraulic fracturing as effective and cost-effective a process as it is. This ingredient is known as guar gum.

Made from the endosperm of the guar seed, which is ground into a fine powder, a tiny concentration of guar gum interacts quickly with hydraulic fracturing water to thicken it. In simple terms, guar gum renders the water viscous and thus capable of evenly suspending and carrying proppant deep into the fractures that are created with the enormous pressures of the pumped water. Its biopolymeric viscosity properties also help reduce friction and augment water pressure.

No guar substitute has yet been developed that is as effective for high-viscosity hydraulic fracturing, although Halliburton, Baker Hughes, Schlumberger, FTS International, or their affiliates, as well as the chemical company Dupont, are working on developing synthetic polymers whose properties might rival those of guar gum.

According to Mickey Callanan, president of PfP Technology, "Guar is a perfect material for hydraulic fracturing." He cites the following elements that guar gum brings to bear:

- Available in large amounts
- Availability currently not limited
- Affordable, low cost
- Superior thickening agent
- Excellent friction reducer
- Crosslinkable
- Breakable
- Biodegradable

Trostle says reported oilfield services industry numbers suggest that an average amount of guar gum required to hydraulically fracture one well could be as much as 20,000 lb. That is the equivalent of about 100 acres of average-yielding west Texas dry-land guar production (at 750 lb/acre). Guar gum is also used as an ingredient in drilling fluids and enhanced-oil-recovery methods, though not as consistently or in such vast quantities as for hydraulic fracturing. Arguably, without guar, shale gas and oil development would not be burgeoning nearly to the extent it is.

Humble Beginnings to Today's Prominence

Although guar pods (with the seeds inside them), which grow in clusters on the plant, are used for human consumption, the traditional use of guar has been for cattle feed. In fact, according to Sudhir Merchant, chairman and chief executive officer of Encore Natural Polymers of Ahmedabad, India, in India "gaw – har" means "cattle – food."

The plant survives despite inconsistent rains and without irrigation in arid and semi-arid areas. "In India," says Callanan, "most guar farmers depend 100% on Mother Nature to provide rain for crops."

"Traditionally, guar has been grown in India as a secondary or tertiary crop," he continues. There, it is often planted amid another crop and selectively harvested—all by hand—on small plots of land farmed mostly at a subsistence level.

But the industry is in the midst of a boom. This boom is virtually entirely attributable to demand from the oil and gas industry.

According to a US Department of Agriculture (USDA) Foreign Agricultural Service Report, dated 31 August 2012, "In calendar 2011, guar emerged as India's largest agricultural export to the US with sales of USD 915 million." Local farmers in the desert belt of northwest India enjoyed increased prices because of the rush on guar.

The report cites a company called Vikas WSP, which distributed 2,000 metric tons of guar seed free to 250,000 Indian farmers in Rajasthan and Punjab, who appear to be trading in their cotton, lentil, or soybean crops. This distribution, in addition to the lure of high prices, has led to the expectation that 2012 will experience a bumper crop of guar.

But speculation on the Indian commodity market shot the price there up to as much as USD 1,723 per 100 kg in first-quarter 2012. High prices generally indicate a declining supply in the face of steep demand. This sparked a decision by Halliburton, according to a markets and news blog called *The Tell*, "to bite the bullet and procure 'a large reserve' of guar based on demand they forecast earlier in the year." According to a Reuters report, "Halliburton itself probably contributed to the rally by embarking on an aggressive and successful campaign to build up a private stockpile that would protect it from future supply gaps."

Because prices of guar gum had increased more than nine-fold, India's commodity market regulator suspended guar futures trading in March. There was not much of an initial decline in guar gum prices after the ban. In fact, according to Callanan, it peaked at a little in excess of USD 2,600 per 100 kg around May.

In June, Mark McCollum, Halliburton's chief financial officer, said, "We have about 4 months of inventory of guar in our warehouses. We're not using that … It is sitting there, but we had built that up, and of course we're buying the current guar in the spot market."

In the week following Halliburton's statement, prices fell for the first time in 2012, quickly halving their value within 6 weeks, according to data from *Agra Informa*.

According to *The Tell* blog in late July, "Looking back at the recent guar glut, Halliburton CEO David Lesar said, 'We bought too much guar too early and paid too much for it.'"

A Bloomberg report states Halliburton's North American operating profit margin drop of 4.8 percentage points to 20.7% in the second quarter compared with the first quarter was blamed on its mistake in stockpiling guar.

By early September, according to one report, prices in India had plunged 69% to about USD 539 per 100 kg, although Callanan states that he never saw prices of the

GUAR POWDER PRECAUTIONS

Guar products are considered to be nonirritating to eyes and skin, based on animal tests. It is nonhazardous, but proper care should be used to prevent inhalation of the product dust. Special precautions are needed to avoid storing or handling powders in the presence of heat or an ignition source. Powder may form explosive mixtures with air. Guar products become slippery when wet.

Opened dry guar pod showing a couple of guar seeds.

Guar seed and processed byproducts (left to right): guar derivative hydroxypropylguar (HPG); food grade guar gum; guar meal (a byproduct including the embryo and seed coat), marketed in nonindustrial uses and sometimes as cattle feed; guar splits (from which gum is processed); guar cracks, or guar seed coats; raw guar seed; guar pod husks and other trash cleaned from seed samples. (Original samples courtesy West Texas Guar.)

grade of guar used in hydraulic fracturing dip below USD 600 per 100 kg.

At the time this article went to press, India's commodity regulator, the Forward Markets Commission (FMC), had indicated it planned to reintroduce guar gum onto the futures market soon. Following its Advisory Committee meeting on 16 October, a recommendation to lift the ban was made. In late October, the FMC suggested reviewing of easy credit by banks and other institutions for trading in commodities like guar, in a bid to curb speculation. This recommendation was made in its final report, submitted to India's Consumer Affairs Ministry, among other suggestions to check speculators' participation in guar trading.

Encore's Merchant has a sharper view. "We are fighting with the government not to start speculation," he says. "Guar is a narrow commodity, and when it's narrow, it's easy to manipulate. The very important part that needs to be considered is guar usage. It should actually be considered a 'specialized commodity'—something in between a commodity and a specialty chemical."

Growing Guar

Guar, or clusterbean (*Cyamopsis tetragonoloba* [L.] Taub), is an obligatorily self-pollinated drought-tolerant annual legume. Guar grows adequately under a wide range of soil conditions. However, clayey soils are not recommended. It performs best on medium- and sandy-textured soils, including dry-land pivot corners (in US farming). According to Trostle, guar makes a good rotation with just about any major annual crop, such as cotton, lentil, soybean, and sorghum. Humid environments are less desirable. Optimum temperatures for root development are 77° to 95°F. Guar is an indeterminate plant, which means when moisture is limited, the plant stops growing but it does not die. Guar does respond to irrigation during dry periods, but is grown in areas without irrigation with 10 to 40 in. of annual rainfall. Its long taproots reach moisture deep below the soil surface.

Guar is grown for seed, as a vegetable for human consumption, for cattle feed, and as a green manure crop. The plants have single stems, fine branching, or basal branching, depending on the variety, and grow to be 18 to 40 in. tall. Pods are generally 1½ to 4 in. long and contain 5 to 12 seeds each. The pods are allowed to dry on the stem in the field, which causes the seeds to harden as well as change color from the original green.

The pods are harvested and the seeds extracted. Seeds vary in color from dull-white to pink to light gray or black. The number of seeds per ounce ranges from 900 to 1,600. Desired seed size is about 4 mm.

OTHER USES OF GUAR GUM

The most important property of guar gum is its ability to hydrate rapidly in cold or hot water to attain uniform and very high viscosity at relatively low concentrations. The advantage of guar gum is it provides full viscosity even in cold water. In addition to being a cost-effective stabilizer and emulsifier, it improves texture, enhances mouth feel, and controls crystal formation due to superior water-binding properties. It is inert in nature and resistant to greases, oil, and solvents. It also has excellent synergy with other hydrocolloids, such as xanthan gum.

Food Additives

According to the General Standard for Food Additives (GSF: Codex Alimentarius Commission; UN Food and Agricultural Organization; Rome, Italy), guar gum is listed as No. 412, synonymous with guar flour and gum cyamopsis, as an emulsifier, stabilizer, and thickener that can be used in any of the 61 GSF food categories listed. Guar gum is used in relatively small percentages in a wide variety of foods, in which, to perform a similar function, a larger percentage of starch or other thickening agent would be needed. Some of these include the following:

Dairy-based drinks, flavored and/or fermented
Milk powder and cream powder and powder analogs (plain)
Unripened, ripened, and processed cheese, and cheese analogs
Dairy-based desserts, such as pudding, and fruit or flavored yogurt
Edible ices, including sherbet and sorbet
Dried vegetables, seaweeds, and nuts and seeds
Confectionery
Breakfast cereals, including rolled oats
Baked goods
Processed meat, poultry, and game products
Egg-based desserts
Table-top sweeteners
Seasonings and condiments
Vinegars, mustards, soups, and broths
Sauces, salads, yeasts
Dietetic formulas for slimming and weight reduction
Food supplements
Water-based flavored drinks, beer, cider, and wines (other than grape)
Prepared foods

- In baked goods, guar gum increases dough yield, gives greater resiliency, and improves texture and shelf life.
- In dairy products, it thickens milk, yogurt, kefir, and liquid cheese products, and helps maintain homogeneity and texture of ice creams and sherbets.
- For meat, it functions as a binder, preservative, and lubricating agent.
- In condiments, it improves the stability and appearance of salad dressings, barbecue sauces, relishes, ketchups, and others.
- It is also used in dry soups, instant oatmeal, sweet desserts, canned fish in sauce, frozen food items, and dog and cat food.
- Guar gum is a water-soluble fiber that acts as a bulk-forming laxative.

Industrial Applications

Textile industry—sizing, finishing, and printing
Paper industry—improved sheet formation and folding, and denser surface for printing
Explosives industry—as waterproofing agent mixed with ammonium nitrate, nitroglycerin, slurry explosives, and dynamite explosives
Pharmaceutical industry—as a binder or disintegrator in tablets
Cosmetics and toiletries industries—thickener in toothpastes, conditioner in shampoos
Mining—chemical flotation agents that get absorbed onto hydrated mineral surfaces
Hydroseeding—formation of seed-bearing "guar tack," often preblended with hydromulch
Medical institutions—used to thicken liquids and foods for patients with trouble swallowing

Guar gum is also used in insecticides and pesticides, detergents and soaps, paint industry, electrodes and brazing fluxes, plywood, leather industry, foundry, tobacco processing, pencils and crayons, and adhesives.

The seed consists roughly of a germ (embryo and radicle) (45%), seed coat (15%), and endosperm (40%). Unlike the seeds of other legumes, guar beans have a large endosperm. Only the endosperm contains guar gum. Trostle estimates that currently about 28% of the raw seed weight is net extractable gum.

Eighty to 85% of guar seed endosperm is galactomannan polysaccharide. This is the viscosifying component of guar. The remaining portion is composed of water, protein, enzyme, and several other nonpolymer carbohydrates. The major nonviscosifying sugar, arabinose, is present at about 5% by weight of the endosperm.

Processing the Guar Endosperm

The guar seeds are dehusked, milled, and screened to obtain the guar gum (also called guar powder or flour). The byproducts—the seed coat and germ—are ground together as guar meal, which adds to profits by making a protein-rich feed supplement for animals.

Calvin Trostle, Texas A&M AgriLife Extension agronomist, Lubbock, Texas, examines the terminal growing point of late-season guar. Guar producers are considering means to terminate the guar crop before waiting for a freeze, in order to hasten harvest a month or more and potentially better preserve guar seed and gum quality.

Guar seeds are dicotyledones, which indicates there are two endosperm halves per seed. The purity of the polymer depends on effective separation of the hull and germ from the endosperm. Endosperm halves, known as splits, are processed into any of a multitude of guar products with specialized properties. (See sidebar for other uses of guar products.)

Initially, guar seeds are cleaned and split; the meal and unbroken beans are removed; the splits are heated to aid in de-hulling; then they are sifted to remove the hull and broken splits.

The resulting splits are hydrated, then milled under high pressure and shear conditions. These conditions provide for effective rupturing of the cell walls, thereby releasing the galactomannan content of the split while maintaining the high molecular weight of the polymer.

After the initial milling, the resulting product is dried and reground to produce the desired final granulation.

Guar Gum: The Premium Galactomannan

In his book, *Industrial Galactomannan Polysaccharides* (CRC Press, 2012), author N.K. Mathur, citing his nearly 4-decade-long association with the guar gum industry, calls guar gum "the premium galactomannan." The versatility and range of its properties, which determine its usefulness across a broad range of industries, are quite astounding.

Guar gum (or powder or flour) is a branched polysaccharide biopolymer composed of the sugars mannopyranose and galactopyranose—essentially a long-chain carbohydrate molecule of repeated monomer units joined together by glycosidic bonds. Known as a type of galactomannan, it is hydrocolloidal and has one of the highest molecular weights of all the naturally occurring water-soluble polymers.

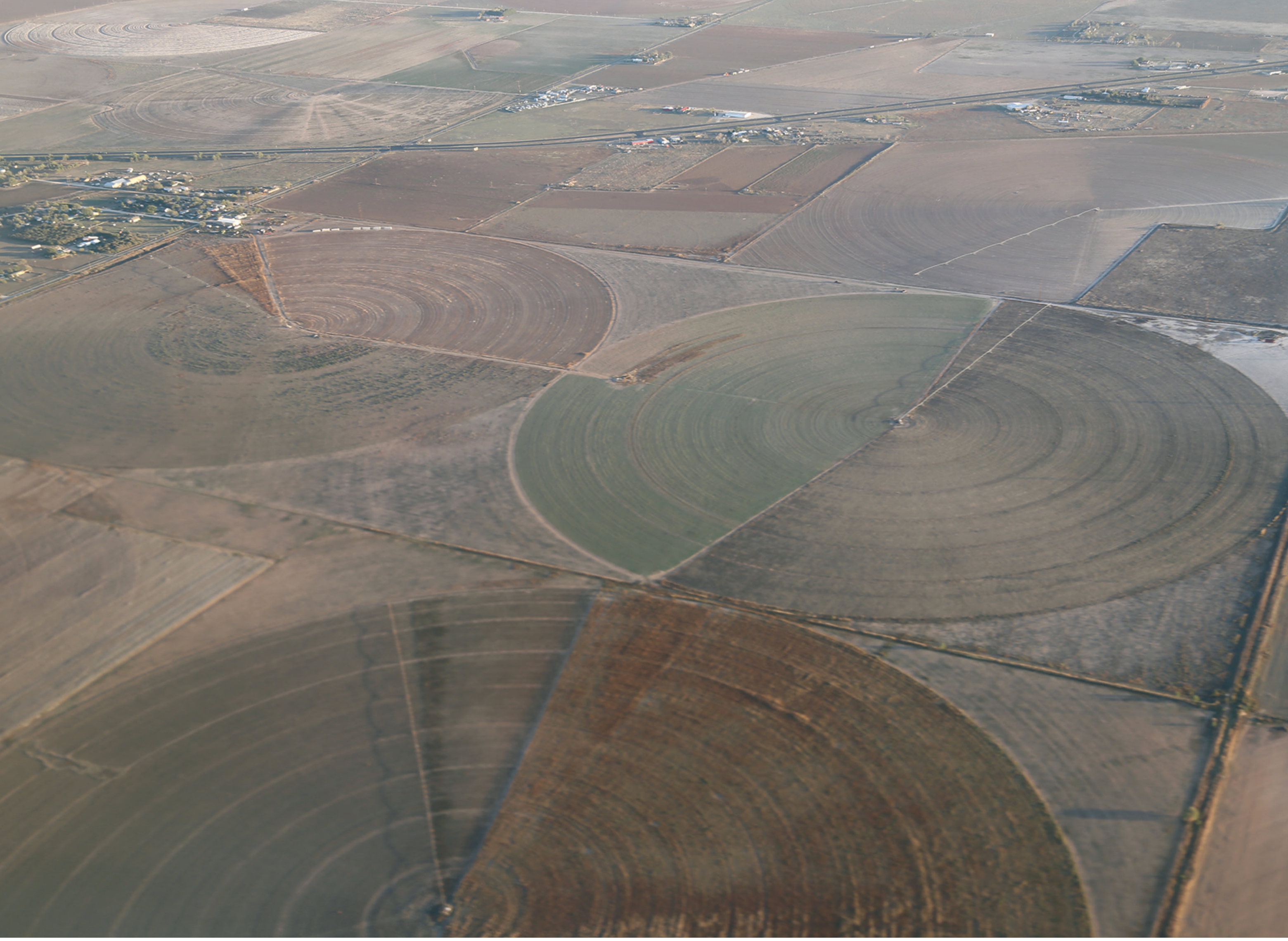
The viscosity of a polymer in solution is a function of its molecular weight, where viscosity increases with increasing chain length. High-viscosity hydraulic fracturing depends on fast-hydrating guars (FHGs) so fluid viscosity can be quickly and precisely timed. A hydrocolloid, often called a gum, is a hydrophilic (literally: water-loving) polymer. It should be noted that not all hydrocolloids are gums and not all gums are hydrocolloids. Notable among the latter are chewing gums and many gum adhesives, which are water-insoluble rubbery materials.

Galactomannans from different legume seeds differ in their mannose-to-galactose (M:G) ratio, molecular weight, and the mode in which the galactose grafts are arranged on the mannan backbone. Guar gum has excellent cold-water solubility because of its high M:G ratio. "Nobody has studied and recorded the full range of guar ratios," says Noureddine Abidi, associate professor and head of biopolymer research, Fiber and Biopolymer Research Institute, Department of Plant & Soil Science, Texas Tech University. "They're somewhere between 1.6:1 and 2:1."

Abidi scoured the literature, but could not find anything discussing variation in guar's galactomannan ratio. "We want to see how the ratio varies throughout 50 cultivars," he says. "Cultivar" is the agronomic term for genotype.

He is involved in research using ion chromatography, which is a process that establishes the carbohydrate profiles of biopolymers. Abidi is also using size-exclusion chromatography or gel-permeation chromatography to analyze the guar galactomannan to quantify how many monomers are in the polymer (degree of polymerization) and to determine molecular weight. He also uses rheology analysis equipment.

The purpose of this is to determine which cultivars produce crops with desired characteristics, such as drought resistance, yield maximization, or endosperm quality. The oil and gas industry now is responsible for pushing demand for guar to levels Encore's Merchant estimates at



Pivot irrigation farming outside Lubbock, Texas. The pivot corners, which are not irrigated, can be good sites for growing guar. When a pivot is divided in half, each side can be planted with a different crop with different irrigation needs.

upwards of 70% of the total market—a level comparable to that estimated for US-grown guar by Klint Forbes, president of West Texas Guar. The focus of Abidi's research, therefore, is on developing cultivars whose galactomannan characteristics are best suited to the industrial grades of FHGs favored by hydraulic fracturing.

"If you change something on the genetic level," he explains, "you want to see how this changes the chemical properties." The genetic level is extremely small—the nano level—whereas the chemical level is orders of magnitude larger—on the molecular level.

Alternatives to Unmodified Guar

According to Lewis Norman, a chemist at Halliburton, "In today's shale gas market, somewhat more than half of the fluid pumped contains gel guar." The other half is made "slick" through the use of synthetic polymers. Polyacrylamide and its derivatives are synthetic polymers commonly used in low concentrations, as guar gum is, to create viscosity in an aqueous solution that is pumped in high volumes during slickwater hydraulic fracturing. In this usage, polyacrylamide is known as a friction-reducer.

Slickwater fracturing is dependent on much higher volumes of water than high-viscosity hydraulic fracturing, which depends largely on guar gum and its derivatives to thicken the water and suspend and carry the proppant. More viscous fluids can carry higher concentrations of proppant. High-viscosity fracturing tends to cause large dominant fractures, while high-rate (slickwater) fracturing tends to cause small spread-out micro-fractures. The viscosities of polyacrylamide and its derivatives are less than those achieved with guar gum and its derivatives; hence the need with slickwater fracturing for higher volumes of water. These synthetic polymers are also dependent on the use of freshwater, while guar works well also with salty water.

The authors of paper SPE 140176—both from Baker Hughes—describe a new synthetic polymer developed in order to maintain high-temperature stability. It is based on a polymer of acrylamide and acrylamido-methylpropane sulfonate, with a percentage of vinyl phosphonate in the chain for crosslinking. The system uses exceedingly low polymer concentrations (18 to 40 pptg) compared to others (60 to 100 pptg) at temperatures from 350° to over 450°F.

Guar derivatives are also used. They include hydroxypropylguar (HPG), carboxymethylguar (CMG), and carboxymethylhydroxypropylguar (CMHPG). According to Norman, guar derivatives are made from guar splits, just as the guar flour (i.e., powder) is made. The guar splits are treated with a mixture of water, caustic soda, and the appropriate chemicals needed to react with the guar. For HPG, the chemical is propylene oxide; for CMG, it is sodium chloroacetate; and for CMHPG, it is a mixture of the two. The guar splits and the chemicals are heated at a particular temperature and pressure for a couple of hours, washed repeatedly with water, then ground to a fine powder just as in making regular guar flour.

Norman estimates that of the total amount of guar gum used in hydraulic fracturing, about 80% is straight guar powder and the remainder consists of the guar derivatives, HPG, CMG, or CMHPG; Callanan estimates total hydraulic fracturing usage of derivatives at less than 10%. Among other characteristics, such as an expanded range of temperatures and pH under which they will retain viscosity, derivatized guars have lower residue than unmodified guar as a result of chemical treatment. While unmodified guar can leave a downhole residue of between 6.5% and 7.5% on a weight basis using oxidative degradation, HPG's residue is typically between 2% and 3% and CMHPG's is between 1% and 2%. This insoluble residue—primarily cellulose and proteins—can impair the flow of oil or gas through the formation or propped fracture.

Guar and its derivatives used in hydraulic fracturing are typically crosslinked. Aqueous solutions of guar and guar derivatives develop increased viscosity upon crosslinking through the addition of various metal ions. Viscoelastic gels are formed by chemical linking of two or more polymer chains. The result is a more ordered network structure which increases the molecular weight and thereby the viscosity. Much less polymer is needed to achieve the same or better effect, with greatly reduced residue issues. Boron is the most commonly used guar crosslinker, along with titanium, aluminum, antimony, zirconium, and chromium.

Breaking the Gel

Although viscosity is used to carry proppant into the formation, when a well is being flowed back or produced, it is undesirable to have the fluid pull the proppant out of the formation. For this reason, a chemical known as a breaker is almost always pumped with all gel or crosslinked fluids to reduce their viscosity as soon as they have achieved their proppant-placement purpose.

A borate crosslinked guar fluid system, illustrating its viscosity, is shown at PfP Technology.

This chemical is usually an oxidizer or an enzyme. The oxidizer reacts with the gel to break it down, reducing the fluid's viscosity and ensuring that no proppant is pulled from the formation. An enzyme acts as a catalyst for breaking down the gel. Sometimes pH modifiers are used to break down the polymer crosslink at the end of a hydraulic fracture job, as many fracturing fluids require a pH buffer system to stay viscous.

A Little History

Evidence for the presence of guar in India between 1500 and 1000 BCE is based on Sanskrit names that were used to describe the plant. The task of determining when and where guar was domesticated is difficult because of a lack of botanical and agricultural records.

It was introduced into the United States in 1903 from India as a soil-improving legume used as a rotation crop. Although some reports indicate guar can fix up to 300 lb

A typical guar powder inventory, packaged in 2,000-lb bulk bags, at PfP Technology's Katy, Texas, facility.

of nitrogen per acre, due to lack of significat nodulation, according to Trostle, it appears that guar may make only minor contributions to soil nitrogen in most fields.

Interest in guar as a potential economic crop did not develop until the late 1940s. The impetus for this development was a USDA investigative project to establish a domestic source of guar. The first cash market for guar seeds was established in 1952.

Guar seed processing for its gum was started in India in the late 1950s and early 1960s. This technology was brought to India by two US companies—General Mills and Stein, Hall & Company—and with their collaboration, guar galactomannan-based industries were established in India. Subsequently, similar industries were also established in Pakistan. As these industries developed on the Indian subcontinent, processing of guar seed into gum powder was gradually reduced in the US and Europe.

However the export of guar seed splits from India has continued even now to most of Europe, Japan, and the US, where some value-added specialty guar gum products are still manufactured according to proprietary and patented procedures. Rhodia, a European chemical company with a location in Vernon, Texas, is one of the companies that imports splits to the US from India and Pakistan for further processing. Mostly, though, companies, such as Houston-based PfP Technology—the second-largest guar supplier to the oil and gas industry—import the gum or gum derivatives.

Upstart US Guar Production

India, with an estimated acreage of upwards of 10 million, now accounts for about 80% of the guar gum market, with Pakistan accounting for about 15%. The remainder comes from the US, Australia, China, and Africa.

In January 2012, oilfield research and consulting firm Spears & Associates predicted US horizontal drilling would rise to almost 19,000 new wells this year, beating 2011's record 16,000 wells. In 2011, four companies provided more than half of North American hydraulic fracturing services: Halliburton (18%), Schlumberger (13%), Baker Hughes' BJ Services unit (12%), and FTS International (11%). Trostle notes that FTS has stated its 2012 monthly use is around 1,700 tons of guar gum a month, which is three to four times current annual US production.

Since the US is the major destination for guar exports from India, given that the vast majority of shale gas and oil hydraulic fracturing currently occurs in the US, a small but tenacious guar producing and processing industry has been growing there ever since Klint Forbes formed West Texas Guar 14 years ago. "This is the seventh time in the history of US guar production that the agriculture industry has heard 'produce guar, we have to have it,'" says Forbes. "Every time within 3 years the market crashes or we overproduce and crash the market. Nearly every time demand stopped."

West Texas Guar is licensed to grow and distribute guar seed; contracts with farmers in Texas, Oklahoma, New Mexico, and Arizona to produce guar, locking in a guaranteed price for their harvest; processes the seed into split and powder; and farms its own acreage—all the phases of guar production present in the Indian market. "We compete head-on with India," says Forbes. "We're the only one outside of India and Pakistan."

"We started with an understanding of production agriculture," he explains. "And having consistent markets gave us sustainable production, because without sustainable production, you can have no consistency of production volumes of product with consistent quality material. If it's not good quality, they won't buy it."

PfP Technology's Katy, Texas, facility, showing stacks of 2,000-lb bags of guar powder and delivery of the bags via a box van.

He further explains, "We as a company are trying to figure out how to manage the bust when it comes, because invariably India will lower the price of guar and put countries out of the guar production business."

Forbes is not in favor of commoditizing guar. Once you do that, he says, emphasis on low cost will mean minimal quality, and it will no longer be cost-effective to produce high-quality guar gum with specially cultivated chemistries. "Guar is very much a specialty crop due to the need to maintain its uniqueness across such a wide range of uses impacting so many different industries," he says. "There is a need to sustain the highly desired traits and unique characteristics of the endosperm piece of the guar bean."

According to Forbes, ultimately, the growth of the guar industry in the US is dependent on the willingness of the oil and gas and food industries to diversify their supply to US production as a sustainable alternative to fluctuating prices. "We *are* the US guar industry," he says of his company. "We have that on our shoulders."

"Our goal is sustainability; we're not a fly-by-night operation," explains Forbes. "It's a five-headed beast most days."

Guar Imported from India

PfP Technology utilizes several warehouses throughout the Houston area that are routinely filled with stacks of huge bags of guar powder. Callanan, the company's president, says, "There's 2,000 lb of guar powder in one bag, with 20 bags (40,000 lb) placed in an overseas shipping container."

When it began operations 11 years ago, PfP Technology sold only one or two containers of guar powder every month. Now it is the No. 2 supplier of dry guar powder and liquefied guar slurries to the oil and gas industry globally.

Both Callanan and Jim Lovelace, PfP vice president of new business development, guesstimated the volume of guar usage in the US oil and gas industry (what they referred to as the "burn rate") as of late October at about 1,250 containers per month. This works out to be about 50 million lb/month or 25,000 tons/month. They based this on their estimate of PfP's market share and their knowledge of service companies' burn rates. At last year's peak, they said, it was around 2,000 containers. But this was artificial because of stockpiling.

Due to advancements in horizontal well completions technology, guar in a powder or liquefied form as well as other collateral chemicals are being used in much larger quantities. "On a given pad, up to six horizontals might be drilled," explains Callanan. "Guar slurry requirements can be over 150,000 gallons. Managing wellsite logistics becomes a nightmare, and traditional packaging of dry chemicals in sacks and liquids in 55-gal drums or plastic totes is rapidly becoming impractical."

As a result, packaging logistics continue to evolve. For this reason, more companies are moving in the direction of bulk materials handling. If the customer has the proper dry powder mixing equipment at the wellsite, says Callanan, the powder will be transported in bulk pneumatic trailers, like those used by the proppant industry, and the powder can be metered directly into the water. However, this method, known as "dry on the fly," is offered by only a few of the service companies. The majority of the service companies use liquefied guar slurries. The liquefied guar is metered into the fracturing water, and as it is being pumped, the mineral oil carrier is stripped from the guar instantly via chemical technology.

Virtually all guar powder PfP imports is received at the Port of Houston, where it is transferred from the overseas

HISTORY OF GUAR GEL USE IN FRACTURING

Some critical developments involving guar gel fracturing technology are mentioned by NSI Technologies' Carl T. Montgomery and Michael B. Smith in their *JPT* (December 2010) article "Hydraulic Fracturing: History of an Enduring Technology":

With the advent in 1953 of water as a fracturing fluid, a number of gelling agents were developed. The first patent (US Patent 3058909) on guar crosslinked by borate was issued to Loyd Kern with Arco on October 16, 1962. One of the legends of hydraulic fracturing, Tom Perkins, was granted the first patent (US Patent 3163219) on December 29, 1964 on a borate gel breaker.

In the early 1970s, a major innovation in fracturing fluids was the use of metal-based crosslinking agents to enhance the viscosity of gelled water-based fracturing fluids for higher-temperature wells. It is interesting to note that the chemistry used to develop these fluids was "borrowed" from the plastic explosives industry. An essential parallel development meant fewer pounds of gelling agent were required to obtain a desired viscosity. As more and more fracturing treatments have involved high-temperature wells, gel stabilizers have been developed, the first of which was the use of approximately 5% methanol. Later, chemical stabilizers were developed that could be used alone or with the methanol.

Improvements in crosslinkers and gelling agents have resulted in systems that permit the fluid to reach the bottom of the hole in high-temperature wells prior to crosslinking, thus minimizing the effects of high shear in the tubing. Ultraclean gelling agents based on surfactant-association chemistry and encapsulated breaker systems that activate when the fracture closes have been developed to minimize fracture-conductivity damage.

shipping container into a box van for distribution to PfP operating facilities. Offering a broad array of chemicals to the oil and gas industry, PfP transports the guar powder to its operations in south Texas, west Texas, Wyoming, Montana, and, soon, in Ohio. "The closer we can get to where our products are being used in the field, the better," says Lovelace.

In Callanan's experience, "In the US, it's easy to drive from state to state. But when you step outside this country, the logistics and infrastructure setup gets a lot more complex." This is one factor that slows the spread of shale hydraulic fracturing, he says. "Outside the US, the slope of the growth curve is not very steep."

But he does see change happening in India's guar industry. "Big farms, the industry approach you find in the US, and more acreage," says Callanan. "This is happening in India, too, with mechanization coming, and larger, more efficient farms."

Lingering Issues

Quality. Calvin Trostle says the late-season weathering of Texas guar left in the field until killed by a freeze in order to harvest, which may be subject to rainy weather during this time (more likely to the east in the Texas Rolling Plains than in the High Plains region), will likely lead to more black or darkened seed. This is perhaps perceived as being a seed of lesser quality than the light-colored seeds that are uniformly prevalent in India.

PfP's Callanan says the color of the split itself, which can be a result of rainfall timing and quantity, can say a lot about the quality of the final guar gum product.

Trostle believes that the darker seed leads to difficulty in splitting (effectively removing all the seed coat due to changes in seed-coat properties, or perhaps cracking of the seed coat). As a result this could diminish gum quality or the ability to obtain higher purity guar gum without seed-coat fragments.

"Moving forward," says Trostle, "US farmers are increasingly likely to use harvest aids to terminate the crop—as is routinely done for cotton and also other crops like grain sorghum or sunflower—once yield has been made but prior to a freeze. This will dry the crop quickly and enable harvest a month or more sooner, which may curtail potential processing and gum quality issues."

Risk Mitigation. For Encore's Merchant, "The major pitfall of guar is price fluctuations. Price stability is a very important factor."

Callanan is cautiously optimistic: "As the Indian guar providers have improved their understanding of the use of guar in the oil and gas industry, they have re-evaluated its value and will be reluctant to go back down to more historical prices."

Ryan Williams, Texas Tech assistant professor of agricultural and applied economics, views risk in broad terms. "The challenge as an economist is you have to hold some things constant," he says. "But it's different when dealing with plants. In agriculture, there's risk on both the supply and the demand sides. And what you're trying to do is smooth out risk. You're not only at the mercy of yield issues like weeds, rain, sun, and temperature, but you're also at the mercy of supply in the rest of the world and global demand."

Trostle, who is also a member of Texas A&M's Soil & Crop Sciences Department, cited a major concern, shared by Williams, that "The lack of meaningful guar crop insurance in the US is without question the No. 1 reservation prospective growers put forth to growing guar. Crop insurance is needed to manage risk in a semi-arid region, may be required by agricultural lenders, and is just too important to readily forego."

Another factor Trostle cites is the fact that guar historically does not generate high gross revenue per acre. "For this reason," he says, "it is not likely a crop that farmers can readily grow if they are trying to service a high debt load."

"Fortunately, though," he adds, "guar is an inexpensive crop for a farmer to produce."

"The main risk for a guar farmer is," according to Williams, "Is there a buyer?"

West Texas Guar provides its producers with farm production contracts that lock in a price, thus giving them some guarantee of return. "Guar contracts with US growers have always been based on acres of production rather than pounds per acre," says Trostle. "This makes the contracts much less risky especially for the US Southwest, where yields can fluctuate dramatically due to drought or storm damage."

Because price and global supply show such high levels of volatility, says Dick Auld, holder of the Rockwell Chair in Plant & Soil Science at Texas Tech University and Texas A&M AgriLife Research–Lubbock, various guar-breeding and research efforts have been ongoing at both institutions. He cites the Halliburton-supported guar-breeding program, headed by Ellen Peffley from 1998 to 2007. The program generated two US Plant Variety Protection guar varieties, jointly owned by Texas Tech and Halliburton—Matador (2005) and Monument (2010)—with increased gum content, as well as several hundred breeding lines that have been in cold storage. Both Texas Tech and Texas A&M AgriLife have increased breeders' seed of both varieties (i.e., grown guar for its seed, thus increasing the amount of the seed variety available). In addition, work has been initiated to develop guar lines using both conventional and molecular genetics, with the physical and chemical properties to promote better use in hydraulic fracturing. The aim of these efforts is to dovetail with crop production and processing technologies that promote development of an economically stable guar gum production industry in the US.

Oilfield service companies wanted to propel 2012 Texas guar acreage far higher, well above 100,000 acres, according to Trostle. However, the current tendency among guar industry players in the US, he says—and this is confirmed by West Texas Guar's Klint Forbes—is to emphasize stable, long-term production of guar as a viable rotation crop rather than quickly increasing production by multiples of current production acreage to meet immediate needs. This approach brings integrity to US guar farming, with the kind of discipline it takes to resist a lucrative but most likely short-lived opportunity in favor of developing an economically reliable guar industry that will last for the long term. **JPT**