ACID-SOLUBLE DRILLING, COMPLETION AND WORKOVER FLUIDS

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INTRODUCTION

Because of the oil shortage a great deal more attention is now being paid to the loss of productivity resulting from contamination of the reservoir by mud during well completion or workover jobs. There are two principal forms of impairment—impairment by the mud filtrate and impairment by the mud solids. The latter is frequently overlooked because the standard API filter test is made with filter paper which effectively filters out most of the solids. However, down the hole the mud filters against porous sand or rock. Laboratory experiments in which mud was filtered against cores have shown that the finer mud particles can penetrate several inches into porous rocks[1,2,3] causing considerable loss of permeability; and this permeability cannot be restored by backflow. Impairment by mud solids would be much greater were it not for the fortunate circumstance that a filter cake forms rapidly on the face of the borehole. Once established, this cake acts as a very efficient bottomhole filter, and thereafter, only clear filtrate enters the formation.

The extent of impairment by mud solids varies greatly from well to well depending on the nature of the reservoir rock, the composition of the mud, the method of completion, etc. The important thing is to be able to recognize when it is likely to be severe and take steps to minimize it. One approach is to use clear water or brine when conditions permit. However, this has a disadvantage in that the rate of filtrate invasion is very high, of the order of 10,000 times greater than the rate when mud is in the hole. This deep filtrate invasion gives rise to adverse relative permeability effects (water-blocking) when the well is brought into production, and also can cause severe solids impairment because the so-called "clear" fluid always carries fine suspended solids. The concentration of these solids may be very low; but since there is no filter cake, they are carried into the formation as long as the fluid is in the hole and reduce permeability by accumulating at narrow points in the flow channels. A similar phenomenon has been noted by Barkman and Davidson in waterflood operations.[4] Highly viscous brine will not stop loss of fluid, but it will slow the rate of loss. Solids are necessary to bridge the openings of the pores in order to reduce the loss to a minimum.

A better way to eliminate solids impairment is to use an acid-soluble mud. These muds have the same filtration and rheological characteristics as conventional muds; but since all solid components are soluble in acid, their impairment can be eliminated by acidizing when the well is completed. To avoid excessive acid requirements, it is important to keep the depth of solids invasion as low as possible. As mentioned above, solids invasion is controlled by the rate of formation of a filter cake. We will, therefore, discuss the principles of filter cake formation in general before proceeding to discuss acid-soluble muds.

PRINCIPLES OF FILTER CAKE FORMATION

When the formation is first exposed to the pressure of the mud column there is a surge of mud into its pores. Particles considerably smaller than the pore openings are carried in unimpeded, but particles that are just about the size of the pores (down to about one-third the size of the opening) are trapped just inside the surface pores. Once the pores are bridged by particles of this critical size, successively smaller particles are trapped until finally only clear filtrate enters the formation. Thus, the formation is contaminated only by the solids that are carried in while the filter cake is being established, and the quicker the cake is formed, the smaller this mud spurt (as it is called) will be. The rate of filter cake formation depends primarily on the amount of particulate solids in the mud. It follows that, contrary to popular belief, solids impairment is generally greatest with low-solids muds and least with high-solids muds.

The critical bridging size, of course, depends on the size and shape of pores in the rock, and is only approximately related to permeability. It is therefore impossible to specify critical bridging size precisely; but, as a general rule, muds with a maximum particle size of 0.002 in. (300 mesh) will bridge all formations except coarse unconsolidated sands and fractured formations. Drilled solids and weighting materials generally provide drilling muds with enough particles in this size range but production repair fluids that are not used for drilling must have bridging solids added to them. The particle size of these solids should range from the critical bridging size down to submicron. A minimum of 5 ppb is required.

WHEN TO USE ACID-SOLUBLE MUDS

Well Completion in Highly Permeable Reservoirs

Coarse sands, say above 5000 md, often require bridging particles larger than those usually present in drilling mud, and as a consequence, deep solids invasion or even loss of circulation occurs. Larger particles should, of course, be added but the difficulty is to know in advance what size to use. Therefore, it is a wise precaution to drill into such reservoirs with an acid-soluble mud so that, if impairment does occur, it can be removed by acid treatment.

Completion in Carbonate Reservoirs

It makes sense to drill into carbonate reservoirs with an acid-soluble mud. The well is almost certainly going to be acidized and it is an obvious advantage to have an acid-soluble filter cake.

In addition, many carbonate reservoirs have a low matrix permeability and depend on a network of open fractures for productivity. Fractures as wide as 0.02 in. have been observed in cores, but usually are much smaller. Laboratory experiments have shown that mud can enter such fractures, filter internally against its sides, and plug them with filter cake[4]. This impairment cannot be removed by backflow but the fractures can be cleaned out by acid when an acid-soluble mud is used. Promising results have been obtained with carbonate reservoirs completed with an acid-soluble mud in Alberta.[5]

Acid-Soluble Muds as Workover Fluids

Production repair wells are especially liable to solids impairment; indeed, it is a common field experience to find that, after a production repair operation, the well does not return to its previous production rate.

There are several possible reasons for the prevalence of such impairment.

1. The muds are manufactured from a colloid base such as bentonite, starch or polymer, and have no bridging particles; or the wrong size or amount are added.
2. Previous production may have opened up flow channels which become plugged with mud during the production repair operation.
3. The fluid pressure in depleted reservoirs is very low, sometimes below hydrostatic. This promotes high mud spurts and increases the possibility of mud-induced fracturing.

Because of the likelihood of solids contamination, it is good practice always to use an acid-soluble mud in production repair work. In depleted reservoirs a good approach is to start by sealing off the producing face quickly by setting a pill containing a high concentration of bridging solids, say 50 ppb. The advantages of this procedure are: low cost, low head of mud on the formation and therefore low mud spurt, and minimum chance of losing circulation. Subsequently, the well may be circulated, if desired, with a mud containing a reduced amount of bridging solids, say 5 ppb; or sometimes it is possible to carry out the remaining operations with brine or diesel oil.

Certain Completion Methods

As mentioned above, drilling muds generally contain plenty of bridging solids. Consequently, solids do not penetrate more than an inch or so into normal formation, and any impairment cause thereby can be eliminated by shot perforations. However, if the well is not completed by shot perforations, such impairment can be significant. Further, the filter cake can block perforations, screen, or gravel pack when the well is brought into production. When such completion methods are practiced, the well should be drilled with a conventional mud and then the filter cake and contaminated zone removed by underreaming with an acid-soluble mud before running the oil string or liner.

Water Injection Well Completions

When cleaning up water injection wells it is very important to remove all solids because any solids left in the hole will eventually be carried into the perforations when injection starts. Completing with an acid-soluble mud is a good way of ensuring this removal.

Cement Bonding

A good bond between the formation and the cement can be obtained on wells that have been drilled with an acid-soluble mud by preceding the cement with a water spacer, followed by an acid slug. This technique has been successful in separating closely spaced, permeable zones in West Texas wells, whereas great difficulty in doing so had previously been experienced in wells drilled with clay mud.[5]

ACID-SOLUBLE OIL-BASE FLUIDS

Acid-soluble oil-base fluids should be used whenever there is a chance of impairment by aqueous filtrates as well as by solids impairment, or when low-density fluids are required for depleted reservoirs. One such fluid, known as chalk emulsion, was developed in the research laboratories of the Shell Development Co.[5,6] This is an invert emulsion with the unusual feature being that the emulsifying agent is finely divided chalk. The chalk is made partially oil-wet so that the particles are adsorbed as a skin around the water droplets, preventing their coalescence. However, when contacted by acid, the skin is dissolved and the emulsion breaks at once to clear oil and water. About 5 ppb of carbonate particles with a maximum size of 0.002 in. are usually added for bridging purposes, and ground carbonates are also used for weighting up to 12 ppg. The aqueous phase can be either fresh water or sodium chloride brine of any salinity up to saturation. The oil phase is either diesel or crude oil. The viscosity of the emulsion depends on the viscosity of the oil used, the oil-water ratio, the temperature and the amount of weighting agents used. An unweighted emulsion with a 40/60 diesel oil/water ratio has a Fann PV of 45 and a YP of 20 at 75°F, and 12 and 8 respectively at 200°F. An API filter loss of 3cc is readily obtainable. The emulsion exhibits unusually low mud spurts on sandpacks because the skin around the droplets makes them act like bridging solids. The emulsion breaks slowly at high temperature and cannot be used at temperatures above 230°F.

Chalk emulsion should be distinguished from conventional inverts which are designed for drilling and therefore have strong emulsifying agents which make the emulsion very difficult to break by any means. Chalk emulsion is designed as a completion fluid and breaks on contact with acid, thus eliminating any possibility of emulsion blocking. It is less expensive than conventional inverts, and can be supplied as a one-sack product ready for mixing with oil and water in the rig hopper. This, and the fact that it can be mixed with crude oil, make it expecially suitable for remote and overseas locations. It has been used in many areas such as the Province of Alberta, West and South Texas, Louisiana, Egypt, and Nigeria.

Another acid-soluble oil-base emulsion is available which can be used in wells having bottomhole temperatures up to 350°F. The emulsifier is in the form of a dry powder. Rheology is controled by the concentration of emulsifier and the oil/water ratio. For certain cases where density is increased with calcium carbonates, it is necessary to add a dispersant. The emulsion must be made with diesel oil and either fresh or salt water up to saturation, with preference for salt brine. Densities from 7.5 to 12.0 ppg are obtainable. Calcium carbonates are used to increase density and as bridging solids.

At 150°F this emulsion is broken by acid more slowly than is chalk emulsion; however, the rate increases with temperature. Therefore, this emulsion should be used in wells where bottomhole temperatures are in excess of the capabilities of chalk emulsion, and not as a substitute for chalk emulsion.

When lost circulation is encountered, high concentrations of bridging calcium carbonates and emulsifier may be mixed for application as a pill with either of these emulsions.

It should be noted that both of the above emulsions are soluble in HCl; the end result is a clear water and a clear oil phase. Calcium carbonates may be added to a conventional oil-base emulsion. The calcium carbonates, of course, are soluble in acid; however, the emulsion is essentially unaffected by acid and the acid cannot penetrate pores or mud cakes and contact the carbonates.

ACID-SOLUBLE WATER-BASE COMPOSITIONS

Completely acid-soluble brine fluids have been successfully used in wells with bottomhole temperatures to 375°F. The practical weight range is from 8.4 to 11.6 ppg. Brine containing KCl, NaCl, $CaCl_2$, $CaBr_2$, and combinations of these may be used. Regardless of the weight required, at least a minimum concentration of one of these salts is recommended for inhibition if hydratable clays are present. The maximum weights obtainable are as follows: NaCl - 10.0 ppg, KCl - 9.7 ppg, and $CaCl_2$ - 11.6 ppg. Weights in excess of 11.6 ppg may be obtained by using asbestos or polymer to suspend calcium carbonate or by adding $CaBr_2$.

Combinations of $CaBr_2$ and $CaCl_2$ may be used to obtain densities above 11.6 ppg. Cost inhibits wide use of this brine combination.

CALCIUM CARBONATE BRIDGING SOLIDS

In the basic brine-base fluid, an acid-soluble polymer is used for viscosity, complexed lignosulfonate for fluid loss, and graded calcium carbonates for bridging. There are two types of fluids—circulating fluids and pills for lost circulation. The pills are of the same basic composition as the circulating fluids, but contain a much higher concentration of the various components.

Circulating fluids generally have API fluid losses in the 10 to 15 cc per 30-minute range and Marsh funnel viscosities of 28 to 38 seconds, depending on whether the hole is open or cased and the size of the hole. The largest size bridging solids are approximately 0.002 in. (300 mesh); these will not plug a 0.008 in. slot in a screen.

Pills have API fluid losses of from 0 to 4 cc per 30 minutes and Marsh funnel viscosities of from 80 to 300+ seconds. The bridging solids in a pill are sized according to need, i.e., to about 3/8 in. in diameter. Normally, a broad range of sizes up to 40 mesh is sufficient, with usage of 3/8-in. bridging particles being quite rare.

Costs for a circulating fluid start at about \$2.00/bbl and costs for a pill start at about \$16.00/bbl.

In some wells the formation fluid contains Ba^{++} ion. In the presence of the sulfate ions in lignosulfonates, an insoluble precipitate may form. To circumvent this, fluid loss properties can be obtained with a combination of acid-soluble polymers. Otherwise, bridging and viscosity may be controlled as with the lignosulfonate fluids.

ACID SOLUBILITY

If a material is soluble in acid, it will result in a clear solution, although it may be colored. Calcium carbonates react with HCl to give $CaCl_2$, which is very soluble in water. Lignosulfonate gives a brown solution which is clear.

Polymers are a special case. Usually polymer solutions are clear when they are at neutral or slightly alkaline pH. When acidified, one of three things may occur with polymer solutions. First, the polymer may precipitate and become capable of acting as plugging solids. Second, there may be little or no change in the polymer and the viscosity of the solution. The third and most desirable action is the destruction of the polymer by the acid, accompanied by a pronounced decrease in viscosity of the solution. In effect, long polymer chains are broken into many smaller ones by acid hydrolysis. This action of acid is limited to very few polymers.

Two points are worth special note. First, mud acid should never be used on a carbonate fluid. Hydrochloric acid is preferred; and it may be followed with a slug of brine, then the mud acid if this is desired.

Second, the fact that these products are acid-soluble does not automatically mean that acidization is required for cleanup. Factors such as proper range of sizes in bridging particles, permeability and type of formation, the type production, the overburden pressure, and the methods and techniques used in spotting the pills will determine if acidization will be necessary. Many times where there is low overburden pressure, acidization is unnecessary if good technique is used; however, there is no rule-of-thumb as to when or when not to acidize.

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