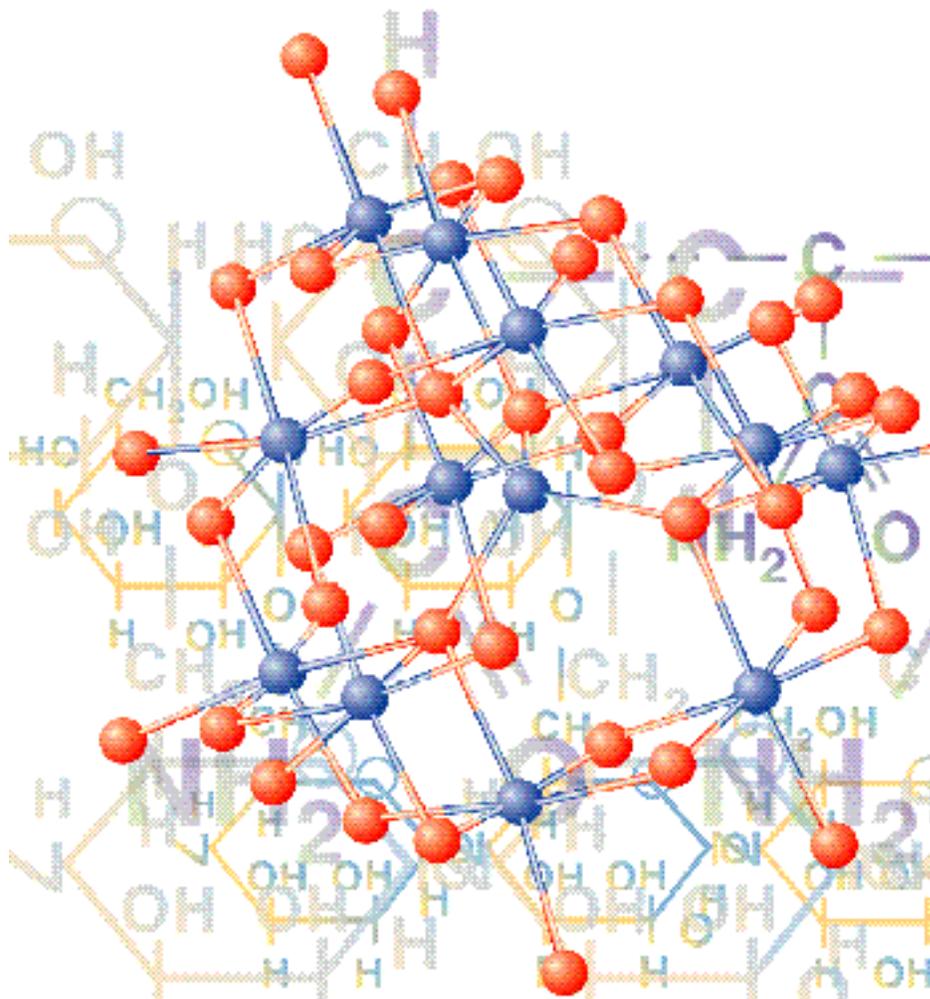


Specialty Chemicals in the Oil Field

Achieving greater oilfield efficiency and productivity depends on wellsite operations that cost-effectively maximize recovery of oil and gas reserves, while minimizing the impact on the environment. Pivotal to these operations are specialty chemicals that impart unique capabilities and functionality for well drilling, completion and intervention services. The last decade's progress in upgrading chemical quality, deliverability and environmental compliance is paying off for operators in terms of field performance and longevity.



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The old expression "garbage in, garbage out" has particular meaning when applied to oil and gas reservoirs. Hydrocarbon-bearing formations are highly susceptible to damage and plugging from a variety of sources—both natural and induced. The permeability and porosity of virgin reservoirs may be altered dramatically unless drilling, completion and intervention practices are conducted with the utmost diligence and attention to detail. If not, well productivity and ultimate reserve recovery suffer, while field maintenance, workover and environmental protection costs skyrocket.¹

Many services performed in the oil field rely on specialty fluids and additives that fulfill specific functions within the wellbore or formation. This article describes the types of specialty chemicals that are employed daily to drill and treat oil and gas wells and how a pervasive focus on their quality, reliability and deliverability is helping operators get the most from field developments.

The Role of Specialty Oilfield Chemicals

Well drilling, completion, treating and workover fluids perform to their utmost because of the specialty chemicals that are added to impart unique properties and functionality. These chemicals fall into a broad variety of categories, with a staggering overall number of different compounds and blends (*below*). If designed and manufactured to proper physical and performance standards—defined and confirmed through extensive field application—specialty chemicals become invaluable solutions to overcome problems that plague oil and gas wells throughout their lifetimes.²

If these chemicals are prepared, stored, mixed or pumped incorrectly, however, they can become a well's worst nightmare—leading to significant problems, such as plugging or precipitation, because of the presence of, and interactions caused by, inferior materials. Whether it's a drilling fluid that causes excessive formation damage (see "A New Slogan for Drilling Fluids Engineers," *page 2*) or a fracturing fluid that leaves flow-restricting polymer residue in the proppant pack, increased costs, reduced efficiency and lower profits can be the end result of faulty selection or application.³

During the boom years of the late 1970s and early 1980s, attention to chemical quality control and performance consistency was often lax. Operator and service company personnel and facilities were stretched to the limit just getting wells drilled and treated on schedule without costly mistakes. Often, there was simply insufficient time to fine-tune field formulations to achieve optimal results. The same was true for chemical suppliers, working all-out to satisfy demand for their products during a period of peak activity. There was little chance to concentrate on improving in-plant production and distribution procedures.

The situation was complicated further by growing demand for more sophisticated fluids. Over the years, simple fluids had given way to more complex ones. By the time the total depth of a well was reached, for example, a drilling mud might contain 20 or more distinct chemical types, many of which had been added to offset the effects of other components present during earlier phases of drilling. A large number of additives means that a complicated set of chemical and physical interactions have to be thoroughly analyzed before the impact of the total fluid system on the formation can be understood.

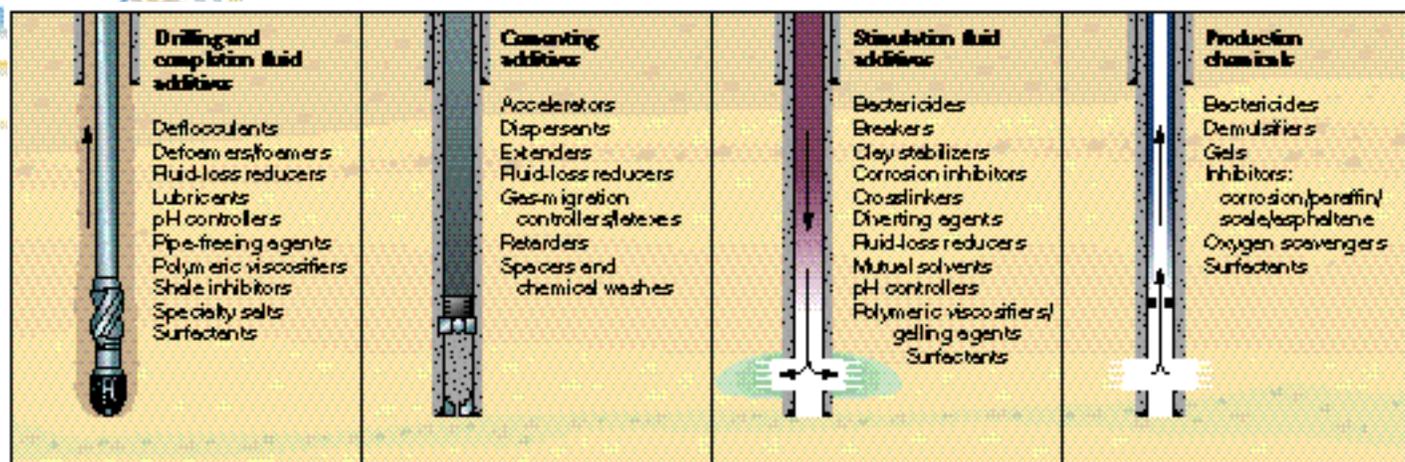
Rising to the Challenge

Following the mid-1980s oil crisis, a new quality drive emerged throughout the oil field—reinforcing industry efficiency and productivity initiatives already in place. These initiatives first led operators and service companies to restructure and streamline their operations in an effort to improve profitability. Industry-wide consolidation and a refocusing on core competencies accompanied a host of cost-reduction steps.

When attention then turned to providing greater quality and value in each phase of the business, operators—concerned about the need to concurrently lower costs and improve well performance—began requesting more detailed information about the chemical additives present in fluids being pumped by service companies. Service companies, in turn, demanded more information from their chemical suppliers.

At the same time, a rising tide of public and governmental concern about health, safety and environmental (HSE) issues—from personnel exposure to potentially harmful materials in chemical plants and at the rigsite, to protection of marine life and aquifer quality—prompted a concerted reevaluation of oilfield chemicals and their

1. Kruger RF: "An Overview of Formation Damage and Well Productivity in Oilfield Operations," *Journal of Petroleum Technology*, (February 1986): 131-152.
2. Drilling, Completion and Workover Fluids; Cementing; Fracturing; and Acidizing supplements to *World Oil* (1996).
3. Hawkins GW: "Laboratory Study of Proppant-Pack Permeability Reduction Caused by Fracturing Fluids Concentrated During Closure," paper SPE 18261, presented at the 63rd SPE Annual Technical Conference & Exhibition, Houston, Texas, USA, October 2-5, 1988.



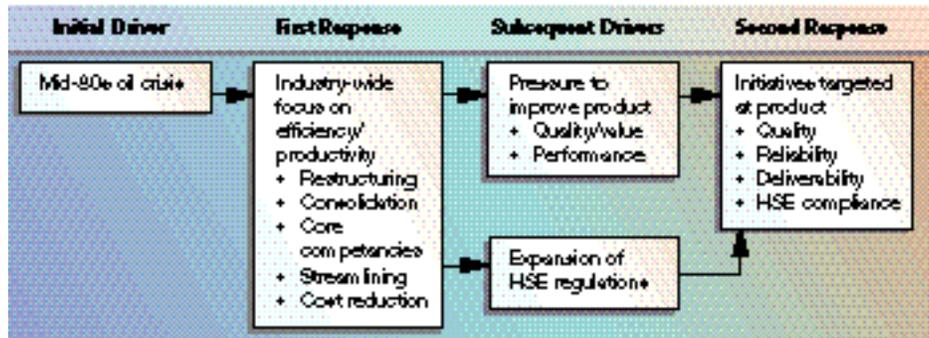
□ Categories of specialty oilfield chemicals used at the wellsite. Hundreds of different chemical compounds are pumped downhole during the lifetime of a typical oil or gas well. Specialty additives provide the necessary fluid properties required for basic drilling, cementing, completion, stimulation and production operations at bottomhole temperatures and pressures. Although the most important additives vary from well to well, those listed here represent a typical set.

effects on both the surface and subsurface. A host of regulations that had impacted oilfield operations since the 1970s and new legislation, enacted principally within the USA and the North Sea, combined to dramatically affect chemical approval, usage, handling and disposal (*below*).

Governmental decrees, coupled with the industry's commitment to doing business in a more open manner, focused increased attention on fluids pumped into a well or discharged in the vicinity of the wellsite. Operators wanted details of any practices with potential negative impact so that they could fulfill obligations to regulatory agencies and answer questions from environmental groups.

Specialty chemical suppliers were faced with a wide range of challenges and queries. To their credit, they reacted swiftly with a well-directed, comprehensive approach. As a result, there have been tremendous strides over the past decade in product quality control, reliability, deliverability and HSE compliance (*above*)

During the 1990s, the drive for continuous improvement and higher standards has led the oil field beyond regulatory compliance. The industry now expects more from itself and has begun to evaluate resource consumption and environmental burdens associated with oilfield activities. The concept of sustainable development—a belief that operators and service companies can meet



Market drivers and industry response. The oil crisis of the mid-1980s sparked major efficiency and productivity actions within the industry—highlighted by restructuring, streamlining and cost-reduction steps. Next came a concerted push for improved quality, value, performance and HSE compliance in products and services that has been realized through broad initiatives by specialty chemical manufacturers and service companies.

the world's energy needs without compromising the environment for the future—is being employed at all levels to integrate quality and HSE goals into everyday business strategies and action plans. This evolution has been documented in over 350 papers published since 1992.⁴

The Modern Specialty Chemical Plant

Chemical manufacturing and blending plants are now operated to much stricter standards, with broader checks and balances on product quality. Advanced process control and optimization of reaction conditions have improved product reproducibility and increased product cost-effectiveness. In-plant safety and environmental awareness, packaging and inventorying, and distribution practices have been scrutinized and upgraded. At the same time, research conducted by service companies and specialty

chemical manufacturers has led to a new crop of innovative, value-added materials and application methods that have extended the capabilities of well operations to deeper, higher temperature and higher pressure environments (*next page*).

4. Over 90% of the papers cited were presented at the: SPE/UKOOA European Environmental Conference, Aberdeen, Scotland, April 15-16, 1997. The Third International Conference on Health, Safety and Environment, New Orleans, Louisiana, USA, June 9-12, 1996. The Second International Conference on Health, Safety and Environment, Jakarta, Indonesia, January 25-27, 1994 and published in: "Environmental Considerations," SPE reprint series, no. 37, 1992.

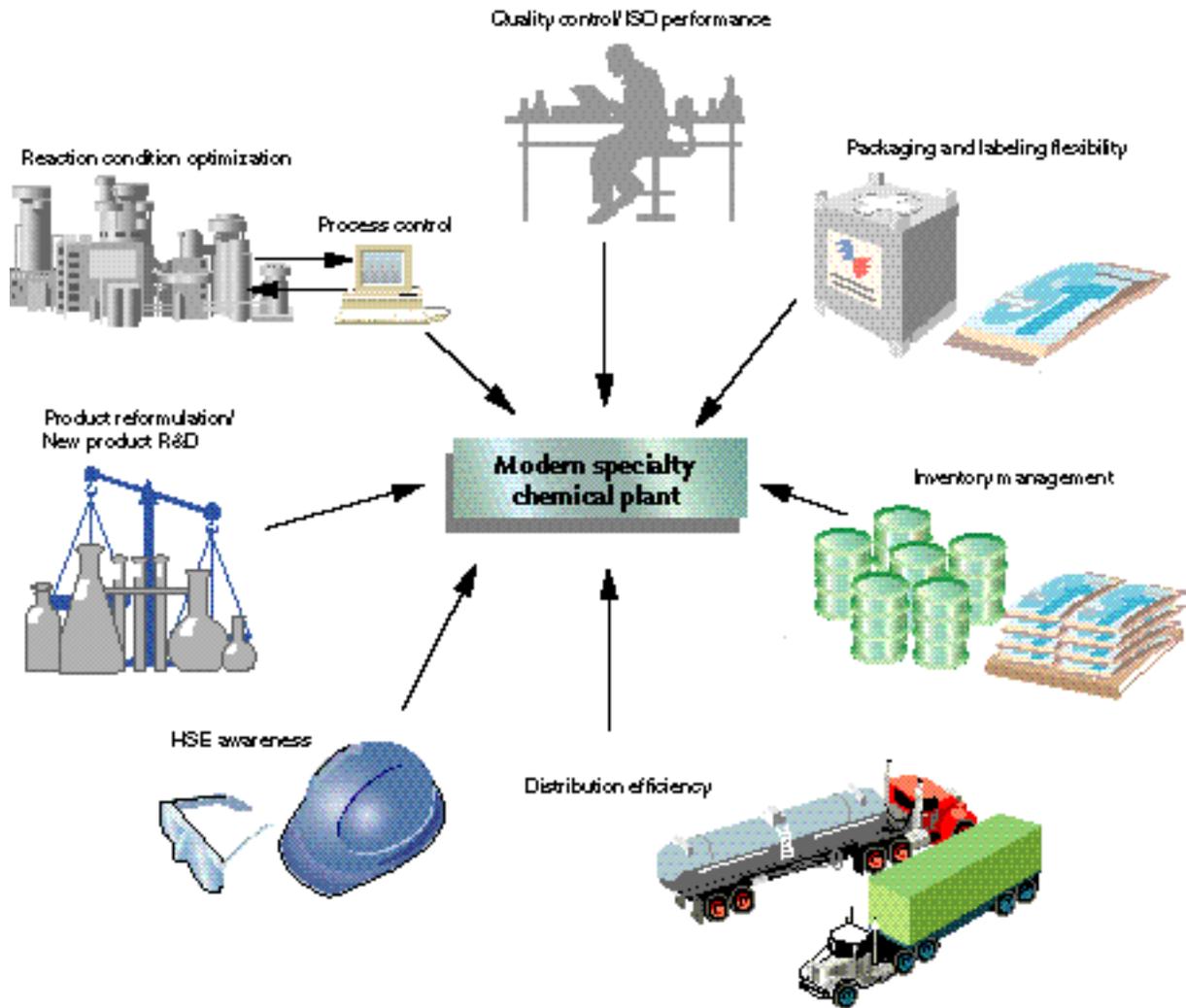
Environmental actions impacting the application of oilfield chemicals. The USA has been the leader in enacting legislation protecting the environment, with many of the major milestones shown on the time line. Several regulations have directly or indirectly influenced the use of specialty oilfield chemicals. As the United Nations (UN) and other organizations representing countries around the world became involved, the impact broadened, as shown by milestones designated with an asterisk(*).

From 1880 to 1960, the US Congress passed a total of eight acts related to the environment. Six more followed from 1960 to 1969. From 1970 to 1990, however, the trend accelerated dramatically, and 50 acts were passed—ranging from the creation of the Environmental Protection Agency (EPA) to establishment and amendment of the Superfund Act. In addition, international actions by OSPARCOM—the Oslo and Paris Commissions for the Protection of the Marine Environment of the

Northeast Atlantic—set the foundation for laws governing protection of oceans and coastlines from hydrocarbons, and regulations for disposal of offshore platforms.

US laws intended to preserve unexploited natural wilderness and wetlands areas have reduced or prevented seismic activity in certain areas and prompted the development of sophisticated seismic and wireline tools and software to limit environmental impact. Air and water emission and waste restrictions have led to





□The modern oilfield chemical plant. Today's facilities bear only passing resemblance to those of 15 years ago. In-plant logistics have been improved. Adoption of ISO quality standards, computer control of reaction and blending processes, and advances in packaging, warehousing and tracking have combined with heightened HSE awareness and product optimization studies to increase plant throughput and product quality.

improved techniques to decrease or eliminate unwanted off-gas and water production. Disposal considerations have changed the nature of oilfield chemical packaging from small, disposable containers to large, reusable containers. Radiation laws have spurred development of surface and downhole tools that rely on non-radioactive instead of radioactive sources.

In the US, the dominant laws affecting the oil field have been RCRA and CERCLA/Superfund. Although passed in 1976

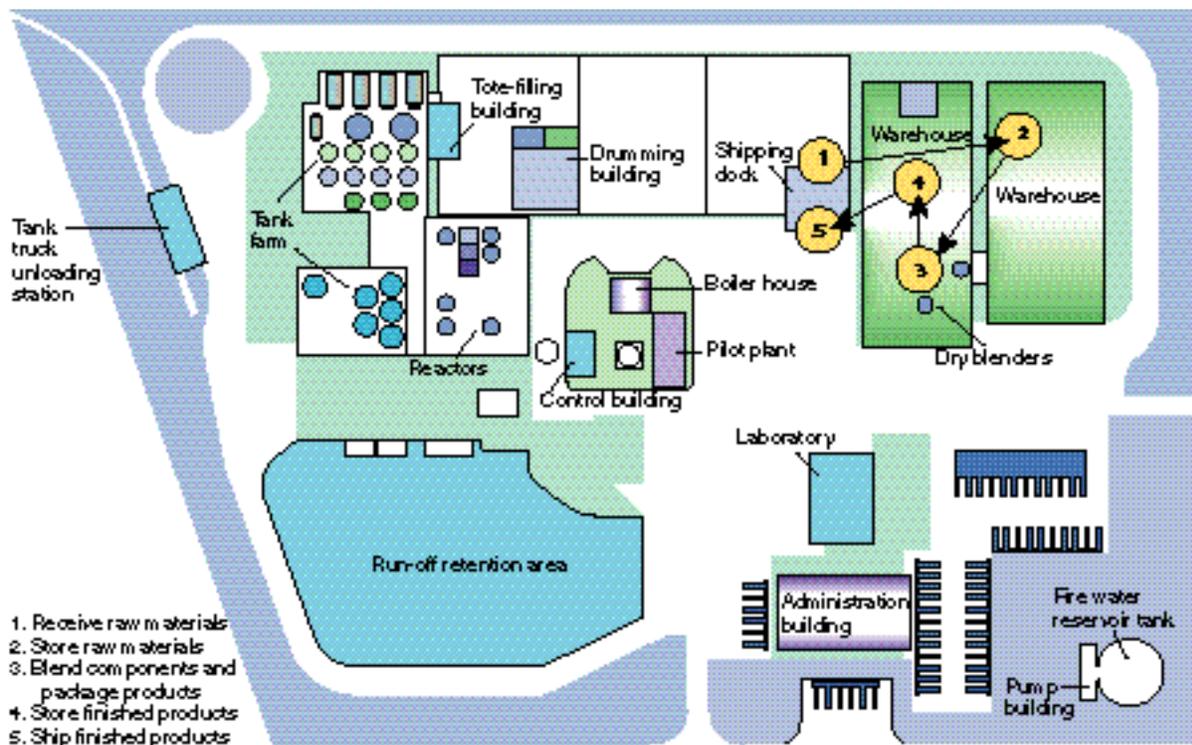
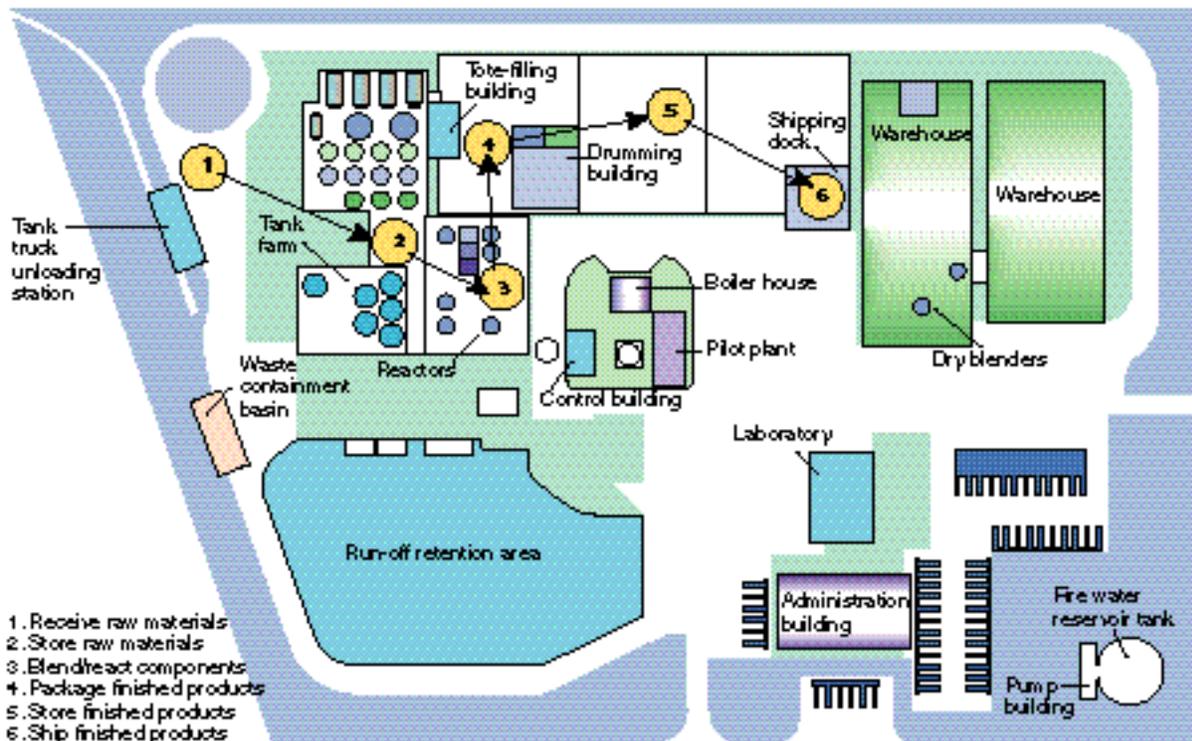
and 1980, respectively, it took several years for the agencies involved to promulgate enforceable regulations. Oil and gas E&P activities were exempt from these regulations during the industry's restructuring period in the mid- to late-1980s. In return, 9.7 cents of each barrel of produced or imported oil went to Superfund.

In the North Sea, actions by OSPAR-COM have impacted exploration, drilling, cementing and stimulation practices. Drilling fluids have moved from oil-base

to synthetic or water-base systems. Stimulation treatments now include corrosion inhibitors, crosslinkers and other additives with lower toxicity.

On a global basis, developing nations are facing similar environmental issues. Chile, for example, is expected to issue enforceable environmental regulations later this year. Many countries are considering requiring ISO 14000 or a similar standard as a management system to foster proactive, beyond-compliance environmental activities.





□ Material flow for liquid (top) and dry (bottom) products. The logistical complexity of specialty chemical manufacturing facilities has prompted studies targeted at optimizing material flow and sequencing within each sector of the plant to improve product scheduling and deliverability.



□The Dowell Chemical Manufacturing Plant in Tulsa, Oklahoma, USA. This facility, which achieved ISO 9002 certification in 1992 and ISO 9001 certification in 1996, has one of the most consistent product on-time delivery records in the specialty chemical manufacturing business.

Given the number of raw materials, reaction intermediates and finished products—along with packaging, labeling and storage options—specialty chemical manufacturing plants are among the most logistically complex facilities to be found anywhere in the world. Today's plants have adopted quality and productivity programs that have been proven to be effective in other industries. Some have been introduced out of necessity, due to the complex nature of the operation. Others are a direct result of application of general quality standards, while still others reflect guidelines established through International Standard Organization (ISO) certification or mandated by environmental regulations.⁵

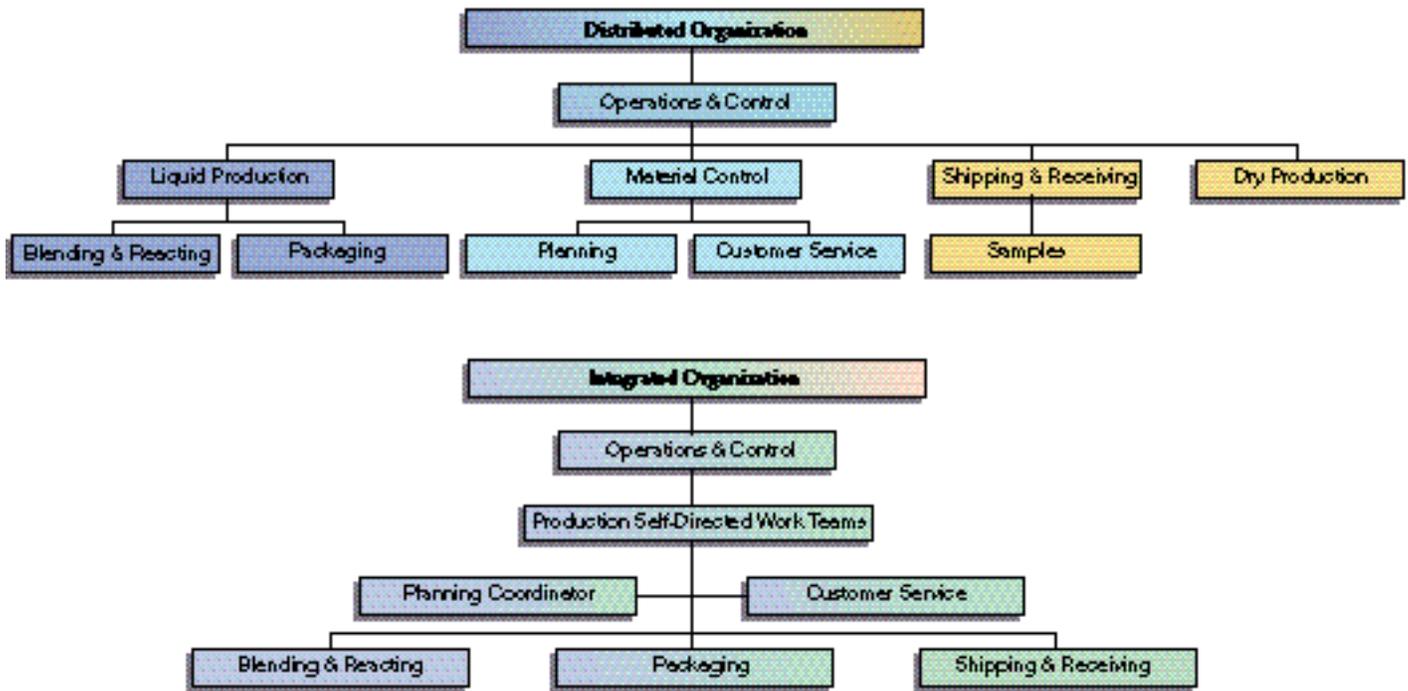
Compared to a decade ago, materials flow has been streamlined to simplify in-plant logistics and support new product delivery concepts, such as just-in-time manufacturing. For both liquid and dry products, the optimization process has affected the amount of space allocated to various functions—such as raw material receipt and storage, reaction and blending, packaging, finished product storage and shipment—as well as their proximity and interactions (*previous page*). The result: increased plant throughput, greater productivity of plant personnel, improved product delivery and shortened order lead times.

For example, 89% of all North American field orders are now shipped within two days from the Dowell specialty chemical plant in Tulsa, Oklahoma, USA, a 33% improvement from the three-day average a few years ago. Shipments to overseas loca-

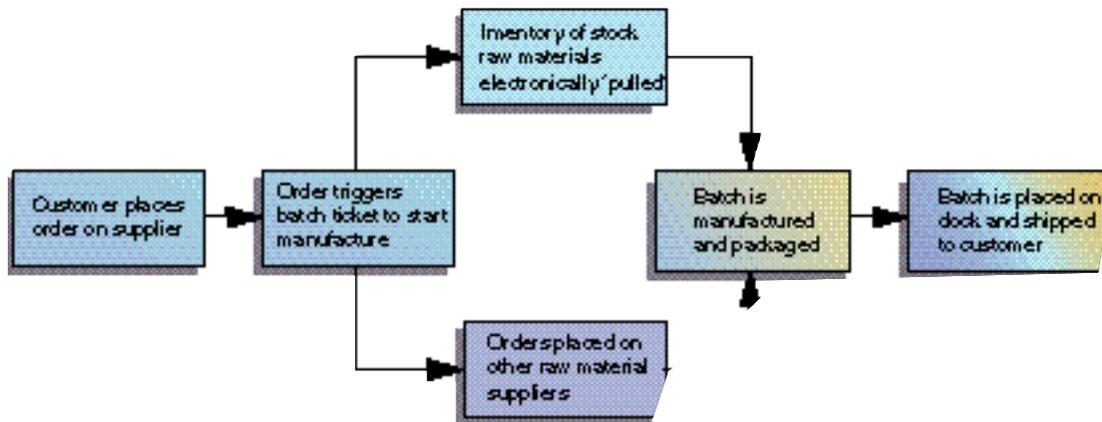
tions typically take two weeks today, instead of the previous three (*above*).

Better packaging techniques for liquid products have greatly improved accuracy. Instead of filling containers according to volume, which is subject to variations of $\pm 1\%$ based on the temperature of the material at the time of loading and other factors, weight has become the standard. State-of-the-art mass flowmeters provide an accuracy within 0.15%.

5. The International Standards Organization, based in Geneva, Switzerland, is the main body that has established quality procedures and controls adopted by the oil and gas industry. Its ISO family of programs have become the recognized standard for a quality system.



□ Change in plant organizational structure. The traditional distributed organization (top) is giving way to an integrated, concurrent structure (bottom) that will be composed of self-directed work teams dedicated to particular process streams within the plant. This structure will empower employees to become intimately involved in all aspects of quality control and quality assurance programs.



□ Just-in-time manufacturing flow. Just-in-time production is generally defined as a system of managing operations with little or no delay time or idle inventories between one process and the next. Modern specialty chemical plants have improved raw material flow and chemical production by adopting just-in-time processes similar to those used in small-parts manufacturing plants. Just-in-time production is most evident in a continuous process in which material arrivals are timed to coincide with the production run. Batch processes vary from this methodology along the following lines:

- For high-volume products purchased by many customers, some finished products are typically held in inventory, but with a minimum trigger level that causes additional batches to be scheduled to maintain that level.
- For medium-volume products, a plant typically carries inventories of the raw materials. Products are not made until an order is received.
- For low-volume products, particularly those sold to a single customer, the only raw material inventories are those used in other, high-volume products. When a customer orders the product, the plant, in turn, orders the raw materials specific to that product.
- High-volume raw materials have a minimum trigger level for reordering, but low-volume raw materials are ordered only as needed.

The combination of packaging improvements, along with less off-specification material produced and tighter quality control, has meant fewer product returns from the field and more satisfied customers. An added benefit is minimization of waste at the wellsite and at the manufacturing plant.

Equipment and logistics improvements are only part of the story, however. There has also been a revolution in information systems and organizational work practices. Technological advances in linked computer systems and software, increased intervention by regulatory agencies and an emphasis on reduced inventory levels have been instru-

mental in driving improvements in plant efficiency. These changes have occurred in both supplier plants and customer facilities.

Organizationally, major gains are being achieved by encouraging people on the plant floor to directly influence product quality and deliverability. Rather than separating functions as in the past, there is a move toward self-directed work teams that oversee all aspects of the planning, preparation, packaging and shipping of particular product streams. This concurrent organization instills a sense of pride and ownership, not unlike the strides that have been achieved in automotive assembly. Potential problems are caught sooner. Employees are encouraged to submit suggestions for further improvements, with a promise of rapid management review and response (*previous page, top*).⁶

In total, there have been a multitude of changes that are having pronounced benefits both for plant and field operations. The remainder of this article focuses in greater depth on four:

Within the plant—

- Improved deliverability using just-in-time principles
- Quality control through organizational and informational changes
- Chemical product reformulation

At the wellsite—

- Minimizing waste discharge

Improved Deliverability Using Just-in-Time Principles

Many service companies and other specialty chemical customers now place smaller, more frequent orders with shorter lead times, thereby reducing their inventories and carrying costs. For many plants, the volume of chemicals shipped has not changed appreciably, but the number of orders has increased significantly. Manpower and costs associated with order processing are linked more closely to the number of orders, rather than order size. Thus, chemical suppliers have adopted more sophisticated means of processing orders to keep from increasing staffing levels. This has led to adoption of just-in-time manufacturing principles at facilities like the Nalco/Exxon Energy Chemicals Plant in Sugar Land, Texas, USA (*above*).⁷

In the current marketplace, service companies strive to minimize inventories and apply more sophisticated scheduling and inventory management methods. This is contrary to traditional practices in which large inventories were maintained to avoid running out of materials. Today, without an inventory cushion, on-time shipments become critical, and the communication link between supplier and customer must be flawless.



□The Nalco/Exxon Energy Chemicals Plant in Sugar Land, Texas, USA. Nalco/Exxon was one of the pioneers of just-in-time specialty chemical manufacturing for the oilfield market and an innovator in applying new informational systems. The Sugar Land plant received ISO 9002 certification in 1992.

On the manufacturing side—with a single plant producing as many as 500 products starting from as many raw materials—inventory costs are significant. Methods to minimize raw material inventory can be key to keeping production costs low. The 20/80 rule-of-thumb applies—about 20% of the raw materials are used in about 80% of the products. The balance may be used only occasionally—with most of the remainder appearing in only one to three products. Large inventories increase the probability of overstocking, with a corresponding negative impact on overall costs.

Production scheduling formerly was “eyeballed” by an experienced individual based on historical norms. For just-in-time production, scheduling requires integrated databases that track customer orders, production status, raw materials in plant inventory and in transit, equipment constraints, and environmental regulations that limit which products may be made in which pieces of processing equipment (*previous page, bottom*).

6. Duncan E, Gervais I, Le Moign Y, Pangarkar S, Stibbs B, McMarran P, Nordquist E, Pittman T, Schindler H and Scott P: “Quality in Drilling Operations,” *Oilfield Review* 8, no. 1 (Spring 1996): 20-35.

7. Schonberger RJ: *Building a Chain of Customers: Linking Business Functions to Create a World-Class Company*. New York, New York, USA: The Free Press, 1990.

Traditional	Vessel time	Batch hold time	Packaging time	Warehouse time	Dock time	Invoice time	Customer time	Payment received
Ideal	Vessel time	Packaging time	Customer time	Payment received				

□ Cycle-time history. By using just-in-time principles and changing from traditional business practices based on large-batch production, specialty chemical plants have cut the total cycle time to make and deliver a product. These methods significantly reduce the time between receipt of an order and receipt of payment after product delivery.

Traditional product costing tends to be batch-based, driving production to larger batches and increased inventories. New methods had to be developed to reflect the true cost structure more accurately in a changing market. With the trend to smaller batch sizes and quicker equipment changeover to meet order demand, the traditional chemical production line has evolved into something more akin to a small-parts assembly line.

Large general-purpose reaction and blending vessels with long batch times are used less frequently. Instead, smaller vessels with rapid turnover—segregated to similar process families to reduce waste and washing—are now the mainstay of plants, along with automated in-line blending equipment for selected product/chemistry lines. Computer systems throughout the production facility now bring up-to-the-minute information, such as batch status and inventory consumption, directly into the scheduling office, moving plants like Nalco/Exxon toward a make-to-order facility.

Packaging and labeling are additional areas that have seen radical change. Products are shipped in a variety of package types and sizes, including traditional 55-gal [208-L] drums, returnable tote tanks and disposable containers, such as small pails. Returnable tote tanks represent an additional capital resource and require some alterations to the normal manufacturing and packaging cycle. As we will see later, however, substantial overall cost savings and environmental benefits result from their use.

Many customers demand customized container labeling to fit their facility and inventory management needs. Bar coding on containers and portable radio-frequency readers make storage and access easier when dealing with numerous, random locations. Tracking becomes critical in optimiz-

ing warehouse space and managing minimum inventories, which in many cases may be only a few containers. Bar coding also reduces random errors in shipping, something to be avoided at all cost in a reduced-inventory, just-in-time delivery market.

Quality Control Through Organizational and Informational Changes

As noted earlier, fundamental changes in organizational work practices have improved production efficiency for specialty chemicals. The quality and ISO processes provide structure in what used to be a relatively unstructured business and form the basis for a set of recognized guidelines and a common operating language for raw material vendors, chemical manufacturers and clients.

This common approach has led to a major advance in product quality assurance through application of standardized test methods, as well as procedures for equipment calibration and maintenance. By reducing the testing required to statistically validate processes, cycle times have been decreased (*above*). The ISO structure, by its very nature, provides a means for better assimilating the increasingly complex information that is being generated, defining disciplined standards and tools for data organization that allow productivity improvements in a diverse, dynamic business environment.

In the past, it was difficult or impossible to set product specifications and define raw material evaluation methods that were mutually agreeable to raw material suppliers, specialty manufacturers and clients alike. Today, as a result of adoption of quality processes, specifications are routinely established and diligently adhered to. Raw material vendors understand that their performance will be continually monitored using a comprehensive set of criteria—where price is only one parameter. Other factors include on-time delivery, correct labeling, correct loading in the delivery truck, completeness of paperwork, and container condition. In combination, these data provide input to a rating system in which each supplier's performance is determined, compared to a site standard and then ranked against the performance of other vendors. A critical part of the process is providing comprehensive feedback to vendors on areas for improvement. If noncompliance with site standards occurs, formal written documentation outlines the deficiencies and requests explanation of causes and provisions for short-term fixes and longer-term solutions. The rating system is useful for other purposes also, such as identifying suppliers who consistently exhibit superior performance and might be considered as candidates to participate in alliances (*next page, top*).

Multifunctional teams—including representatives from research, marketing, engineering, purchasing, quality assurance and HSE—evaluate and select vendors. For critical high-volume products, clients may also be involved in the vendor selection process. The multifunctional team, in conjunction with a similar team from the vendor, determines the product specifications, quality assurance testing procedures and communications protocol.

These specifications and quality assurance data are compiled into a common informational database that also includes operating procedures, health and safety information, maintenance records and the most recent environmental regulations. With networked computers, employees throughout the plant have access to the same, up-to-date information on raw materials and finished products. Common databases allow plant

employees to respond accurately and quickly to client inquiries related to product manufacture, testing, and environmental compliance.

Changes in environmental regulations significantly affect specialty chemical plants because of the wide variety of raw materials employed and the types of products that are manufactured. Just a decade ago, a plant would have only a few environmental engineers, but today nearly half of the engineers work on environmental issues and regulatory compliance. Information on production and plant practices must be retained longer and in more detailed formats to comply with regulatory guidelines. Networked computer systems allow instant access to particular product information in the event of unannounced environmental audits. Without linked information systems, data retrieval would be difficult, slow and costly (*below*). The quality process has brought disciplined measures and tools to help manage the collection and use of massive amounts of data in this highly complex business.

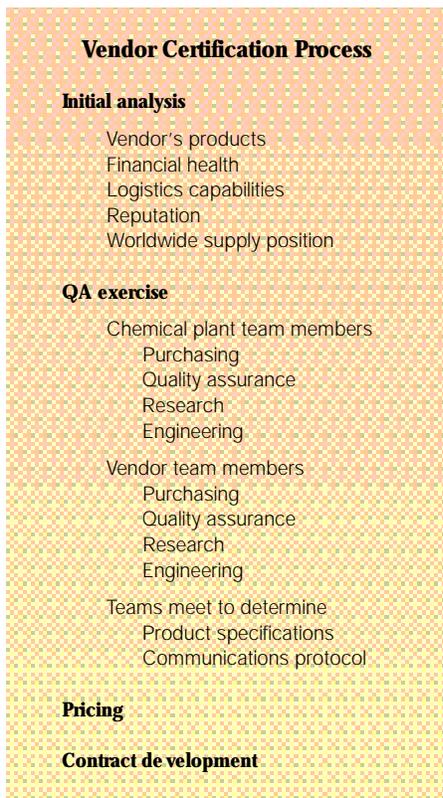
Chemical Product Reformulation

Several forces drive the reformulation—or reengineering—of specialty chemicals. The most notable are the need to:

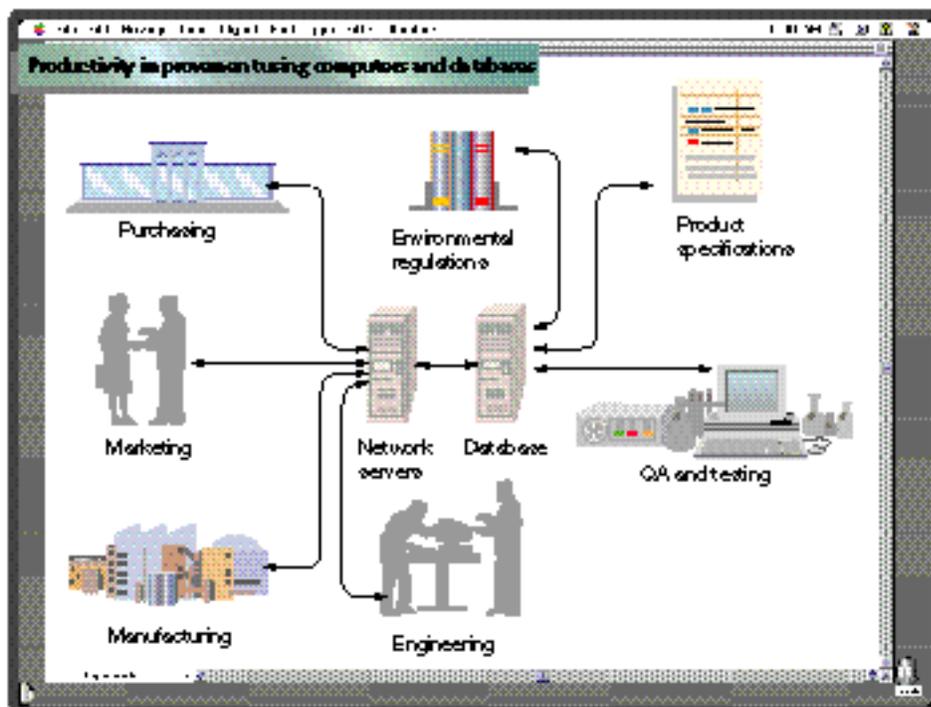
- improve performance
- reduce cost
- minimize safety or environmental hazards.

Chemical manufacturers and service companies have addressed these reformulation problems singly and in combination, with a beneficial impact on wellsite execution efficiency, well performance, environmental protection and overall chemical usage and cost.

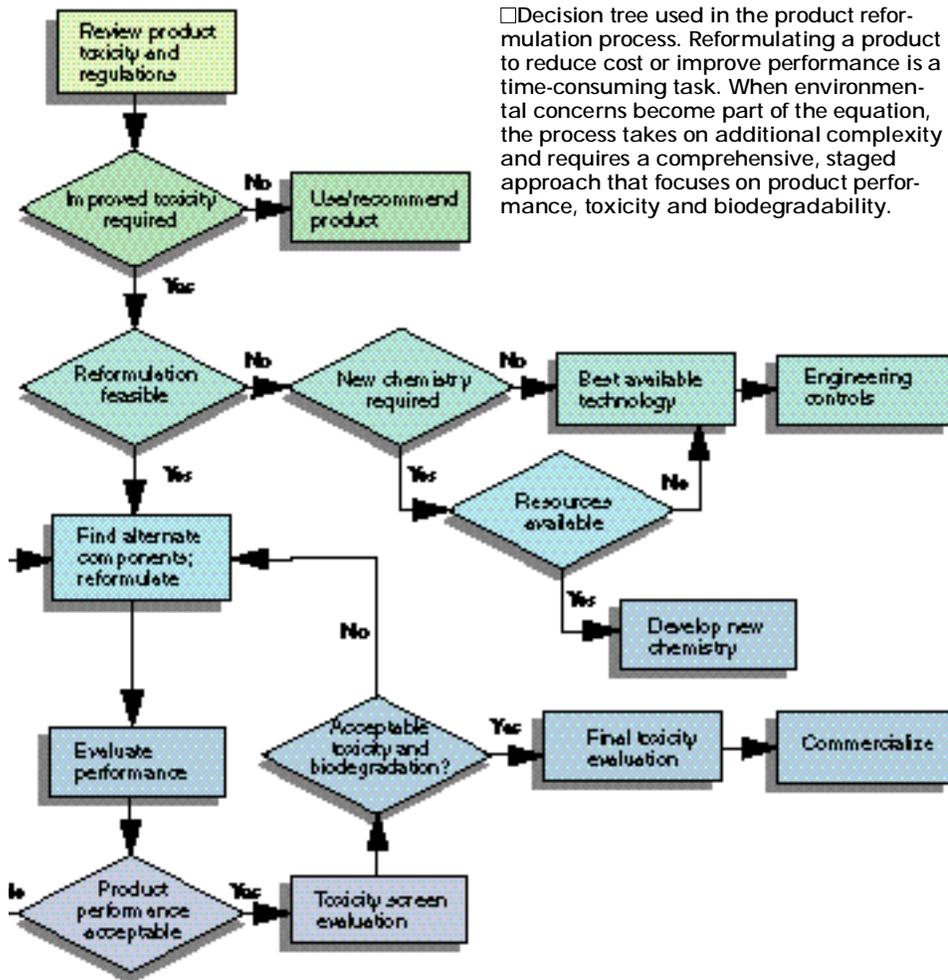
Research studies targeted at improving the understanding of mechanisms controlling chemical interactions have led to revised material design specifications and extensions in functionality that allow field temperature and concentration ranges to be broadened. Process optimization within



□ Vendor certification process. The vendor selection process includes an analysis of the raw materials, the supplier's stability, the supplier's shipping and timing capabilities, and finally price. Once a multi-functional team selects a raw material vendor to supply a product, groups from the vendor, chemical plant and often the end-user meet to determine raw material and product specifications, quality assurance testing and logistics for shipping materials worldwide.



□ Productivity improvement using computers and databases. Part of the revolution in the specialty chemical manufacturing industry has centered on information systems and organizational work practices, not just new equipment and chemical processes. Networked computers allow information about products to be retained with greater detail and retrieved more easily for compliance with environmental regulations. Through common databases, information on production runs and product testing is immediately available to personnel in all areas of the plant.



□ Decision tree used in the product reformulation process. Reformulating a product to reduce cost or improve performance is a time-consuming task. When environmental concerns become part of the equation, the process takes on additional complexity and requires a comprehensive, staged approach that focuses on product performance, toxicity and biodegradability.

handling or mixing constraints. Industry-wide, a concerted effort on product reformulation has helped guarantee a continuous supply of laboratory-optimized products and spurred competitive pricing among raw material vendors who offer similar product lines.

The oil crisis of the mid-1980s and enactment of environmental regulations have undoubtedly had the greatest impact on specialty chemical reformulation efforts. Chemical-cost reduction became a potentially quick and easy way to reduce wellsite costs and improve profitability in the face of depressed oil prices. As with replacement materials that broaden production and delivery capabilities, the main goal was to introduce alternative, lower-cost materials that do not demonstrate adverse effects, while still adhering to the product's original performance specifications.

For example, a high-volume corrosion inhibitor used in matrix acidizing stimulation treatments could no longer be produced because one of its key ingredients was no longer available. Thorough laboratory testing led to a suitable material that satisfied four objectives simultaneously, exceeding expectations established at the outset. The price of the final product could be reduced by 18% due to lower raw material costs and the new inhibitor demonstrated better dispersability in acid—a key criterion for product performance. Corrosion rates on samples of well tubing showed protection equal to the existing material, and the reformulated product posed reduced handling and mixing hazards.

Product reformulation, however, takes on its most important aspect when safety or environmental considerations come into play. The basic chemistry of many specialty oilfield products makes them potentially harmful if discharged into the environment. Reducing their impact may require elimination of materials banned by regulatory mandate or incorporation of components that offer reduced levels of toxicity. In both cases, the choice of replacements must be such that acceptable product performance is maintained. When environmentally sensitive materials form part of the reformulation equation, the evaluation and testing process becomes more complicated than in the case of replacing materials for cost or

specialty chemical plants—centered on parametric studies of reaction and blending conditions such as temperature, pressure, exposure time and raw material addition sequencing—has increased product yield and reduced byproducts. Product consistency, reproducibility and reliability have improved, dovetailing directly with complementary programs geared toward quality control and quality assurance.

New delivery methods that permit increased additive concentrations and pinpoint placement of materials, such as encapsulation techniques for fracturing fluid breakers, have provided breakthroughs in pumping and treating procedures.⁸ Multifunctional additives have helped limit the

number of fluid components needed for a given functionality, thereby reducing complexity, simplifying chemical and physical interactions within the fluid and the formation, reducing inventory requirements, and increasing mixing and blending efficiency at the wellsite.

Reformulation often is not elective—it becomes mandatory if one or more raw materials is restricted or no longer manufactured. To lower risk, especially for critical chemicals that maintain well productivity, it pays to anticipate—particularly if availability is limited to a single vendor and continuity of supply cannot be assured. In these instances, reformulation entails extensive testing and evaluation of a suite of alternative materials from multiple vendors to determine the most cost-effective replacement candidate. Care must be taken to ensure that product performance does not suffer and that there are no unexpected

Chemical product	Product toxicity* (EC 50)		Surfactant	Surfactant component biodegradability	
	Existing	Replacement		Existing	Replacement
Stimulation surfactant	0.4-1.0 mg/L	3.94 mg/L	1 2 3	78% 25% —	80% 82% 62%
Acid-corrosion inhibitor	0.27 mg/L	2.57 mg/L	1 2	42% 27%	85% —
Acid-gelling agent	0.32 mg/L	1.89 mg/L		0%	94.6%

*For *Skeletonema costatum*

□ Results of product reformulation efforts for the North Sea. Three products were reformulated to improve environmental acceptability. Each new material showed lower toxicity values—as measured by EC50 standards on *Skeletonema costatum* (algae)—and improved surfactant biodegradability. [* EC50 is a European Community-approved procedure for measuring the toxicity of various chemicals to marine life. The EC50 value is the concentration at which 50% of the species exposed to the chemical survive.]

performance reasons. Interplay among composition, performance, toxicity and ultimate environmental impact must be considered, requiring a phased approach to design, testing, cross-checking and application⁹ (previous page).

In 1995, a replacement program for specific products used in the North Sea was initiated at the Dowell product center in Tulsa. The initial objective was to replace eight chemicals, selected based on criteria established by clients and usage volumes. The goals were to eliminate any nonylphenol surfactants—which had been banned in selected areas of the North Sea—decrease product toxicity and improve biodegradability.

Four products in particular—a stimulation surfactant, acid-corrosion inhibitor, acid-gelling agent and brine viscosifier—required extensive reformulation work. Each presented the team of chemists working on the program with different challenges—dictated by chemical composition, complexity and intended use. For the stimulation surfactant, a suitable reformulated product was devel-

oped that exhibited lower toxicity without a significant loss in product performance. For the acid-corrosion inhibitor, an alternative product showed improved biodegradability for all but one component, and dramatically reduced toxicity. Reformulation of the acid-gelling agent resulted in a product with equivalent performance, and eliminated the nonylphenol surfactant previously included. Studies of the brine viscosifier showed that novel chemistry would need to be developed before a long-term solution could be achieved (above).

While this highly successful program is only one example of numerous studies being conducted within the industry, it was also time-consuming and expensive—requiring 18 months and costing about \$75,000 US per product. Extending such studies to reformulate an entire slate of hundreds of specialty chemical products is a major undertaking. It is critical to balance the objective of improved environmental compatibility with the cost and technical requirements involved so that maximum benefit can be achieved in the most expeditious and cost-effective manner.

Minimizing Waste Discharge

Daily, millions of barrels of drilling and treating fluids are pumped into wells around the world. The industry's goal is to pump the minimum volumes necessary to achieve design objectives—in other words, use the highest-performing, most time- and cost-effective fluids possible. In most cases, this means minimizing the amount of fluid lost to the formation. In wells that contact significant intervals of highly permeable formations, this is no small challenge. Equally important—since the introduction of stricter environmental rulings—is the reduction or elimination of waste streams at the surface that require treatment or disposal, particularly since this treatment or disposal may be very expensive (next page).

Downhole, progress in fluid design and specialty additive formulation has pushed operating limits forward. Today, we see drilling fluids with lower static and dynamic filtration rates that still give acceptable penetration rates; fracturing fluids with greater fluid efficiency, that allow the creation of deeper, wider fractures at the same stimulation treatment volume; and loss-controlled matrix stimulation fluids that eliminate wormholing and rapid acid spending, react with more formation surface area and provide an etching pattern that leads to greater stimulation.¹⁰

At the surface, from the spudding of a well through completion, first oil or gas delivery, and ongoing production, the industry has dramatically reduced the volumes of fluid required for disposal on and around the wellsite. Partially closed or completely self-contained, non-effluent drilling mud treating systems have eliminated the need for onshore reserve pits and offshore discharges into the marine environment. The advent

8. Gulbis J, King MT, Hawkins GW and Brannon HD: "Encapsulated Breaker for Aqueous Polymeric Fluids," paper SPE 19433, presented at the 9th SPE Formation Damage Symposium, Lafayette, Louisiana, USA, February 22-23, 1990.

9. O'Neill JE and Hill DG: "Reduction of Risk to the Marine Environment from Oilfield Chemicals—Balancing Environmental and Technical Needs," paper SPE 35946, presented at the Third International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, New Orleans, Louisiana, USA, June 9-12, 1996.

Minimize fluid lost to the formation

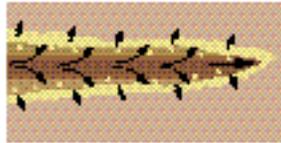
Drilling



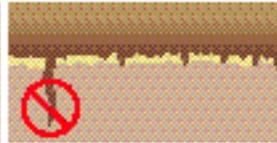
Reduced static and dynamic fluid loss

Stimulation

Increased fracturing fluid efficiency

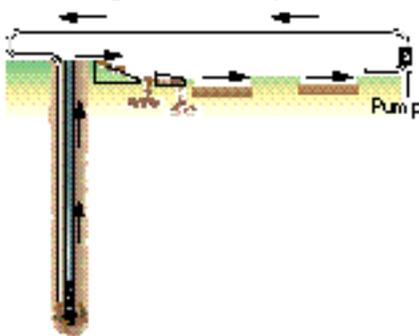


Mitigation of acid wormholing

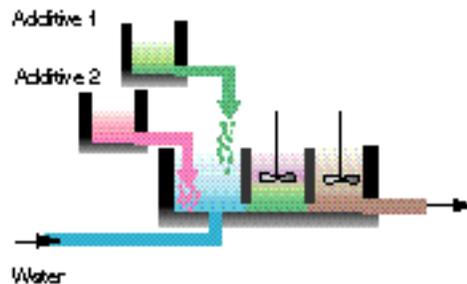


Minimize surface waste discharge

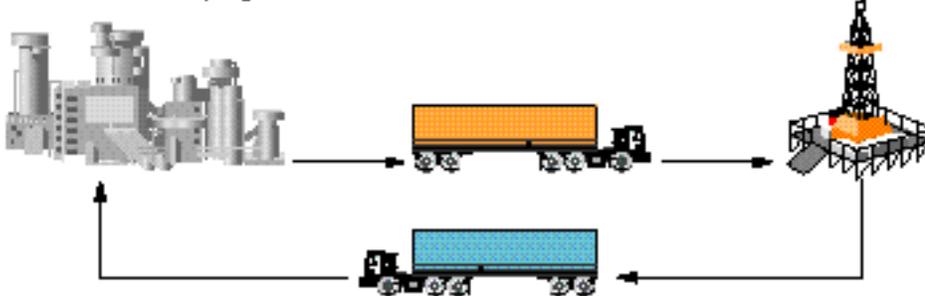
Closed drilling mud treatment system



Continuous versus batch mixing



Tote tank and drum recycling



□Minimizing fluid lost to the formation and wellsite waste discharges. Fluid lost during well drilling and treatment can be reduced through application of innovative chemical technology that simultaneously decreases formation damage. At the wellsite, use of closed-loop mud treatment equipment, continuous-mix systems and container (tote tank and drum) recycling programs can dramatically reduce cost and environmental impact.

and routine use of continuous-mix systems, replacing batch-mix systems, have significantly decreased or eliminated tank bottoms by allowing on-the-fly preparation and delivery of fluids with adjustable

properties.¹¹ Continuous-mix processes can greatly improve technical and environmental performance and represent the application of hazard control through engineering advances and risk management.

Stimulation vessels operating in the North Sea were among the first to employ continuous-mix technology. A typical stimulation treatment may require up to 200,000 gal [757 m³] of hydrochloric acid containing a variety of chemical additives. Previously, materials were batch mixed up to a day in advance. The potential waste to be disposed of from tank bottoms could be as high as 15 to 20% of the total treatment volume, or up to 80,000 gal [302 m³]. Today, with continuous-mixing methods, a similar size treatment generates no waste.¹²

Of the various practices that have aided this process, one that has had a major impact is reduction in the number of disposable chemical containers—through recycling and alternative technology. Until the early 1990s, 55-gal steel and plastic drums were the preferred method for delivering liquids to the wellsite—comprising nearly 100% of the packaging produced by many specialty chemical manufacturing plants. Drums were convenient, widely accepted, readily available and relatively cheap to transport.

The problem came with the end user in the field. Inventories of used drums at well-sites and at service company field offices grew, creating a major disposal problem. Direct disposal costs, often in the range of \$7 US per drum, and the potential for environmental liability were a growing concern. As business activity increased, so did the number of drums requiring disposal, increasing costs and cutting into margins. Rules governing drum disposal in the USA vary, depending on size and construction material. The combination of logistics and accompanying documentation, complicated by numerous stocking points and drum usage exceeding tens of thousands annually, presented a sizable challenge for service companies. The challenge extended to Canada, where drum disposal costs were even higher and it was necessary in certain locations to stockpile containers until a credible disposal firm could be identified. With time, the problem began affecting many oil-producing countries around the world.

To meet the challenge in the USA, some companies opted for interim solutions—implementation of 55-gal drum recycling programs or providing materials in smaller volume containers that were easier to dispose of or could be recycled. The former entailed empty container transport back to the origination point, washing, disposal of wash materials and refilling. In many cases,



□ Reusable chemical tote tank. This standard Nalco/Exxon 4- × 4- × 4-ft [1.2- × 1.2- × 1.2-m] reusable chemical tank holds 375 gal [1419 L].

the costs incurred exceeded those for drum disposal and, with time, several companies dropped or cut back on such programs. In the latter case, some companies are now focusing on recycling smaller, 5-gal [18.9-L] containers, and the containers are returned, shredded, remanufactured and then reused.

A successful long-term approach has been the use of returnable stainless steel and composite tote tanks, available in a variety of sizes with 100-, 150- and 330-gal [378-, 567- and 1249-L] most common. (*above*). Built for durability, these containers have a life expectancy of five years or more. Within many companies, the tote-tank program was begun on a trial basis as a supplement to continuing delivery of the bulk of their products in drums. As the benefits of this approach were demonstrated, the initiative grew and currently many service companies and specialty chemical manufacturing plants use tote tanks as the primary vessels for liquid products. The Dowell Tulsa plant, for example, ships 98% of its liquid products in tote tanks and the remaining 2% in composite, instead of steel, 55-gal drums.

Tote tanks reduce overall material delivery costs to the wellsite. While requiring an initial capital investment and ongoing freight and handling costs for transportation back to the chemical plant, these costs are more than offset by savings in drum costs, disposal fees and reduction of environmental exposure. Long-term savings outweigh initial investment and maintenance costs. As the number of tote tanks has increased, suppliers have learned how to optimize delivery and return logistics to lower transportation costs.

What the Future Holds

Producing oil and gas as cheaply and efficiently as possible requires cost-effective specialty chemical additives tailored to provide optimal well drilling, completion and intervention services. The past decade has seen a concerted effort by chemical manufacturers and service companies to improve quality and reliability, and extend the operational capabilities of these materials. By using the latest tools and techniques, much has been accomplished, with major benefits both in the plant and at the wellsite.

For the future, there will be a continuing drive for efficiency and productivity in every aspect of oilfield operations. This will include expansion of synergistic efforts in the specialty chemical sector—just-in-time manufacturing and inventory practices, quality control and quality assurance programs that utilize the latest information technology, product cost and performance optimization through reformulation, and even greater emphasis on environmental compatibility. The cornerstone of today's oilfield business is delivering solutions, rather than simply supplying products and services. This is the key to successfully leading the industry forward, and is especially true for specialty oilfield chemicals.

—DEO/KPR

10. Fluid efficiency is defined as the volume of fluid remaining in the fracture divided by the volume of fluid pumped into the fracture. Higher efficiency means less fluid lost to the formation.
11. Geehan T, Helland B, Thorbjomsen K, Maddin C, McIntire B, Shepherd B and Page W: "Reducing the Oilfield's Environmental Footprint," *Oilfield Review* 2, no. 4 (October 1990): 53-63.
12. O'Neill and Hill, reference 9.