

Oil Well Sand Consolidation. I. Resins for a Three-Step Process

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Synopsis

Oil-bearing formations often consist of loose sandy material. In the production of oil from these formations sand tends to be carried to the well bore along with the oil. The flow of sand can be prevented by consolidating or cementing together the sand particles of the formation around the well bore. The cementing has to be accomplished in such a manner that fluid flow channels between particles remain open. This paper describes a new three-step process that was developed to consolidate oil well sand. The steps in the process involve injection of: (1) resin, (2) inert fluid, and (3) inert fluid containing a catalyst. In the first step of the process, resin is injected into the formation where it fully saturates the interstices between sand grains. Permeability is established in the second step by displacement of the excess resin from the interstices, thereby leaving a thin film of resin on the sand grains. In the third step, polymerization is activated by migration of catalyst from the inert fluid into the thin resin film on the sand. The process has the advantage that resin is placed and permeability is established before the resin is catalyzed. This avoids premature polymerization of the resin which might cause plugging of the formation or the tubing string used to inject resin. Desirable characteristics of a resin for the three-step process are: (1) viscosity of 25-200 cp. at well bore temperature; (2) stability for several days at well bore temperature; (3) high adhesion to sand in the presence of an inert flushing fluid; (4) polymerization by less than 10% catalyst; (5) the polymerized resin binds sand together with a strong bond that is not affected by well fluids. Five different resin types have been tested for use in the three-step sand consolidation process. These are: (1) epoxy-anhydride cured with a tertiary amine; (2) epoxy-epoxy diluent cured with a primary-tertiary amine mixture; (3) furan; (4) unsaturated polyester-vinylpyrrolidone; (5) unsaturated polyester-styrene. The two epoxy resins give strong, permeable consolidated sand which is resistant to well fluids such as brine and crude oil. The furan resin gives a weak consolidation. The unsaturated polyester-vinylpyrrolidone gives good strength and oil resistance but is sensitive to brine. The unsaturated polyester-styrene is difficult to apply. Many oil wells have been successfully treated in the Gulf Coast area and in California with the two epoxy resins. Almost all of these wells are producing free of sand, and, to date, more than five million barrels of oil have been produced from these wells.

INTRODUCTION

Production of oil and gas from underground formations sometimes is hampered by sand that is produced along with the oil. Sand influx into

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the well usually causes serious problems both with downhole and surface equipment. The problem is especially severe if the formations are unconsolidated and consist of fine sand and silt. As a result, wells drilled into these formations may require costly repairs to remove sand and the wells may prematurely become uneconomical to produce.

To cope with the sanding problem, various mechanical screens have been used either inside or outside the well bore to filter out sand. These screens, however, tend to become plugged by fine formation particles. The high flow rates of formation fluids just outside the well bore carry these particles along with the produced fluids and deposit them on the screens. A few feet away from the well bore the flow rate is usually much lower, so that fine formation particles are not moved towards the well. An ideal sand control method is one which cements together formation particles over a sufficiently large radial distance from the well to prevent particulate matter from moving. It is evident that fluid flow channels should remain open so that the cementing process should insure that adequate formation permeability is retained.

Several organic and inorganic consolidating agents for oil well sands have been suggested in the literature during the past twenty years.¹⁻⁵ The inorganic consolidating agents tend to be water-sensitive and lose their adhesive strength in a short time.² The organic cementing agents proposed to consolidate sand, such as phenolic⁴ and epoxy⁵ resins, seem to have qualities that could produce consolidated sand with adequate strength retention upon exposure to well fluids. However, in the processes that use these resins, a catalyst is mixed with the resin solution at the surface before injection of the resin into the well. Consequently, polymerization is initiated at the surface so that these processes have the disadvantage of being time dependent.

This paper presents a new three-step process for applying cementing agents to well formations.⁶⁻⁸ The process has the advantage of being less time dependent than previous processes. Laboratory test results using various organic polymers as cementing agents in the three-step process are described below. The merits of each polymer are discussed, and the properties desired for an ideal resin for the three-step process are described.

PROCESSES FOR SAND CONSOLIDATION

Plastic sand consolidation processes can be differentiated from each other by the number of steps in each process such as, for example, a one-step or a three-step process.

In a one-step process, the formation is consolidated by means of a solution that contains active monomers or prepolymers which react to form a polymer. The polymer precipitates from solution and cements sand grains together. The amount of monomer in the solution affects the permeability retention. Lower monomer concentrations give higher permeability retentions. In the one-step process, the resin solution is catalyzed or activated before it is pumped into the well. A certain amount of time is avail-

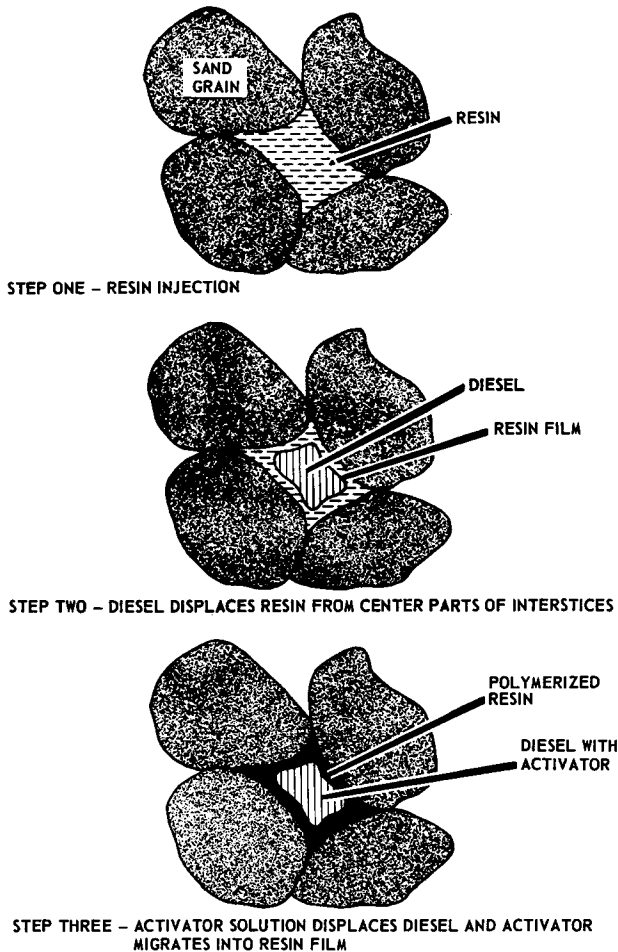


Fig. 1. Illustration of three-step process for sand consolidation.

able before the resin polymerizes and precipitates from solution to cement the sand grains together. This time is dependent on the particular resin system used and the amount and type of catalyst mixed with the resin. However, once the resin solution and activator are mixed, the time available before polymerization is fixed. It is evident that the solution should be pumped into the formation prior to resin precipitation or the resin may precipitate in the injection string. This requirement is not always easy to meet in actual field operations because unexpected pump breakdowns may occur. Because this process requires that fluids be pumped into the formation in a particular time interval, the process can be called time dependent.

An alternate process for resin placement is the three-step process. In this process, the activators or catalysts are not mixed with the resin at the surface. In the first step of the process, an uncatalyzed resin is pumped

into the formation. In the second step, a fluid such as diesel oil is pumped into the resin-saturated formation to displace resin from the center parts of the interstices while maintaining a thin film of resin on the sand grains. In the third step, a catalyst solution displaces the diesel from the previous step. The resin surrounding the sand grains is now in contact with a catalyst-containing solution. The catalyst diffuses into the resin and initiates polymerization to yield a consolidated permeable sand.

A significant advantage of the three-step process is that the resin is not catalyzed until after it is displaced into the formation and after permeability has been established. Therefore, the process is less time dependent than the one-step or precatalyzed process and is a more reliable process. The three-step process is illustrated in Figure 1.

EXPERIMENTAL

Resins were screened by measuring viscosity of the resin at well temperatures and by measuring the solubility of the resin and of the catalyst in a hydrocarbon such as diesel. Catalyst stoichiometry and polymerization rate were measured by observing gel time and Barcol hardness of $1/4$ -in. thick samples in 100-ml. polyethylene beakers after various times at temperature.

The effect of well materials on the resin prior to consolidation was measured by mixing the resin and well material at formation temperature and then measuring viscosity and polymerization rate after exposure. These tests will be described in detail in a subsequent publication.

Adhesion of resin to glass plates and migration rate of catalyst from oil to resin was measured qualitatively by depositing a 1.5-mil resin film on a glass plate and then covering the resin with a 1.5-mil film of oil-containing catalyst. The cured resin films on glass were then exposed to well fluids to measure qualitatively the durability of both the resin bonds and the resin-silica bonds. Durability of the pure resin was determined in some cases by measuring tensile strength retention of 4-mil films of resin after exposure to brine. Considerable care was required in preparation of these 4-mil films to avoid cracks in the edges of the brittle test specimens.

Resins which showed promise in the above tests were screened in a Hassler cell as follows. Sand was packed into a 1-in. diameter rubber tube with lengths ranging from 5 in. to 5 ft. in different experiments. The tubing was placed in a cell in which pressure could be applied to the outside of the tube to simulate overburden pressure. The cell could be heated to simulate formation temperature. The sand was placed under formation conditions of temperature (100–200°F.) and pressure (2000 psi). Next, the sand was filled with diesel oil, brine, or formation crude oil, and the initial permeability was determined. The consolidation chemicals were then injected into the sand pack.

Upon completion of consolidation, the flow rate of fluid through the sand pack was measured to determine final permeability and permeability

retention. The consolidated core was then removed from the cell and the extent of consolidation noted. Consolidated sections were cut into pieces 1.5-in. long which were used to measure permeability, compressive strength, resin content, and stability to well fluids.

Resin content was determined by burning the resin from the sand and by measuring the amount of sand left. Resistance to well fluids was measured by measuring compressive strength of 1.5-in. consolidated sand samples after exposure to formation fluids such as brine and oil at formation temperatures for periods up to one year. Compressive strength and permeability were reproducible to ± 200 psi and $\pm 5\%$, respectively.

The Hassler cell and flow tests are described in more detail elsewhere.⁹

RESIN REQUIREMENTS FOR A THREE-STEP PROCESS

The consolidation materials to be used in the three-step process should have several properties to be adaptable to oil field conditions. They should react chemically in a prescribed manner under the diverse conditions of pressure, temperature, and chemical environment in wells. They should produce a consolidated sand of high strength and high permeability which is resistant to well fluids. Properties of an ideal resin for the three-step process are described below.

Resin Viscosity

The resin should have a low enough viscosity to permit injection of the resin into the formation at pressures well below the fracturing pressure of the formation. Also, it should be low enough so that a flush fluid can effectively remove excess resin from the centers of the interstices while leaving a resin film on the formation particles. However, the viscosity of the resin should be high enough to displace the fluids that saturate the formation. A resin with a viscosity ranging from 25 to 200 cp. at formation temperature appears best when diesel is the fluid to be displaced from the formation and is also the fluid that establishes permeability.

Resin Stability Before Polymerization

Viscosity of the resin should not increase excessively at formation temperatures or in the presence of common well materials. The uncatalyzed resin should be stable for several days under formation conditions for the process to be independent of time.

Resin Adhesion and Solubility

The resin should be insoluble in the second-step flushing fluid and should have good adhesion to sand so that a resin film remains between sand grains while the flushing fluid displaces the excess resin. However, to ob-

tain a low viscosity at a low temperature, it may be desirable to have a solvent or reactive diluent mixed with the resin. The diluent may be soluble in the flushing fluid and slowly extracted by it.

Catalyst or Activator

Catalyst for the resins should be effective in relatively low concentration as it must migrate from solution into the thin film of resin. Also, if a high concentration of catalyst is needed, the concentrated solution of catalyst may act as a solvent for the resin and tend to wash the resin from the sand.

The catalyst should have a reasonable distribution coefficient between resin and solvent so that an adequate concentration migrates into the resin. Resins which require 1-10 parts of catalyst per hundred parts of resin seem ideal.

The catalyst should not react too rapidly with the resin or it will seal the resin interface and prevent catalyst from entering all of the resin. However, the rate should be fast enough that final polymerization is completed in less than 24 hr. to permit early initiation of production.

Properties of Consolidated Sand

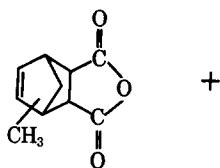
The polymerized resin-sand mixture should have good compressive strength, permeability retention, and resistance to well fluids such as hydrocarbons, brine, and stimulation fluids. A permeability retention that is at least 50% of that of the original sand permeability is desirable. Compressive strength should be 1000 psi or more after several years' exposure to well fluids at well temperatures. To achieve this with most resins seems to require an initial compressive strength of several thousand psi.

A high crosslink density is desirable in the resin to obtain brine resistance. A highly crosslinked or brittle resin can be used here because the system is isothermal, and the resin and sand are not subjected to thermal shock.

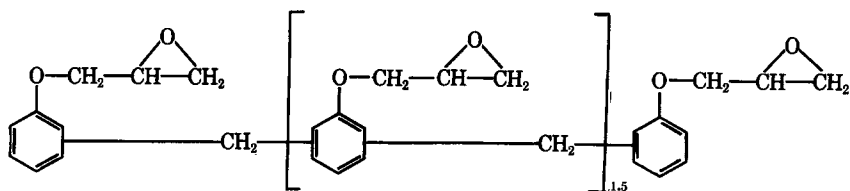
RESINS TESTED FOR THE THREE-STEP SAND CONSOLIDATION PROCESS

Resin Types

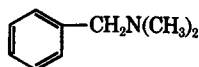
Five resin systems have been tested for use in the three-step process for sand consolidation. These are: (1) epoxy-anhydride (a mixture of epoxy resin and an anhydride); polymerization is activated by a tertiary amine:



Methylbicyclo[2.2.1]
heptene-2,3-dicarboxylic
anhydride

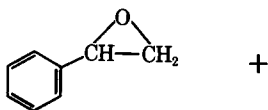


Epoxy novolac
(resin)

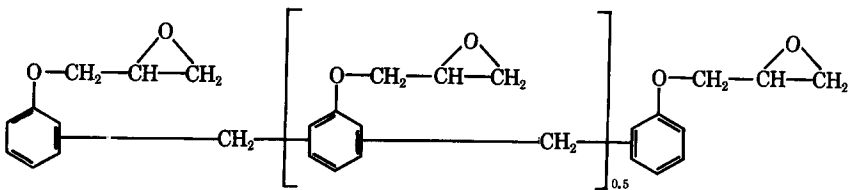


Benzyldimethylamine
(activator)

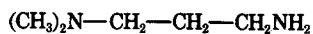
(2) epoxy-amine (a mixture of epoxy resin and an extractable epoxy diluent); polymerization is activated by a primary-tertiary amine mixture:



Styrene oxide

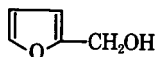


Epoxy novolac
(resin)

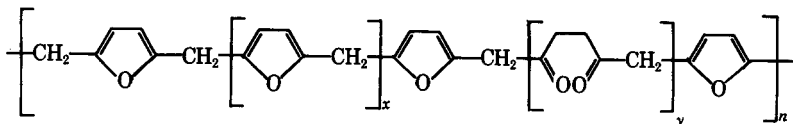


Dimethylaminopropylamine
(activator)

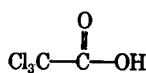
(3) furan (a mixture of furfuryl alcohol and furfuryl alcohol polymer); polymerization is activated by acid:



Furfuryl alcohol



Furfuryl alcohol polymer
(resin)



Trichloroacetic acid
(activator)

(4) polyester-vinylpyrrolidone (a mixture of an unsaturated polyester and *N*-vinylpyrrolidone); polymerization is activated by peroxide (see facing page).

(5) polyester-styrene (a mixture of an unsaturated polyester and styrene); polymerization is activated by peroxide (see facing page).

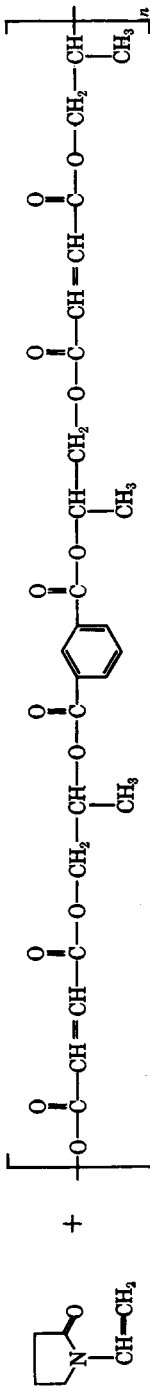
Resin Viscosity

The viscosity of the five sand consolidation resins at 72, 125, and 150°F. is shown in Table I. All of the resins have low enough viscosity for sand consolidation above 125°F. Below 125°F. the epoxy-anhydride is too viscous.

TABLE I
Viscosity of Sand Consolidation Resins at Various Temperatures

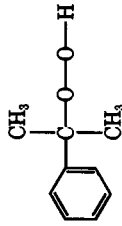
Consolidation resin	Viscosity, cp.		
	72°F.	125°F.	150°F.
Epoxy-anhydride	7000	370	190
Epoxy-amine	200	80	40
Furan	15	5	4
Polyester-vinylpyrrolidone	700	250	150
Polyester-styrene	170	70	50

The viscosity of the epoxy resins can be varied by changes in the epoxy molecular weight and also by varying the amount of low viscosity anhydride or epoxy diluent used. The viscosity of the polyester systems can be varied by changes in the polyester molecular weight and also by changes in the amount of low viscosity vinylpyrrolidone or styrene used. The furan

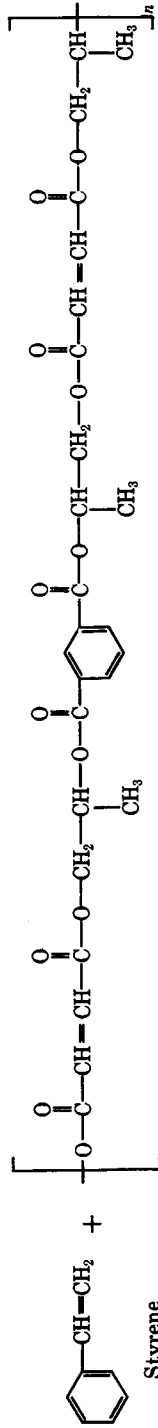


N-Vinylpyrrolidone

Unsaturated Polyester
(resin)



Cumene hydroperoxide
(activator)



Styrene

Unsaturated Polyester
(resin)

Methyl Ethyl Ketone Peroxide
(activator)

viscosity can be varied by varying the molecular weight of the furfuryl alcohol prepolymer and by varying the amount of furfuryl alcohol monomer used.

Effect of Well Temperature

The stability of the five resins to well temperature is shown in Table II. All of the resins have sufficient stability at 150°F. to allow injection into the sand and establishment of permeability with a second-stage flush before excessive viscosity increase.

TABLE II
Viscosity of Sand Consolidation Resins After Exposure to 150°F. Temperature

Consolidation resin	Viscosity increase after 24 hr. at 150°F., %
Epoxy-anhydride	15
Epoxy-amine	0
Furan	0
Polyester-vinylpyrrolidone	0
Polyester-styrene	0

Stability in the epoxy resin systems is obtained by using pure epoxides and anhydrides. The presence of common impurities such as hydroxyl-, phenolic-, and carboxylic acid-containing molecules reduces the stability.

The unsaturated polyester resins can be inhibited with diphenylquinone to give the required stability.¹⁰ The furan resin can be stabilized by neutralization of any acid present.

PLACEMENT AND POLYMERIZATION OF RESINS FOR THE THREE-STEP PROCESS

Catalyst

All of the resins require less than 10% catalyst to develop optimum properties. The epoxy-anhydride, polyester, and furan require only 1-2% catalyst; whereas, the epoxy-amine system requires 4-8% catalyst.

Diffusion of the catalyst into the resin from a hydrocarbon such as diesel oil appears rapid in all cases. With the epoxy-anhydride resin at 150°F. or the epoxy-amine resin at 125°F., sufficient catalyst has migrated from diesel in 4 hr. to cure the resin completely.

Polymerization is complete in less than 24 hr. at 150°F. with all of the resins. Below 130°F. the epoxy-anhydride rate is slow and may require several days to reach maximum properties.

Resin Placement

All of the resins except the polyester-styrene are easily displaced in sand by following the resin with a hydrocarbon such as diesel oil. In the case

of the polyester-styrene, the sand becomes plugged when hydrocarbon is flushed. The styrene is evidently rapidly extracted from the interface between the polyester-styrene solution and the hydrocarbon. The viscous or solid unsaturated polyester is precipitated and causes plugging. Any residual hydrocarbon on the sand will also extract styrene and cause plugging. Substitution of *N*-vinylpyrrolidone for styrene in this formulation makes resin placement easy. The vinylpyrrolidone is relatively hydrocarbon-insoluble, and rapid extraction and plugging are avoided.

In the epoxy-amine case, the styrene oxide is slowly extracted into the diesel oil. Because extraction is slow, the styrene oxide can be almost completely extracted without causing plugging. The epoxy resin is deposited as a thin film on the sand. In this case, the type of epoxy resin seems important. Novolac resins deposit on the sand; whereas, low molecular weight bisphenol epoxides show less adhesion and are more easily washed from the sand. If the epoxy diluent is more rapidly extracted from the resin solution than styrene oxide, the permeability is reduced by the more rapid precipitation of the viscous resin.

Effect of Well Materials on Resin

The viscosity stability of the two epoxy resins, the furan, and the polyester resin upon exposure to brine and to diesel is shown in Table III. The epoxy-anhydride is more sensitive to heat and brine than the other resins. With the epoxy resins, calcium carbonate solution gives about the same viscosity stability as brine. Zinc chloride solutions cause large viscosity increases with both epoxy resins. Non-aqueous salts cause very little viscosity increase. In the absence of water, both the epoxy resins have adequate stability to allow time for the second-step flush to establish permeability. Brine appears to extract the vinylpyrrolidone monomer from the polyester to cause a viscosity increase.

TABLE III
Viscosity of Sand Consolidation Resins after Exposure to Well Materials

Consolidation resin	Exposure temperature, °C.	Viscosity increase after 24 hr. exposure to well materials, %				
		None	1% Brine	20% Brine	1% Diesel	20% Diesel
Epoxy-anhydride	150	15	1000	>4000	15	15
Epoxy-amine	125	0	0	0	0	0
Furan	150	0	0	0	0	0
Polyester-vinylpyrrolidone	150	0	0	90	0	0

Water should be removed from the formation prior to the three-stage process in order to obtain good strength. If water is present, it coats the sand surface and separates the resin from the sand, and poor adhesion is obtained upon polymerization. The water acts as a mold-release agent

does in plastic molding operations. The resin does not adhere to the water which separates the resin from the sand.

Neither diesel oil nor resin can completely displace water from sand surfaces. The water is more polar than either diesel or resin and therefore adheres better to the silica surfaces. However, if a water-soluble material is used for water removal, a miscible displacement takes place, and the water is removed from the sand. Acetone, isopropanol, or ethanol remove water effectively by miscible displacement.

Sand consolidated after preflushing with an acetone flush has a slightly higher permeability than sand that was consolidated after preflushing with the alcohols.

PROPERTIES OF THE CONSOLIDATED SAND

Initial Properties

Strength of sand consolidated with the four resins is shown in Table IV. The epoxy resins give higher initial strength than the polyester or furan. This is probably due to better wetting and a stronger adhesive bond. All of the pure resins have about the same strength, so that the differences are probably caused by differences at the resin-sand interface. The furan resins were not investigated in as much detail as the other resins, and higher strengths might be obtained under more optimum conditions.

The permeability retention of sand consolidated with the four resins is also shown in Table IV. The three-step process gives a high permeability retention, generally 50% or more. Permeability can be varied somewhat

TABLE IV
Strength and Permeability of Sand Consolidated by a Three-Step Process

Consolidation resin	Initial compressive strength, psi	Permeability retention, % of original
Epoxy-anhydride	8500	50
Epoxy-amine	8700	50
Furan	600	70
Polyester-vinylpyrrolidone	4400	50

TABLE V
Effect of Second-Step Flush Volume on Permeability and Strength of Consolidated Sand^a

Volume of second-step flush fluid, pore volumes	Permeability retention, % of original	Compressive strength, psi
2.1	26	10,800
4.3	52	8,500
5.3	74	7,000

^a Resin used was epoxy-amine system.

by varying the volume of the second-step flush. Higher flush volumes wash more resin from the sand give higher permeabilities and lower strengths, as shown in Table V.

Resistance to Well Fluids

Essentially no strength was lost when sand consolidated with any of the resins was exposed to hydrocarbons. Hydrocarbons do not seem to attack the bonds within the resins or to displace the resins from the sand.

Exposure of the consolidated sand to brine causes a reduction in properties in all cases. Strength retention after exposure to boiling brine of sand consolidated with the four resins is shown in Table VI. The epoxy resins show superior resistance to brine. The epoxy-anhydride is a little less brine-resistant than the epoxy-amine system. This is probably due to more rapid hydrolysis of the ester bonds present in the epoxy-anhydride polymer than of the amine and ether bonds present in the epoxy-amine polymer.

TABLE VI
Effect of Brine on Strength of Sand Consolidated with Plastics

Consolidation resin	Compressive strength after exposure to boiling brine for various times, psi				
	30 days	60 days	100 days	180 days	360 days
Epoxy-anhydride	4000	3300	2700	1800	1500
Epoxy-amine	4700	4500	3100	3000	3000
Furan	300	300	—	—	—
Polyester-vinylpyrrolidone	0	0	—	—	—

The polyester-vinylpyrrolidone system is satisfactory for wells which produce no water but is unsatisfactory for wells producing water. All strength is lost from the polyester-vinylpyrrolidone-consolidated sand in 30 days in boiling brine. Switching from styrene to the more polar (and therefore hydrocarbon-insoluble) vinylpyrrolidone makes possible placement with the three-step process. However, use of polar monomers in the unsaturated polyester formulation seems to make the polymer quite water sensitive. Substitution of acrylonitrile for vinylpyrrolidone gives essentially the same results. Substitution of a polyester based on a propylene oxide-bisphenol adduct (Atlas 382 polyester resin, Atlas Powder Company) in the polyester-vinylpyrrolidone system did not improve the 30-day brine resistance of the consolidated sand.

A series of 4-mil films of polyester-vinylpyrrolidone and of polyester-styrene was exposed to brine to test whether the loss in strength of the polyester system was due to a loss in adhesion or cohesion. The polyester-vinyl-pyrrolidone films lost all strength of cohesion after 6 months, whereas, cohesive strength was retained in the polyester-styrene system as shown in Table VII. This failure of sand consolidated with the poly-

ester-vinylpyrrolidone system is probably due to hydrolysis of the ester bonds which cause a loss in cohesive strength.

In initial tests with the condensation polymers there seems to be some correlation between Barcol hardness of castings and brine resistance of the

TABLE VII
Tensile Strength Retention of Polyester Films After Aging in Boiling Brine

Resin type	Tensile strength retention of polyester films after exposure to boiling brine at various times, %			
	0	1 month	2 months	6 months
Polyester-vinylpyrrolidone	100	100	100	0
Polyester-styrene	100	100	100	100

resins. A resin with a Barcol hardness of 35 or greater on the Barcol Meter 934-1 was generally brine-resistant. Softer resins were less brine-resistant. High hardness evidently is indicative of a high crosslink density. The high crosslink density makes it difficult for water to penetrate the resin and hydrolyze the bonds.

FIELD EXPERIENCE

To date, many oil wells in the Gulf Coast Area and in California have been successfully treated with the three-step process¹¹ in which epoxy resins were used as the cementing agent. More than five million barrels of oil have been produced from the wells that were treated with the three-step resin process and nearly all these wells are producing free of sand.

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Résumé

Les gisements où naît le pétrole consistent souvent en des matériaux sablonneux mous. Dans la production de pétrole au départ de ces gisements le sable tend à être entraîné vers le puit de forage en même temps que la ligné. L'écoulement du sable peut être empêché en consolidant ou en cimentant les particules de sable autour du puit de forage. Le cimentage doit être accompli de sorte que les canaux d'écoulement liquide restent ouvert entre les particules. Ce manuscrit décrit un processus en trois étapes qui a été mis au point pour consolider le sable des puits de pétrole. Les étapes du processus comportent l'injection (1) de résine, (2) de fluide inerte, (3) de fluide inerte contenant un catalyseur. Dans la première étape du processus, la résine est injectée dans la formation où elle remplit complètement les interstices entre les grains de sable. La perméabilité est assurée dans la seconde étape en déplaçant l'excès de résine des interstices, laissant ainsi un film fin de résine sur les grains de sable. Dans une troisième étape, la polymérisation est initiée par migration du catalyseur depuis le fluide inerte jusqu'au sein du film fin de la résine sur le sable. Le processus présente l'avantage en ce que la résine est mise en place et la perméabilité est assurée avant que la résine soit catalysée. Ceci évite une polymérisation prématurée de la résine qui pourrait causer une obstruction ou un rétrécissement de la canalisation utilisée pour injecter la résine. Les caractéristiques souhaitées de la résine dans ce processus à trois étapes, sont (1) une viscosité de 25 à 200 centipoises à la température de forage de la source, (2) une stabilité de plusieurs jours à température de forage de la source, (3) une grande adhésion au sable en présence d'un fluide inerte en rinçage, (4) une polymérisation en présence de moins de 10% de catalyseur, (5) la résine polymérisée lie le sable de façon à ce que celui-ci ne soit pas affecté par les fluides de la source. Cinq types différents de résines ont été testés à l'usage dans le processus de consolidation du sable en trois étapes. Ils sont: (1) résine époxy-anhydride traitée avec une amine tertiaire, (2) résine époxy-époxy diluée traitée avec un mélange d'amines primaire et tertiaire, (3) le furanne, (4) polyesters insaturés-vinylpyrrolidone, (5) polyester insaturé-styrène. Les deux résines époxy donne un sable solide perméable, qui résiste aux fluides de la source, tels l'eau salée et le pétrole brut. La résine furanimique ne donne qu'une faible consolidation. Le mélange polyester insaturé-vinylpyrrolidone donne une bonne solidité, et résistance à l'huile, mais est sensible à la saumure. Le système polyester insaturé-styrène est difficile à appliquer. Beaucoup de puits de pétrole ont été traités avec succès dans la zone de la côte du Golfe et en Californie avec les deux résines époxy. La plupart de ces puits fournissent du produit sans sable, à ce jour, plus de 5 millions de barrils de pétrole ont été produits au départ de ces puits.

Zusammenfassung

Ölführende Schichten bestehen oft aus lockerem, sandigen Material. Bei der Gewinnung von Öl aus diesen Schichten wird der Sand mit dem Öl zur Bohrung geführt. Die Sandbewegung kann durch eine Verfestigung oder Zementierung der Sandteilchen der Schichte um die Bohrung verhindert werden. Die Zementierung muss so durchgeführt werden, dass Kanäle für die Flüssigkeit zwischen den Teilchen offen bleiben. In der vorliegenden Arbeit wird ein neuer dreistufiger Prozess beschrieben, der zur Verfestigung von Ölbohrungssand entwickelt wurde. Die Stufen des Prozesses bestehen in der Injektion von (1) Harz; (2) inerter Flüssigkeit und (3) inerter Flüssigkeit mit Katalysator. Im ersten Schritt des Prozesses wird Harz in die Schichte injiziert, wo es die Zwischenräume zwischen den Sandkörnern völlig ausfüllt. Die Permeabilität wird im zweiten Schritt durch Verdrängung des Harzüberschusses aus den Zwischenräumen unter Zurücklassung eines dünnen Harzfilmes auf den Sandkörnern erreicht. Im dritten Schritt wird die Polymerisation durch Wanderung des Katalysators aus der inerten Flüssigkeit in den dünnen Harzfilm am Sand aktiviert. Der Prozess hat den Vorteil, dass das Harz eingebracht und die Permeabilität erreicht wird, bevor die Katalyse des Harzes erfolgt. Dadurch wird eine vorzeitige Polymerisation des Harzes vermieden,

welche zu einer Verstopfung der Schichte oder der zur Injektion des Harzes verwendeten Röhren führen könnte. Die für den Dreistufen-Prozess erwünschten Eigenschaften eines Harzes sind: (1) eine Viskosität von 25–200 Centipoise bei der Temperatur der Bohrung; (2) eine Stabilität für mehrere Tage bei der Temperatur der Bohrung; (3) hohe Adhäsion zu Sand in Gegenwart einer inerten Spülflüssigkeit; (4) Polymerisation mit weniger als 10% Katalysator; feste durch Bohrungsfüssigkeiten nicht beeinflusste Verbindung des Sandes durch das polymerisierte Harz. Fünf verschiedene Harztypen wurden auf ihre Verwendbarkeit in dem dreistufigen Sandverfestigungsprozess getestet. Diese sind: (1) Epoxy-Anhydrid, mit einem tertiären Amin gehärtet; (2) Epoxy-Epoxyverdünner, mit einer Mischung aus primärem und tertiärem Amin gehärtet; (3) Furan; (4) ungesättigter Polyester-Vinylpyrrolidon; (5) ungesättigter Polyester-Styrol. Die beiden Epoxyharze liefern festen, permeabel konsolidierten, gegen Bohrungsfüssigkeiten wie salzwasser und Rohöl beständigen Sand. Das Furanharz gibt eine schwache Verfestigung. Das System ungesättigter Polyester-Vinylpyrrolidon liefert gute Festigkeit und Ölbeständigkeit, ist aber gegen salzwasser empfindlich. Das System ungesättigter Polyester-Styrol zeigt Schwierigkeiten bei der Anwendung. Viele Ölbohrungen im Golfküstengebiet und in Californien wurden mit beiden Epoxyharzen erfolgreich behandelt. Fast alle diese Bohrungen haben eine sandfreie Produktion und die Ölgewinnung daraus betrug bis jetzt mehr als fünf Millionen Barrel.

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