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SHELL INTERNATIONALE RESEARCH
MAATSCHAPPIJ B.V.

Carel van Bylandtlaan 30
2596 HR LA HAYE
PAYS-BAS

(72) Inventeur(s) :
1) COWAN Kenneth Michael
1019 Sugardale Court
SUGAR LAND, Texas 77478
(E.U.A.)

2) NAHM James Jang Woo (E.U.A.)
(suite au verso)

(74) Mandataire : CABINET CAZENAVE
B.P. 500 YAOUNDE (Cameroun)

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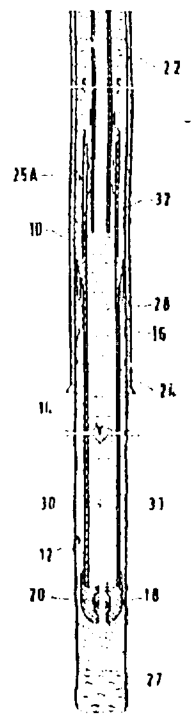
(57) Abrégé :

A cementitious slurry containing blast furnace slag and a surfactant is utilized to displace an oil based drilling fluid without causing contamination by the blast furnace slag cement. In a specific embodiment, a cementitious slurry comprising blast furnace slag, a surfactant and water is used in the cementing of an annulus surrounding a casing or liner wherein a synthetic oil-containing drilling fluid is present.



(57) Abrégé (suite) :

(72) Inventeurs (suite) :

3) WYANT Reece Eugene
(E.U.A.)

(73) Titulaires (suite) :

METHOD FOR DRILLING AND CEMENTING A WELL

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This invention relates to drilling and cementing a well.

The rotary drilling of a borehole is accomplished using a rotary drilling assembly comprising a by rotating a drill bit attached to the lower end of a drill string. Weight is applied to the drill bit while rotating to create a borehole into the earth. The drill string is hollow and pipe sections are added to the drill string to increase its length as the borehole is deepened. In rotary drilling the drill bit can be rotated by rotating the drill string and/or by driving a downhole motor arranged at the lower end of the drill string.

This rotary drilling process creates significant amounts of friction which produces heat along with fragments of the strata being penetrated. The fragments of the strata must be removed from the borehole and the drill bit must be cooled to extend its useful life. Both of these necessities are accomplished by the circulation of a fluid down through the drill string and up to the surface between the drill string and the wall of the borehole.

Once the borehole has been drilled to the desired depth, it may be desirable to isolate the separate areas, zones or formations traversed by the borehole. For extraction of fluids from formations, a conduit (casing) must be inserted into the borehole extending from the surface downward, and liners may be hung inside the casing.

At this point it becomes necessary to fill the annulus between the casing and the borehole wall or between the liner and casing with a material which will seal the annulus and provide structural support for the casing or liner. This is commonly referred to as primary cementing.

Generally, the borehole, into which the casing or liner to be cemented is installed, is filled with drilling fluid. Therein lie several problems. Conventional Portland cement and conventional drilling fluids are incompatible. Thus, as the cement is forced down the casing or liner and up into the annulus it is commingled with the drilling fluid at any interface between the mud and the cement. The resulting mixture generally thickens or becomes a gel and does not set up into a strong cement. In addition, the gel strength and viscosity become uncontrollable and the mixture may either become too viscous to pump or may get thinner. If the mixture gets thinner it can allow solids to settle downward in the annulus where they may bridge and restrict the passage of the cement slurry. In either event, the situation is unsatisfactory.

The industry has developed a complex system to attempt to circumvent this problem. A device generally known as a landing collar is attached to the bottom of the casing or liner being cemented. The landing collar has an annular shoulder projecting inwardly. A first wiper plug with a diaphragm which can be ruptured is introduced into the casing or liner followed by a spacer fluid, the cementitious slurry and finally, a solid wiper plug. Displacement fluid then pushes the solid wiper plug downward thus displacing the spacer fluid and the cementitious slurry through the ruptured first wiper plug, out of the casing or liner and into an area at the bottom thereof where it changes direction and flows upwardly into the annulus. When the second wiper plug reaches the area of the landing collar it is stopped by the first wiper plug which is resting on the shoulder.

The spacer fluid, however, can create its own set of problems because it mixes somewhat with both the drilling fluid ahead of it and the cementitious slurry behind it. Usually, the most damaging is the contamination of the drilling fluid. The spacer fluid remains a fluid in admixture with the drilling fluid and thus cannot be easily separated therefrom. In many instances this necessitates the disposing of the thus-contaminated drilling fluid. This is an economic problem with any drilling fluid but with more expensive, less environmentally friendly oil based fluids, it is a major obstacle to successful operation. In addition, the mixture of spacer fluid and drilling fluid usually results in a more viscous material thus exacerbating the pumping problems. This can even result in a total failure of the cement job because a good seal at the top of the liner may not be obtained and this is where any cement weakened by drilling fluid contamination most likely will be.

USA patent specification No. 5 058 679 discloses a method for drilling and cementing a well, comprising: drilling a borehole utilizing a drilling fluid, thus producing a used drilling fluid to be displaced out of the borehole; combining ingredients comprising water and blast furnace slag to produce a cementitious slurry; disposing a pipe within the borehole; passing the cementitious slurry into the borehole thus at least partially displacing the used drilling fluid with the cementitious slurry; and displacing the cementitious slurry into an annulus surrounding the pipe.

This publication discloses that blast furnace slag is compatible with drilling fluids, and excellent cementitious compositions can be produced by combining blast furnace slag and drilling fluids. Even blast furnace slag, however, can contaminate oil based drilling fluids when the two are mixed.

Oil based drilling fluids are disclosed in USA patent specification No. 3 899 431.

It is an object of this invention to cement a casing or liner in a wellbore drilled with an oil based drilling fluid without the necessity for a wiper plug or a float collar.

It is a further object of this invention to cement a casing or liner in a wellbore drilled with an oil based drilling fluid without rendering the drilling fluid useless for further drilling operations.

It is yet a further object of this invention to avoid having to treat an oil based drilling fluid contaminated with cement and/or spacer fluid.

It is yet a further object of this invention to minimize or eliminate disposing of drilling fluid which is contaminated with cement and/or spacer fluid.

It is yet a further object of this invention to avoid viscosity or gelation problems during primary cementing in boreholes drilled using an oil based drilling fluid.

To this end the method for drilling and cementing a well according to the present invention is characterized in that the drilling fluid is an oil based drilling fluid, in that the cementitious slurry further contains a surfactant, and in that used drilling fluid is displaced by direct fluid contact with the cementitious slurry.

It has been discovered that by utilizing a surfactant in a blast furnace slag cementitious slurry, an oil based drilling fluid can be displaced without destructive contamination of the drilling fluid.

Reference is made to Derwent's abstract No. 86-19535/03. This publication discloses an aqueous cementitious composition for plugging a borehole, the composition comprises Portland cement and blast furnace slag. The composition further comprises a chemical additive which is obtained by reacting carboxymethyl cellulose with ethanolamine and a mixture of freshly prepared nitrolignin and calcined soda.

Reference is also made to USA patent specification No. 5 016 711. This publication discloses that a cement-to-casing sealing in a wellbore is improved by adding to the cement an additive for enhancing the interfacial sealing and bonding of cement to casing and borehole in the form of a surfactant. The cement composition comprises water, cement and surfactant. The cement is a Portland cement. The surfactant is added to improve the interfacial bonding between cement and casing or borehole. This publication discloses squeeze cementing in a well drilled with an oil mud, wherein a cement slurry is used which contains an ethoxylated alcchol sulphonate (example 3). This example does not indicate whether displacement is direct, nor does the example specify the kind of cement used. In the description it is said that several kinds of cements may be used amongst others blast furnace slag.

Reference is further made to USA patent specification No. 3 557 876, which publication discloses converting a drilling fluid to a cement slurry.

These three publications are not relevant to the present invention.

In this description the term 'cementitious material' means blast furnace slag which, on contact with water or water and activators, hardens or sets into a solidified composition.

An aqueous slurry of cementitious material and the component or components which cause it to harden is referred to herein as a 'cementitious slurry'.

By 'direct fluid contact' between the displacement fluid and the cementitious slurry is meant that the displacement fluid directly contacts the upper surface of the column of cementitious slurry as opposed to having a solid wiper plug disposed between the cementitious slurry and the displacement fluid. By 'direct fluid contact' between the cementitious slurry and the drilling fluid or mud is meant that the cementitious slurry directly contacts the upper surface of the column of drilling fluid or mud in a pipe as opposed to having a wiper plug with a rupturable diaphragm disposed between the cementitious slurry and the drilling fluid or mud. This is of particular value in cementing large diameter pipe, i.e., pipe having an outside diameter of 30 to 75 cm, generally 40 cm or larger.

The term 'pipe' means either a casing or a liner.

The term 'primary cementing' refers to any cementing operation wherein a cementitious slurry is passed into an annulus surrounding a pipe and thus encompasses both the cementing of casings wherein the annulus is between the casing and the borehole wall and the cementing of liners where the annulus includes an annulus between the liner and the casing.

By 'activator system' is meant either a single activator or a mixture of activators used for setting of blast furnace slag.

As used herein 'down' or 'bottom' as it relates to a drill string or casing, means in a direction towards the farthest reach of the borehole even though in rare instances the borehole can be disposed in a horizontal position. Similarly, 'up' or 'top' means back towards the beginning of the borehole.

The invention will now be described by way of example in more detail with reference to the accompanying drawings, wherein

Figure 1 is a cross sectional representation of a borehole filled with drilling fluid after a liner has been inserted preparatory to displacing the drilling fluid out with a cementitious slurry; and

Figure 2 is a cross sectional view of the borehole at a later stage in the process wherein the liner is cemented.

In the drawings, forming a part hereof, wherein like reference characters denote like parts in the various views.

Referring now to Figure 1, there is shown an initial stage in a cementing operation wherein a wellbore has been drilled in a subterranean formation, the drill string removed and a liner hung in an existing casing. A casing 10 is shown in an upper portion of the wellbore and a further extension of the wellbore as defined by wellbore walls 12 is depicted. Disposed within the wellbore is a liner pipe 14 to be cemented in place. A centralizer 16 centers the liner pipe. A casing joint equipped with a float shoe 18 having a valve 20 is affixed to a lower portion of the liner. The borehole from the bottom all the way to the surface, is filled with drilling fluid or mud from the drilling operation, the drilling fluid or mud being depicted by reference character 22. Cementitious slurry 24 is disposed above the drilling fluid in direct fluid contact therewith at interface 25. Some cementitious slurry/drilling fluid mixing occurs at interface 25. Most of the mixing, however, occurs at corresponding interface 25A as depicted in Figure 2, since flow through the annuli is more subject to mixing forces.

Figure 2 shows a later stage in the cementitious slurry displacement in accordance with the invention. Drilling fluid 22 has been displaced by the surfactant-containing cementitious slurry 24 out of the liner and out of the annulus between the liner and the borehole (and between the liner and the casing), with some drilling fluid remaining in rat hole 27. The cementitious slurry is now displaced into the annulus surrounding the liner by displacement fluid 28. As can be seen, displacement fluid 28 is in direct fluid contact with the cementitious slurry at interface 30.

As can be further seen from Figure 2, the displacement is stopped with the cementitious slurry/drilling fluid interface 25A near the top of the liner in annulus 32 between the liner and the casing. This is one of the most important areas in the cement job. The present invention results in a good quality cement here rather than a weak mixture of incompatible cement and drilling fluid as in the prior art when wiper plugs are not used. This good lead cement gives a good seal, thus ensuring that the well will pass a top of the liner pressure test.

This improvement flows from the fact that in the prior art the cementitious slurry and/or spacer fluid, in fact, mixes with the drilling fluids above it (in the annulus). As noted, the same is true in accordance with the invention. There is a region around interface 25A between cementitious slurry 24 and drilling fluid 22 as depicted in Figure 2 wherein there is, in fact, a mixture of drilling fluid and cementitious slurry. However, the mixture of surfactant-containing blast furnace slag cementitious slurry 24 with oil based drilling fluid 22 does not give a bad reaction because the hydration product (cement) of the blast furnace slag is compatible with the drilling fluid and this compatibility is enhanced by the surfactant. This contrasts with Portland cement which, upon hydration, produces calcium hydroxide which is a major source of mud contamination. Because the blast furnace slag component of cementitious slurry 24 is a latent hydraulic material which will eventually set after contact with water, any cementitious slurry present in the drilling fluid will form a solid with time. This reaction is speeded up by elevated temperatures. Any set solid which is later drilled out can be removed by shale shakers in the normal manner in which cuttings and other solid materials are removed from the drilling fluids. Those particles that may be too small to be removed by the shale shaker will be incorporated into the drilling fluid as are normal drill solids. Blast furnace slag does not produce any reacted particles when set that are harmful to the drilling fluid. The setting reactions are completed and thus the set material will not react further to damage the mud.

While this has been described in connection with the cementing of a liner wherein the cementitious slurry is forced into the annular space 32 between the liner and the casing 10 or the annular space 33 between the liner and borehole 12, it is equally applicable to cementing a casing where the cementitious slurry is forced up into an annulus between a casing and the borehole wall.

Surfactant-containing blast furnace slag cementitious slurries can also be used in other primary cementing operations such as cementing a pipe by pumping the cementitious slurry directly into the annulus surrounding the pipe (reverse cementing) and in secondary cementing or remedial cementing operations where there is displacement of an oil based drilling fluid with a cementitious slurry.

The oil-based drilling fluids generally contain, in addition to the oil, other additives such as viscosifiers, thinners, fluid loss additives, dissolved salts, solids from the drilled formations and solid weighting agents to increase the fluid density.

The term 'oil-based drilling fluids' is meant to cover muds having oil as the continuous phase, including low water content oil-base mud, 100% oil-based mud and invert oil emulsion mud.

The invention is applicable to all oil based drilling fluids. These fluids are expensive and hence the ability, through the use of this invention, to avoid destructive contamination, and thus waste, of the expensive oil based mud is of great economic and ecological significance. Indeed, the invention is particularly applicable for use with oil based drilling fluids utilizing the new and very expensive synthetic oils, vegetable and other natural oils which are biodegradable or which are formulated to avoid sheen. The drilling fluids recovered from drilling and cementing operations can be reused. In some instances, recovered drilling fluids are conditioned with additives before reuse.

Oil-base muds are often prepared in a liquid mud plant and transported to the well site. A premixing technique is employed using high shear mixing devices not only for convenience, but also for providing stable oil muds. Oil mud additives can be mixed on location and the mud properties can be changed to cope with changes in the downhole conditions. A variety of chemical are needed to prepare a complete mud system or to provide adequate control. The types of additives used can be grouped as follows: suspending (gelling) agents; emulsifiers and wetting agents (surfactants); filtration control agents; viscosity control agents; density control agents; and alkalinity control agents.

As noted above, the oil mud can either be a 100% oil-base mud, or it can be an oil-based continuous phase mud with a small amount of water as an internal phase. Some special considerations apply if the oil mud is an invert emulsion with a small amount of water as the internal phase.

For one thing, it is desirable to adjust the electrolyte concentration at which a given shale will neither swell nor dehydrate. These techniques involve adding sufficient NaCl, $CaCl_2$ or other salts to the water phase of the mud so that the chemical potential of the water in the mud is equal to the chemical potential of the water in the shale.

The term "activity" is used to define the unit of measure of the chemical potential for water in mud or shales. Shales adsorb water because of differences in chemical potential or activity or the water contained in the shales and that found in the mud. Water moves from a less concentrated solution to more concentrated solution in an attempt to equalize the concentrations. When the chemical potentials of the shales and the mud are in balance the movement of water is reduced to zero.

The hydration of shales in contact with oil muds is similar in mechanism to the osmosis of water through a semipermeable membrane (permeable to the solvent but not the solute). In oil muds the interfacial film surrounding each water droplet functions as a semipermeable membrane and the emulsified droplets function as osmotic cells when in contact with shale sections and/or shale cuttings.

It has been established that water transfer from the dispersed water droplets to the cuttings and/or formation can occur when the chemical potential of the formation water is greater than the chemical potential of the mud water. Conversely, the transfer of water from the formation may occur when the aqueous chemical potential in the water phase of the mud exceeds that of the formation.

The chemical potential of the mud is controlled by the type and concentration of electrolyte (NaCl, $CaCl_2$, $(NH_4)_2SO_4$, $Ca(NO_3)_2$, $MgCl_2$, $ZnCl_2$ or other salts) contained in the internal phase. The adsorptive potential of the formation is primarily a function of the degree of compaction to which that formation has been subjected. Generally, the older the formation, the greater the compaction and the higher the adsorption potential. The objective is to create an osmotic force in the mud which is equal to or greater than the adsorptive force of the formation drilled, thus preventing transfer of internal phase water to the formation.

Calcium chloride is the salt generally used to alter the activity of the water in the oil mud. Calcium chloride is quite soluble, allowing the activity to be varied over a wide range. It is available as technical grade, which is 75-80 percent in purity, or as pure (anhydrous) grade, 95-98 percent $CaCl_2$.

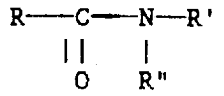
Herein lies a serious problem in the prior art. Calcium chloride is very detrimental to Portland cement because it is a potent accelerator for Portland cement. Hence if the emulsion breaks in an invert emulsion oil mud in contact with Portland cement it can cause major problems. The calcium chloride can accelerate the Portland cement slurry and the resulting slurry can become unpumpable and set up in the pumping system thus the cement job fails. In certain cases of cement failures, the well can be lost. Blast furnace slag, on the other hand, is quite compatible with salts in general including calcium chloride and, indeed, may even be enhanced by the presence of the salt.

The surfactant is preferably a material of the type commonly thought of as surfactants, i.e., one with a relatively high degree of detergency, as opposed to materials which may exhibit only a weak amount of detergency such as the lignosulphonates which are sometimes employed in drilling fluids. That is, it is preferably a material which is capable of producing oriented layers or micelles.

Usually, the surfactants as sold commercially in the oil industry are often 33-75 volume percent active ingredient in a solvent such as an alcohol. Broadly the amount of surfactant, based on the barrels of cementitious slurry, is 0.14 to 140 kg/m^3, preferably 0.3 to 43 kg/m^3, most preferably 2.8 to 28 kg/m^3, but the amount can vary depending on the particular surfactant. These values are for active ingredients based on total volume of cementitious slurry. Stated in terms of the water phase in the cementitious slurry, the surfactant is generally used in an amount within the range of 0.05 to 20 volume percent, preferably 0.2 to 10 volume percent, most preferably 2 to 7 volume percent based on the volume of water in the cementitious slurry. The surfactant can be either ionic, nonionic, or amphoteric, preferably nonionic or anionic, most preferably anionic, although all surfactants broadly are intended to be included.

Suitable surfactants include

1. Alkanol amides (nonionic):



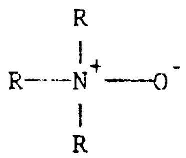
wherein R is a carbon chain (alkyl group) of 8-20 carbons (usually 10-18), wherein R" is hydrogen or an alkanol such as ethanol or isopropanol, and wherein R" is hydrogen or an alkanol such as ethanol or isopropanol.

Examples are lauric monoisopropanol amide, lauric diethanol amide, and coconut diethanol amide for example ALKAMIDE 2106 (trade mark from Alkaril Chemicals Ltd.).

2. Ethoxylated alkyl aryl sulphonate:

Examples are nonyl phenol sulphonate with 8 moles ethylene oxide, and N-decyl benzene sulphonate with 6 moles ethylene oxide.

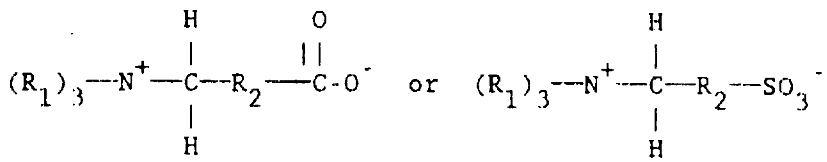
3. Amine oxides (nonionic).



where R = alkyl carbon chains from 1 to 20 carbons, usually one chain is 10 to 18 carbons. Alkyl groups can have hydroxyl or amido functional groups in their chain.

Examples are bis(2-hydroxyethyl) coco amine oxide, bis(2-hydroxyethyl) laurel amine oxide, laurel dimethyl amine oxide, coco amidopropyl dimethyl amine oxide, cetyl dimethyl amine oxide, myristyl dimethyl amine oxide.

4. Betaines and Betaine Derivatives



wherein R_1 is an alkyl chain length between 3 and 20 carbons, R_2 is an alkyl chain length between 1 and 4 carbons. Amide functional groups may be incorporated into the R_1 alkyl chain. Examples are coco amido propyl betaine (R_2 - propyl group of 3 carbons), laurel betaine (R_1 - laurel group of 12 carbons, no R_2), coco betaine (R_1 - coco group of 12-14 carbons, no R_2), oleyl betaine (R_1 - oleyl group of 18 carbons, no R_2), myristic betaine (R_1 - myristyl group of 14 carbons, no R_2), oleamido propyl betaine, isostearamido propyl betaine, laurel sulphobetaine.

5. Ethoxylated Alcohols (nonionic):
Ethoxylated simple alcohols with linear or branched chains having between 8 and 20 carbons with 3 to 20 moles of ethylene oxide groups; 6-14 moles of ethylene oxide are typical. Examples are C_9-C_{11} linear alcohol with 8 moles ethylene oxide, C_{14}-C_{15} linear alcohol with 13 moles ethylene oxide, C_{12}-C_{15} linear alcohol with 9 moles ethylene oxide.

6. Sulphates and Sulphonates of Ethoxylated Alcohols (anionic):
The same ranges apply as in No. 5 supra except ethylene oxide moles may vary between 2 and 14.
Examples are C_{12}-C_{13} linear alcohol sulphate or sulphonate with 3 moles ethylene oxide, C_{12}-C_{15} linear alcohol sulphate or sulphonate with 3 moles ethylene oxide.

7. Ethoxylated Alkyl Phenols (nonionic):
Alkyl chains of 8 to 20 carbons, usually between 4 and 14 carbons and more preferred to be 8 or 9 carbons, with 4-20 moles of ethylene oxide, usually between 7 and 20 moles and more preferred to 8-12 moles.
Examples are nonylphenol with 9 moles ethylene oxide, octylphenol with 8 moles ethylene oxide.

8. Sulphates or Sulphonates of Ethoxylated Alkyl Phenols (and their salts) (anionic)
Examples are nonyl phenol sulphate or sulphonate with 9 moles ethylene oxide; octyl phenol sulphate or sulphonate with 8 moles ethylene oxide.

9. Fluorocarbon-based Surfactants (nonionic, amphoteric, anionic): These must be water-soluble. Fluorocarbon esters such as FC-740 (trade mark from 3M Company) are oil soluble and not appropriate for this use. FC-100, FC-129, FC-170C (trade mark from 3M Company) are commercially available examples of fluorocarbon-based surfactants used in the invention.
Examples are fluoro-octyl sulphonate or sulphate, perfluorated quaternary ammonium oxide, and fluorinated C_9-C_{11} alcohols with 7 moles ethylene oxide.

10. Phosphate Derivatives of Ethoxylated Alcohols:
Examples are C_{14}-C_{16} linear alcohols phosphate with 8 moles ethylene oxide; phosphated nonylphenol with 10 moles ethylene oxide.

11. Quaternary Ammonium Chloride (cationic):
Dimethyl dicoco ammonium chloride, cetyl dimethyl benzyl ammonium chloride, cetyl dimethyl ammonium chloride.

12. Sulphates or Sulphonates of Alcohols (and their salts) (Anionic):
Sulphated simple alcohols with carbon chains of 8-20, usually between 10 and 16 and most common 10-12.
Examples are sodium lauryl sulphate or sulphonate, potassium lauryl sulphate or sulphonate, magnesium lauryl sulphate or sulphonate, sodium n-decyl sulphate or sulphonate, triethanol amine laurel sulphate or sulphonate, sodium 2-ethylhexyl sulphate or sulphonate.

13. Condensation Products of Ethylene Oxide and Propylene Glycol (nonionic):
Examples are propoxylated C_9-C_{14} alcohols with 6 moles ethylene oxide.

Especially preferred are nonylphenol ethoxylates, coco amido betaine, blends of N-alkyl coco trimethyl ammonium chloride and bis(2-hydroxyethyl) cocoamide oxide, blends of ethoxylated trimethylnonanol and perfluoro quaternary ammonium oxide, C_{12}-C_{15} linear alcohol ethoxylate sulphate, C_9-C_{11} linear alcohol ethoxylate sulphates, sodium lauryl sulphate, and ethoxy alcohol sulphates.

By 'blast furnace slag' is meant the hydraulic refuse from the melting of metals or reduction of ores in a furnace. Such material is disclosed in USA patent specification No. 5 058 679.

The preferred blast furnace slag used in this invention is a high glass content slag produced by quickly quenching a molten stream of slag at a temperature of between 1 400 °C and 1 600 °C through intimate contact with large volumes of water. Quenching converts the stream into a material in a glassy state having hydraulic properties. At this stage it is generally a granular material that can be easily ground to the desired degree of fineness. Silicon dioxides, aluminium oxides, iron oxides, calcium oxide, magnesium oxide, sodium oxide, potassium oxide, and sulphur are some of the chemical components in slags. Preferably, the blast furnace slag used in this invention has a particle size such that it exhibits a specific surface area between 2 000 cm^2/g and 15 000 cm^2/g and more preferably, between 3 000 cm^2/g and 15 000 cm^2/g, even more preferably, between 4 000 cm^2/g and 9 000 cm^2/g, most preferably between 4 000 cm^2/g and 8 500 cm^2/g. In each instance the specific surface area or surface area is the Blaine specific surface area. An available blast furnace slag which fulfils these requirements is marketed under the trade name "NEWCEM" by the Blue Circle Cement Company. This slag is obtained from the Bethlehem Steel Corporation blast furnace at Sparrows Point, Maryland.

A usual blast furnace slag composition range in weight percent is: SiO_2, 30-40; Al_2O_3, 8-18; CaO, 35-50; MgO, 0-15; iron oxides, 0-1; S, 0-2 and manganese oxides, 0-2. A typical specific example is: SiO_2, 36.4; Al_2O_3, 16.0; CaO, 43.3; MgO, 3.5; iron oxides, 0.3; S, 0.5; and manganese oxides, < 0.1.

Blast furnace slag having relatively small particle size is frequently desirable because of the greater strength it imparts in many instances to a final cement. Characterized in terms of particle size the term "fine" can be used to describe particles with a specific surface area between 4 000 and 7 000 cm^2/g, corresponding to 16 to 31 micrometer in size; "microfine" can be used to describe those particles with a specific surface area in the 7 000 to 10 000 cm^2/g range that correspond to particles of 5.5-16 micrometer in size and "ultrafine" can be used to describe particles with a specific surface area over 10 000 cm^2/g that correspond to particles 5.5 micrometer and smaller in size. Small particle size blast furnace slags are available from Blue Circle Cement Co., Koch Industries, Tulsa, Oklahoma, under the trade name "WELL-CEM", and from Geochem under the trade name "MICROFINE MC100".

However, it is very time consuming to grind blast furnace slag to these particles sizes. It is not possible to grind blast furnace slag in a manner where particles are entirely one size. Thus, any grinding operation will give a polydispersed particle size distribution. A plot of particle size versus percent of particles having that size would thus give a curve showing the particle size distribution.

In accordance with a preferred embodiment of preparing the cementitious slurry using blast furnace slag, a blast furnace slag having a polydispersed particle size distribution exhibiting at least two nodes on a plot of particle size versus percent of particles in that size is utilized. It has been found that if only a portion of the particles are in the ultrafine category, the remaining, indeed the majority, of the slag can be ground more coarsely and still give essentially the same result as is obtained from the more expensive grinding of all of the blast furnace slag to an ultrafine state. Thus, a grinding process which will give at least 5% of its particles falling within a size range of 1.9 to 5.5 microns offers a particular advantage in economy and effectiveness. More preferably, 6 to 25wt% would fall within the 1.9 to 5.5 micron range. The most straightforward way of obtaining such a composition is simply to grind a minor portion of the blast furnace slag to an ultrafine condition and mix the resulting powder with slag ground under less severe conditions. Even with the less severe conditions there would be some particles within the fine, microfine or ultrafine range. Thus, only a minority, i.e., as little as 4wt% of the slag, would need to be ground to the ultrafine particle size. Generally, 5 to 25wt%, more preferably 5 to 10wt% can be ground to the ultrafine particle size and the remainder ground in a normal way thus giving particles generally in a size range of greater than 11 microns, the majority being in the 11 to 31 micron range.

The amount of blast furnace slag will generally be in the range of from 57 to 1 712 kg/m^3, preferably from 285 to 1 427 kg/m^3, most preferably from 428 to 1 000 kg/m^3 based on the barrels of cementitious slurry. This cementitious slurry can be made by combining the blast furnace slag with water or with drilling fluid.

The use of slag as the hydraulic material gives a final cementitious slurry which is not weakened in the manner that would be the case with Portland cement if the slurry is more dilute. On the other hand, additional slag does not impart extremely high viscosity to the slurry and thus a higher concentration of hydraulic material can be used if desired. Thus if the cementitious slurry is to be made by combining blast furnace slag with drilling fluid, this can be done simply by adding the blast furnace slag directly to the drilling fluid.

However, in the preferred method of using drilling fluid in the cementitious slurry preparation, the drilling fluid is utilized and thereafter diluted prior to or during the addition of blast furnace slag (or additional blast furnace slag if blast furnace slag is present in the drilling fluid). The dilution fluid can be the same as the liquid used to make the drilling fluid or it can be different. Thus, the density of the drilling fluid can be chosen in the first place to be sufficient to avoid inflow into the wellbore because of formation pressure but insufficient to rupture the wellbore wall and force fluid out into the formation. By utilizing the dilution and thereafter the addition of additional blast furnace slag, the cementitious slurry can also have the density tailored to the particular operation the same as the drilling fluid.

The dilution can be carried out in either of two ways. First, a vessel containing drilling fluid can simply be isolated and the desired amount of water or other diluent added thereto. In a preferred embodiment, however, the drilling fluid is passed to a mixing zone as a flowing stream and the diluent added to the flowing stream. Thereafter, the additional blast furnace slag is added. This avoids highly viscous cementitious slurry compositions and allows all of the pumping to be done with piping and pumps associated with the well rig without the need for pumps designed for pumping cement. Thus, it is possible to tailor the final density of the cementitious slurry, if desired, to a value within the range of 30% less to 70% more than the original density of the drilling fluid, preferably within the range of 15% less to 50% more, most preferably essentially the same, i.e., varying by no more than ±5 weight percent.

The blast furnace slag cementitious slurry generally contains an activator system to speed up the setting process.

Suitable activators include lithium hydroxide, lithium carbonate, sodium silicate, sodium fluoride, sodium silicofluoride, magnesium hydroxide, magnesium oxide, magnesium silicofluoride, zinc carbonate, zinc silicofluoride, zinc oxide, sodium carbonate, titanium carbonate, potassium carbonate, sodium hydroxide, potassium hydroxide, potassium sulphate, potassium nitrite, potassium nitrate, calcium hydroxide, sodium sulphate, copper sulphate, calcium oxide, calcium sulphate, calcium nitrate, calcium nitrite, and mixtures thereof. A mixture of caustic soda (sodium hydroxide) and soda ash (sodium carbonate) is preferred because of the effectiveness and ready availability. When mixtures of alkaline agents such as caustic soda and soda ash are used the ratio can vary rather widely since each will function as an accelerator alone. Preferably, 2.8 to 57 kg/m^3 of caustic soda, more preferably 5.7 to 17 kg/m^3 of caustic soda are used in conjunction with from 5.7 to 143 kg/m^3, preferably 5.7 to 57 kg/m^3 of soda ash. The references to 'kg/m^3' means kg per m^3 of final cementitious slurry.

In some instances, it may be desirable to use a material for a particular effect along with the activator even though it may also act as a retarder. For instance, a chromium lignosulphonate may be used as a thinner in the cementitious slurry along with the activator even though it also functions as a retarder.

Other suitable thinners include chrome-free lignosulphonate, lignite, sulphonated lignite, sulphonated styrene maleic-anhydride, sulphomethylated humic acid, naphthalene sulphonate, a blend of polyacrylate and polymethacrylate, an acrylamideacrylic acid copolymer, phenol sulphonate, dodecylbenzene sulphonate, and mixtures thereof.

The following example shows the advantages of using a surfactant in the blast furnace slag cementitious system which is used to displace an oil based drilling fluid. This example contrasts the results obtained with and without the addition of the surfactant to a blast furnace slag cementitious slurry used to directly displace the oil based mud. This example exemplifies the advantage of using a surfactant in a blast furnace slag cementitious slurry when directly displacing an oil base mud.

Table 1. Composition of the cementitious slurry.

1 677 kg/m^3 Cementitious Slurry	SM-1	SM-2
PHB slurry[1], 1	11	11
Seawater,	92	92
SPERSENE[2], kg/m^3	5.7	5.7
RESINEX[3], kg/m^3	11	11
HALAD 413[4], kg/m^3	8.6	8.6
NaOH, kg/m^3	3.57	3.57
$NaCO_3$, kg/m^3	8.6	8.6
NEWCEM[5], kg/m^3	1 000	1 000
Surfactant[6], kg/m^3	0	24

[1] Fresh water slurry containing 86 kg prehydrated bentonite per m^3

[2] Trade name of MI Drilling Fluids for a chrome lignosulphonate dispersant.

[3] Trade name of MI Drilling Fluids for a sulphonated lignite/resin dispersant and fluid loss control agent.

[4] Trade name of Halliburton for a polymer-grafted lignosulphonate fluid loss additive.

[5] Trade name of Blue Circle Cement Co. for ground blast furnace slag having a Blaine Specific Surface Area of 5 500 cm^2/g.

[6] An ethoxylated linear alcohol sulphate.

Table 2. Fann viscosity data at room temperature, wherein the torque readings in Pa are given at 600, 300, 200, 100, 6 and 3 rpm, wherein Pl. V. is the plastic viscosity in mPa.s, wherein Y.P. is the yield point in Pa, and wherein Gel Str. is the gel strength in Pa determined after 10 seconds and 10 minutes.

	Run number								
	1	2	3	4	5	6	7	8	9
SM-1	100			75	50	25			
SM-2		100					75	50	25
NDM			100	25(A)	50(B)	75(C)	25(D)	50(E)	75(F)
Torque									
600	13.9	24.9	53.6	92.4	141.2	46.9	127.4	91.9	53.1
300	7.2	12.9	29.2	59.9	66.1	23.5	78.0	51.2	28.7
200	4.8	9.1	20.6	45.5	49.3	15.8	48.8	36.9	21.1
100	2.9	4.8	11.5	25.4	33.0	9.6	33.5	26.3	12.0
6	0.5	0.5	2.4	2.4	9.6	2.4	1.9	6.2	1.9
3	0.5	0.5	1.9	1.4	9.1	1.9	1.9	4.3	1.4
Pl. V	14.0	25.0	51.0	68.0	157.0	49.0	103.0	85.0	51.0
Y.P.	0.5	1.0	4.8	27.3	-9.1	0.0	28.7	10.5	4.3
Gel Str.									
at 10 s	0.5	0.5	3.4	3.4	14.4	2.4	5.7	4.3	1.9
at 10 min		3.8	5.7						

The compositions of SM-1 and SM-2 are given in Table 1.

NDM is a NOVADRILL (trade name of MI Drilling Fluids) drilling fluid containing sheen-free synthetic oil, the specific gravity of the drilling fluid is 1 425 kg/m^3, and NOVADRILL has the following composition 87 l of NOVASOL (trade name of MI Drilling Fluids) a sheen-free synthetic oil; 41 l of $CaCl_2$ brine; 2.3 kg of NOVAMUL (trade name of MI Drilling Fluids) a primary emulsifier; 0.9 kg of NOVAWET (trade name of MI Drilling Fluids) a secondary wetting agent; 2.7 kg of lime, 1.8 kg of VG-69 (trade name of MI Drilling Fluids) an organophilic clay gelling agent; and 98 kg of barite.

The letters between brackets refer to the following observations:

(A) A slightly grainy mix. No large drops of NDM visible but not as smooth as Run 7

(B) Heavy, lumpy, large curds of SM-1 within the oil base: Severe settling

(C) Small flocs of SM-1 within the oil base mud: Severe settling

(D) Very smooth Mix, no visible drops of NDM, within the SM-1, i.e., H_2O external.

(E) Small flocs of SM-2 within the oil base mud.

(F) Very smooth mix, no visible drops of SM-2 within the oil base mud.

As can be seen from Table 2, the surfactant-containing cementitious slurry, SM-2, gave less mud contamination at all three of the component ratios tested (i.e., as shown by comparing footnote A vs. D, B vs. E, or C vs. F.) Also, while there is some scatter in the data, at a 50/50 ratio of components (Run 8) the viscosity values were excellent for the mixtures formed from the surfactant-containing blast furnace slag cementitious slurry (SM-2).

However, Run 5 and Run 6 for the mixtures formed from the blast furnace slag cementitious slurry (SM-1) having no surfactant had a negative or zero yield point which strongly indicates that the mixtures are settling fluids.

While this invention has been described in detail for the purpose of illustration, it is not to be construed as limited thereby, but is intended to cover all the changes and modifications within the spirit and scope thereof.

AMENDED CLAIMS

1. A method for drilling and cementing a well, comprising:

drilling a borehole utilizing a drilling fluid, thus producing a used drilling fluid (22) to be displaced out of the borehole;

combining ingredients comprising water and blast furnace slag to produce a cementitious slurry (24);

disposing a pipe (14) within the borehole;

passing the cementitious slurry into the borehole thus at least partially displacing the used drilling fluid (22) with the cementitious slurry (24); and

displacing the cementitious slurry (24) into an annulus (32) surrounding the pipe (14),

characterized in that the drilling fluid (22) is an oil based drilling fluid, in that the cementitious slurry (24) further contains a surfactant, and in that used drilling fluid (22) is displaced by direct fluid contact (25, 25A) with the cementitious slurry (24).

2. The method according to claim 1, wherein the oil-based drilling fluid is an invert emulsion and water of an internal phase thereof contains dissolved calcium chloride and wherein the cementitious slurry (24) comprises in addition an activator.

3. The method according to claim 1 or 2, wherein the surfactant is present in an amount within the range of 0.2 to 10 volume percent based on the volume of water in the cementitious slurry (24).

4. The method according to claim 1 or 2, wherein the surfactant is present in an amount within the range of 0.29 to 43 kg/m^3 based on the m^3 of the cementitious slurry (24).

5. The method according to claim 2, wherein the activator is selected from the group consisting of sodium silicate, sodium fluoride, sodium silicofluoride, magnesium silicofluoride, magnesium hydroxide, magnesium oxide, zinc silicofluoride, zinc oxide, zinc carbonate, titanium carbonate, sodium carbonate, potassium sulphate, potassium nitrate, potassium nitrite, potassium carbonate, sodium

hydroxide, potassium hydroxide, copper sulphate, lithium hydroxide, lithium carbonate, calcium oxide, calcium nitrate, calcium nitrite, calcium hydroxide, sodium sulphate and mixtures thereof.

6. The method according to claim 1, wherein the surfactant is selected from an ethoxylated linear alcohol sulphonate, coco amido propyl betaine and ethoxylated nonyl phenol and wherein the cementitious slurry comprises in addition an activator.

7. The method according to claim 1, wherein the drilling fluid is an invert emulsion.

8. The method according to claim 1, wherein the drilling fluid is a low water content-oil based drilling fluid.

9. The method according to claim 1, wherein 5 to 25% of the blast furnace slag has an ultrafine particle size.

10. The method according to claim 1, wherein the cementitious slurry (24) comprises in addition a mixture of sodium hydroxide and sodium carbonate, and wherein the cementitious slurry contains 428 to 1 000 kg/m^3 of the blast furnace slag and wherein the pipe (14) has a diameter of 43 cm or larger.

11. The method according to claim 1, wherein the cementitious slurry (24) is displaced using a displacement fluid comprising drilling fluid.

12. The method according to claim 1, wherein the oil of the oil based drilling fluid is selected from the group consisting of mineral oil; diesel oil; crude oil; sheen-free synthetic hydrocarbon oil; vegetable oil; and an ester oil.

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FIG.1

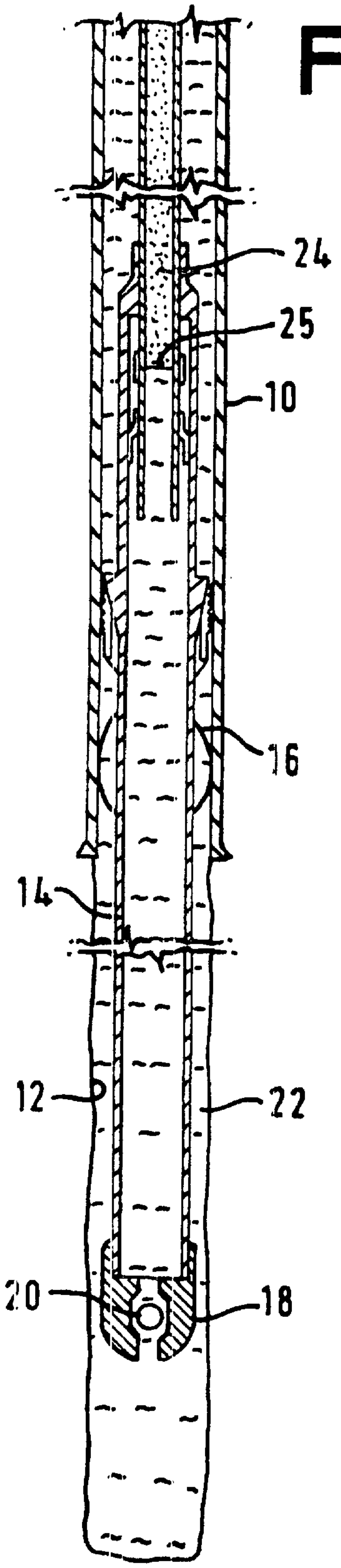

FIG.2