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# An Efficient Environmentally Acceptable, Clean up System for Well Completions

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# AN EFFICIENT, ENVIRONMENTALLY ACCEPTABLE, CLEAN UP SYSTEM FOR WELL COMPLETIONS

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## ABSTRACT

Evaluation of different casing cleaning fluid systems has been a difficult task due to the lack of a standardised laboratory measurement technique for technical performance. In order to meet the need for a reliable evaluation of different chemicals and fluid systems used in casing cleaning, a laboratory procedure for the evaluation of casing cleaning chemicals has been developed. This procedure has been successfully applied in the development of a new environmentally acceptable casing cleaning fluid system.

Two different procedures for the casing cleanup operations are presented. An old method where the drilling fluid was displaced down the annulus and up the drill string was found to be ineffective compared to a method where the drilling fluid was displaced up in the annulus. The application of this new procedure together with the use of the new chemical additive has reduced the cost of casing cleanup operations in the range of 30-40%.



## INTRODUCTION

After finishing the drilling and cementing operations of an oil/gas well it is necessary to displace the well fluid from a drilling fluid system to a completion fluid system. Well completion require the use of a packer fluid in the annulus between the casing and the production tubing. Different well completion designs and reservoir conditions set limits on the content of particles in the packer fluids. The cleanliness of this fluid can vary from several hundred NUT (Nephelometric Turbidity Units[1]) down to 10-20 NTU.

The displacement of a drilling fluid with a completion fluid is normally performed through several steps. First the drilling fluid is displaced by a casing cleaning fluid followed by seawater. Finally the sea water is displaced by the packer fluid. The complete displacement of a fluid by another by hydraulics only is difficult to achieve in an annulus[2]. In order to efficiently displace the drilling fluid with a packer fluid, it is common to use different types of chemical additives in the cleaning fluids pumped between the drilling fluid and the packer fluid[3]. The function of these chemicals is to disperse and break different components of the drilling fluid as well as decrease the surface activity between the two fluids.

During the last years it has been focused on the environmental aspects of all sorts of well operations. The environmental impacts from different chemicals used offshore have received significant attention. The required ecotoxicological laboratory tests of chemicals have been harmonised within the work of the Oslo and Paris Commission. Therefore, to be applicable, a chemical has to be efficient in performance as well as having a low environmental impact.

As the previously used chemical additives for the casing cleaning fluids did not meet the above mentioned environmental regulations, a project was established to find a suitable replacement for these previously used chemical additives. The new chemical additive has to meet both the performance requirements and the environmental regulations. Furthermore, the new chemical additive has to be sufficiently inexpensive.

Comparative laboratory techniques to evaluate the performance of well fluid additives exist for several fluids like cements and drilling fluids. There is, however, no standard laboratory measurement method that is applicable to determine the performance of additives to prewashes or spacer fluids used during well cleanup operations. To be able to compare different cleanup systems and chemicals under acceptable laboratory conditions, it was therefor necessary to develop a laboratory method for evaluation of the technical performance of the chemicals and fluid systems in question.

## DISPLACEMENT IN PRACTICAL OPERATIONS

A necessary task to obtain proper casing cleaning is to have sufficient displacement of the drilling fluid by the cleaning fluid. If there is a thick drilling fluid layer remaining on the casing wall, the effectiveness of the cleaning chemicals has to be extremely good to obtain even only a acceptable result. As known from primary cementing practices the displacement efficiency is dependent on both the drilling fluid properties and of the properties to the displacing fluid. Jakobsen et al.[2] demonstrated experimentally the existence of flow regions with good or unsuitable displacement efficiency in eccentric annuli.

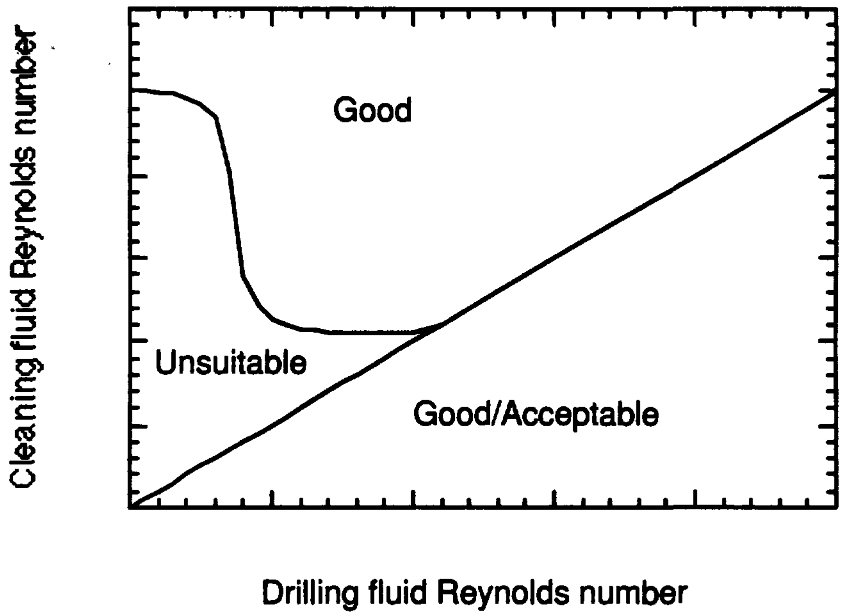


Fig. 1. Flow chart for proper displacement in an eccentric annulus.

The straight line shown in Figure 1 represents the case where the Reynolds number is equal both in the drilling fluid and in the displacing casing cleaning fluid. This type of figure is valid for any eccentricity. However, the boundary line between the Good region and Unsuitable region will change with eccentricity. The best displacement results are obtained in the right hand part of the Good region. To the right of the branch point where all the three regions meet, the flow is sufficiently in turbulence both in the drilling fluid and in the displacing fluid. The shear forces on the casing wall are sufficient to efficiently displace the drilling fluid. Only a small drilling fluid film will be present. It is the objective of the cleaning fluid chemicals to disperse the fluid in this film. The farther it is possible to get vertically from the line with equal Reynolds number the better. Proper displacement can be achieved by sufficient turbulence in the displacing fluid or by having as strong viscous forces as possible in the displacing fluid.

When the drilling fluids Reynolds number is reduced there exists three regions with different displacement efficiencies. In the good region the displacing fluid turbulence strength is sufficiently strong to achieve a good displacement. If the displaced fluid Reynolds number falls into the Unsuitable region, as a result of a to low pump rate, a proper displacement can not be achieved. In this region even the possible turbulence forces are insufficient to prevent channelling of a less viscous fluid through a more viscous fluid. If it is not possible to obtain a displacing fluid Reynolds number being larger than falling into the Unsuitable region, the viscosity of the displacing fluid should be increased. Then the shear stresses will force the drilling fluid adjacent to the wall to channel out. Again only a drilling fluid film will remain at the casing wall.

## TESTING OF CASING CLEANING CHEMICALS

There is no standard procedure for testing of casing cleaning chemicals. Two main methods with different options are used. These tests include a small scale pipeline test and different tests using a VG-type viscometer.

A pipeline test is difficult to use and is not practical if the scope is to compare the effects of different surfactants. The primary reason is that this testing system is relying on equal displacement efficiency. In a pipeline, a flow regime map very similar to the flow regime map of an annulus shown in Figure 1 will be observed. In such a test the drilling fluid is flooded through the pipeline and is thereafter displaced by the casing cleaning fluid system. If a comparison test of different chemicals is to be performed it is necessary to make sure that all experiments are done at the same drilling fluid Reynolds number and at the same Reynolds number of the displacing casing cleaning fluid. Care has to be taken to fulfil this requirement. If not, the chemicals in one of the tests have to disperse a drilling fluid film with a different thickness than in the next experiments.

Two options have been frequently applied when using a VG viscometer for the evaluation of the casing cleaning chemicals. In one of the options the viscometer cylinder has been running in the drilling fluid. Thereafter, the drilling fluid cup has been removed and a cup with casing cleaning chemicals has been mounted. The cylinder has been set to constant rotation and the film condition on the viscometer cylinder has been evaluated visually after a certain time (2-5 min.). This method has removed a lot of the uncertainties apparent in the pipeline method. However, the flow is centrifugal unstable as the drilling fluid film in examination is on the outside of a fast rotating cylinder. Some effects of density and viscosity of the involved fluid systems are therefore to be expected.

The second option of the VG viscometer method is in an experiment similar to the one described in the previous paragraph, but in this case the drilling fluid film remaining on the wall of the viscometer bob is examined after certain time (2-5 min.). The flow in this case is centrifugal stable and should therefore have a much higher degree of reproducibility. Furthermore, it is possible to apply an expected operational shear rate during the test. In a real casing cleaning operation the wall shear rate ($\dot{\gamma}$) will approximate

$$\dot{\gamma} = \frac{12V}{D_o\text{-}D_i}\,\frac{2n+1}{3n} \qquad (1)$$

in laminar flow, where V is the average annual velocity, $D_o$ and $D_i$ are the outer and inner pipe diameter of the annulus and n is the shear thinning index. Therefore it is possible to simulate, at least approximately an anticipated shear rate and thus perform experiments at this shear rate. The laboratory measurements were conducted by following the procedure described below.

## LABORATORY PROCEDURES

The present laboratory test is based on a simple method utilising a standard oil field VG viscometer equipped for viscosity measurements in combination with visual inspection and gravimetric testing. The laboratory measurements were conducted using the following scheme:

- The viscometer cup was filled with the drilling fluid. Thereafter, the viscometer cylinder was rotated at a specified rate for 2 minutes to completely wet the bob surface.
- The slurry cup was removed and free drilling fluid was allowed to drip off for 1 minute.
- A clean glass beaker was filled with the casing cleaning fluid. Thereafter, the viscometer cylinder was rotated at the specified rate for 2 minutes in the glass beaker.
- A clean glass beaker was filled with the sea water. Thereafter, the viscometer cylinder was rotated at the specified rate for 2 minutes in the glass beaker to remove excess volumes of casing cleaning fluids.
- The viscometer cylinder was removed and a visual inspection was made of the surface of the bob for examination and the bob was weighted and the weight was compared with the weight of a clean waterwet bob.

Based on the approximation given in equation 1, the shear rates obtained when pumping a Newtonian fluid (equals n= 1) at a specific flow rate in an annulus is calculated by the equation :

$$\dot{\gamma} = \frac{12V}{D_o\text{-}D_i} \qquad (2)$$

where $\dot{\gamma}$ is the shear rate, V is the average velocity in the annulus, $D_o$ is the outer diameter of the annulus and $D_i$ is the inner diameter of the annulus. This shear rate can be simulated using the viscometer. The shear rate in the viscometer is related to the rotation rate (W, rpm) following Equation 3:

$$\dot{\gamma} = 1.703\ W \qquad (3)$$

To evaluate the effect of the prewash chemical additives a well configuration typical for several North Sea operations was assumed. This typical well configuration consisted of a 5 inch (127 mm) drillpipe in a 9 5/8 inch (244.5 mm) casing with ID=8.835 inches (224.4 mm).

It was assumed that $5m^3$ of prewash was pumped. An increase in pump rate will lead to an increase in shear rate in accordance with Equation 2. However, at the same time the contact time where the drilling fluid residuals at the casing wall are exposed to the prewash will be reduced. The shear rate obtained in the annulus by the pumping was simulated by rotating the viscometer at a shear rate similar to that of the pumping for the same contact time.

**Table 1.** The annular velocity and shear rate obtained by pumping $5m^3$ of prewash through a well consisting of a 5 inch (127 mm) drillpipe in a 9 5/8 inch (244.5 mm) casing with ID=8.835 inches (224.4 mm) during a specified contact time.

| PUMP RATE | ANNULAR SPEED | SHEAR RATES | RPM | CONTACT TIME |
|---|---|---|---|---|
| L/min | m/s | 1/s | | minutes |
| 5000 | 3.1 | 381 | 220 | 1 |
| 2500 | 1.55 | 191 | 112 | 2 |
| 1667 | 1.03 | 127 | 75 | 3 |
| 1000 | 0.61 | 77 | 45 | 5 |
| 500 | 0.31 | 39 | 23 | 10 |
| 333 | 0.2 | 25 | 15 | 15 |
| 250 | 0.15 | 18 | 11 | 20 |

Shorter contact time than 1 minute was not considered. This set an upper limit for the pump rate of 5000 L/min. Even this rate is too high to be practical for most operations. The shear rate obtained at 100 rpm rotation in the viscometer was considered to represent a practical job as this rate simulated pumping at approximately 2230 L/min. The shear rate at 100 rpm is 170 $sec^{-1}$

Several laboratory tests were performed at different temperatures up to about 100°C. A better cleaning efficiency was observed with increasing temperatures. This improved cleaning effect with increase in temperature is anticipated to be a result of the reduction in both drilling fluid and prewash viscosity with temperature.

The gravimetric values from a laboratory test showing the cleaning effect of an old system that did not satisfy the present environmental requirements is shown in Table 2. In the same table it is also shown the gravimetric values for the new cleaning system that satisfy the environmental regulations. It is seen from the table that the cleaning effect is better for the new environmentally acceptable cleaning system than for the old system.

**Table 2.** Gravimetric analysis of viscometer bob. Ester based drilling fluid, 1.57 sg.

| | | Cleaning effect |
|---|---|---|
| Weight of clean waterwet bob | 81.20 g | |
| Weight of EBM wet bob | 84.10 g | |
| Weight of bob after using old system | 83.23 g | 30% |
| Weight of bob after using new system | 81.55 g | 88% |
| Weight difference new/old system | 1.68 g | 58% |

## ENVIRONMENTAL ASPECTS

One of the major tasks in the development of new chemicals for offshore applications is to reduce the environmental impact to an acceptable level. This is of great importance since much of the chemicals used in the operations are discharged directly in to the sea after use. Reduction of the impact on the environment can be obtained by either change the operational procedures in order to avoid discharges, or to develop chemicals that are sufficiently environmentally acceptable. The most cost effective solution is to develop chemicals that can both reduce the discharged volume based on technical performance and at the same time be acceptable from an environmental point of view if it is discharged.

Through the work of the Oslo and Paris Commission a set of guidelines have been proposed which defines procedures of approval, evaluation and testing of offshore chemicals and drilling fluids[4]. The guidelines have been revised several times during the last years and latest during the spring of 1995. The last revision was put into force by SFT in a letter dated 1.6.1996 [5]. The guidelines specifies the requirements regarding testing of chemicals towards toxicity, bioaccumulation and biodegradation.

A disadvantage with traditional well cleaning chemicals is the high toxicity they show towards marine organisms which are low in the food chain. This combined with a high degree of persistency and potential for bioaccumulation of many of the components in the chemicals implies that these types of chemicals may represent a significant hazard to the overall environment if they are dumped directly into the sea.

During the development period, the performance of several casing cleaning chemical formulations were tested in the laboratory. The components in the formulations were all controlled for any known environmental effects. This effort led to the development a new chemical additive for casing cleaning. The laboratory tests were very promising both from an environmental and technical point of view.

The toxicity tests were performed in accordance with the Oslo and Paris Commission Guidelines[4,5] on the following marine organisms:

- Algae: Skeletonema costatum
- Crustacean: Acartia tonsa
- Sediment Reworker: Abra alba

The bioaccumulation potential and biodegradation ability were determined for each of the components by the following methods:

- Bioaccumulation OECD Procedure 117, HPLC Method[6]
- Biodegradation OECD Procedure 306, Biodegradability in seawater[7]

Bioaccumulation and biodegradation data for one of the components are taken from the literature.

The results of the toxicity tests and the bioaccumulation and biodegradation tests are presented in table 3.

**Table 3.** Results from the laboratory testing of toxicity towards marine organisms, bioaccumulation and biodegradation

| TEST | Skeletonema costatum | Acartia tonsa | Abra alba | Bioaccumulation potential | Biodegradation ability |
|---|---|---|---|---|---|
| | $EC_{50}$ mg/l | $LC_{50}$ mg/l | $EC_{50}$ ppm | Log $P_{ow}$ range/ Log(weighted average $P_{ow}$) | % Degradation after 28 days BOD/COD |
| Product | 87 | >2000 | 1083 | | |
| Component 1 | | | | < 0 - 3,3 / 1,3 | 62 |
| Component 2 | | | | < 0 - 3,3 / 1,7 | 41 |
| Component 3 | | | | 0,15 | 99 |

The results from the laboratory tests show that the chemical is of low toxicity and that its components will be degraded in a reasonable short time. The bioaccumulation potential expressed by the log $P_{ow}$ range is higher than the threshold value of log $P_{ow}$=3.0[8] for two of the components. However, the weighted average Log $P_{ow}$ calculated for each of the components is below this threshold value. The calculation of the weighted average Log $P_{ow}$ is performed in accordance with the guidelines in the HOCNF [9] and based on the single $P_{ow}$ values for each of the peeks in the chromatogram and the corresponding area.

Furthermore, in the enterprise of evaluating the different chemicals environmentally it is important also to take into consideration the fluid system and fluid volumes involved in the operations. The new casing cleaning chemical has a substantially lower toxicity and bioaccumulation potential and a higher degree of degradability than the older chemicals. In addition, it has also been possible to reduce both the concentration of chemicals in the casing cleaning fluid and the total volume of fluid needed for the specific job. In this respect it is obtained a large reduction in the fluid volumes dumped to sea and the undesired negative impact on the environment is reduced significantly.

## DESIGN CRITERIA

Oil based and pseudo oil based drilling fluids are often used in the North Sea area when drilling through the oil/gas reservoir. Low formation damage potential, good lubrication and low differential sticking potential have been, and are still important factors when a drilling fluid is selected for the reservoir drilling. The removal of these drilling fluids during the completion operation has shown to be more difficult than removing watermiscible drilling fluid systems.

Oil companies have realised the benefits of having a clean wellbore before running the completion string. Therefore it has been, for several years, a continuous search for better chemicals and operational procedures.

In the development of the new casing cleaning operational method the down hole hardware remained constant. The work string consisted of a 5 inch (127 mm) drill pipe in 9 5/8 inch (244.5 mm) casing with casing scrapers and a 3 1/2 inch (88.9 mm) drill pipe in 7 inch (177.8 mm) liner with casing scrapers.

## CASE HISTORIES

Old procedure

Until 1993 a combination of 3-4 different fluids was applied in a casing cleaning fluid system. These fluids included a surfactant blend, a flocculant mixture, a viscous fluid and a caustic solution; all pumped in sequence.

Prior to the displacement operation the drilling fluid was circulated and diluted to reduce the viscosity. During this fluid conditioning, the work string was rotated and reciprocated to create instabilities in the flow to improve mixing and dilution. The drilling fluid was displaced by the casing cleaning fluids by pumping the fluids in the reverse direction down in the annulus between the work string and casing and up to the surface through the work string. First, 8-15 $m^3$ of the base fluid for the drilling fluid where pumped, dependent on the well configuration. Thereafter, a water wetting surfactant wash fluid was pumped in a volume of 8-10 $m^3$, followed by one hole volume sea water. During this sequence it was not possible to either rotate or reciprocate the work string.

At this point the well was inflow-tested to ensure that the casing could hold pressure from the outside. The flow direction was then changed back to the normal direction that is down the work string and up the annulus. The volumes pumped of casing cleaning fluids were typically 20 $m^3$ with a blend of surfactants, 10 $m^3$ of flocculant mixtures, 10 $m^3$ of a high viscous fluid, and finally 10 $m^3$ caustic solution. This casing cleaning fluid system and the subsequently sea water was pumped at a rate of 2.0-2.5 $m^3$/min. The work string was rotated and reciprocated during this sequence. The returned fluid was continuously measured for cleanliness. The sample was taken as close to the well as possible in the return line. The goal was a cleanliness of 100 NTU and typically the total solid's content was in the range of 100-200 PPM. The total rig time consumed from the start of the drilling fluid conditioning until the well was accepted to be clean was typically 15-20 hours for a 3000 m long and 60 deg. deviated well with a 9 5/8 inch (244.5 mm) casing and 7 inch (177.8 mm) liner installed.

New procedure

A need for changing procedures was seen mainly due to the environmental impact of the discharged fluids. Some of the old chemicals could no longer meet the environmental requirements. As a result of laboratory testing it was decided to exclude the flocculant additives. The remaining fluids in the casing cleaning fluid system was incorporated into one fluid composition only. The idea was to perform the work with less use of rig time, lower chemical cost and less logistic administration.

The new procedure is as follows: After finishing the drilling operation the drilling fluid is circulated and diluted in order to reduce the drilling fluid viscosity. During this operation the work string is rotated and reciprocated. When the drilling fluid consistency is found to be acceptable, the casing cleaning fluid is pumped. This time the pump direction is kept in forward direction such that it is possible to rotate and reciprocate the work string. Such a rotation creates flow instabilities[10] that significantly enhances the displacement quality.

During the casing cleaning operation, normally 10-15 $m^3$ of the base fluid for the drilling fluid is pumped. Immediately thereafter, 15-20 $m^3$ of the casing cleaning viscous surfactant blend is pumped followed by 20-30 $m^3$ sea water plus another 15-20 $m^3$ casing cleaning viscous surfactant followed by seawater. This operation is performed with a pump rate of 2.0-2.5 $m^3$/min. When the well is displaced to sea water an inflow-test is performed to ensure that the casing could hold pressure from the outside. After the inflow-test, seawater circulation starts with a continuously measurement of the effluent fluid from the well.

In all the wells where the new system has been used (20 wells), the time used for total well cleaning to 100 NTU has been reduced with an average of 40 %. A typical time spent on the casing cleaning operation was 15 hours with the old system. Using the new system the operation time has been reduced to 8-10 hours. Furthermore, the overall cost for chemical additives has been reduced. A comparison between the old and new casing cleaning procedures is shown in Table 4. It shows that the chemical costs may be reduced as much as 25 000 US$ and that the operation time may be reduced by 5 hours. If the average rig time cost is 5 300 US$/hr, it is seen that the overall cost reduction may be in the range of 45-60 000 US$ pr. casing cleaning operation.

**Table 4.** A comparison between the old and new casing cleaning procedures

| Casing cleaning system | Old | New | Old | New |
|---|---|---|---|---|
| Drilling fluid system | OBM | OBM | EBM | EBM |
| Measured depth MD (m) | 4500 | 5400 | 3650 | 3500 |
| Hours spent on operation | 12:00 | 7:45 | 9:00 | 3:40 |
| Volume sea water circulated ($m^3$) | 1155 | 217 | 700 | 312 |
| NTU at end of operation | 106 | 28 | 74 | 37 |
| Total chemical costs (US $) | 47 700 | 23 300 | 54 500 | 27 800 |
| Total cost reduction (Rig time included (5300 US$/hr)) | - | 46 900 | - | 55 000 |

**Table 4. Parameter explanation.**

| | |
|---|---|
| Measured depth: | Total length of wellpath. Well inclination is approximately 70 deg. in both cases. |
| Hours spent on operation: | Time from start displacing well to seawater to end displacing well to packer fluid. |
| Volume seawater circulated: | Volume of seawater pumped between drilling fluid conditioning and start displacing well to packer fluid. |
| NTU at end of operation: | Final NTU reading during displacement of the well to packer fluid. |
| Total chemical cost: | Includes cost of all chemicals used in the cleaning operation. Cost of packer fluid is not included. |
| Total cost reduction: | Cost difference between old and new system, including total chemical cost and rigtime cost (5 300 US$/hr). |

## CONCLUSION

- A laboratory procedure for the evaluation of casing cleaning chemicals has been developed.
- This procedure has been successfully applied in the development of a new environmentally acceptable casing cleaning fluid system.
- It has been proven it is an effective method to displace the drilling fluid by the casing cleaning fluids by pumping down the drill string and up in the annulus and at the same time rotate and reciprocate the drill string.
- By combining the new procedure with forward directed displacement together with the use of the new chemical with environmentally acceptable parameters, it has been possible reduced the cost of casing cleaning operations in the magnitude of 30-40%.

## NOMENCLATURE

| | |
|---|---|
| $D_o$ | Inner diameter of casing (m) |
| $D_i$ | Outer diameter of drillpipe ( in ) |
| V | Annular speed ( ft / min ) |
| $\dot{\gamma}$ | Shear rate ( $sec^{-1}$ ) |
| n | Shear thinning index |
| W | RPM, Rotations per minute |
| ID | Inner diameter |
| OBM | Oil based drilling fluid |
| EBM | Ester based drilling fluid |

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