Drilling Fluids Composition and use within the UK Offshore Drilling Industry
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SUMMARY

Occupational exposure to chemicals is a daily occurrence for many workers in the offshore industry. However it is perhaps fair to say that emphasis on the associated health risks has been somewhat overshadowed by the very real safety risks offshore, together with a high degree of emphasis on the environmental impact of chemicals usage. To some degree the reduction of safety and environmental risks has had a beneficial knock-on effect for health risks. However it cannot be assumed that these go hand in hand, and indeed there is evidence that current restrictions on environmental discharges may actually be increasing the potential health risk to workers by modifying both operating practices and the selection of chemical agents. There is an increasing need therefore to gain a clearer understanding of the nature of chemical usage offshore in terms of the agents used, the potential for exposure and the resulting health risks.

This report aims to give necessary background information on offshore chemicals and their usage. Approximately 90% of all chemicals supplied offshore are used during drilling operations, and this is the area of operation where there is perhaps the greatest potential risk for exposure to the operator. The report therefore deals exclusively with the function and composition of drilling muds. Information has been collated from published material, as well as through consultation with the main UK drilling mud suppliers. Three key objectives have been addressed:

- An overview of drilling mud function and composition.
- An overview of trends in drilling mud usage within UK waters
- A summary of available information on the health hazards associated with drilling muds.

Drilling muds are an often complex formulation of a range of chemicals designed to have specific properties under very specific drilling conditions. As a result, the range of additives is large, with over 1000 components available within the UK alone. The composition of muds using water as the continuous medium (water based muds) is particularly variable, as additives are used to overcome the limitations of the water base. Using oil as the continuous medium (oil based muds) reduces many of the problems associated with water, such as low lubricity and low inhibition, and as a result the common additives are fewer, and the mode of usage is very different. Drilling within UK waters has been dominated by oil based muds from the early 1970's, with early diesel-based muds being replaced by low aromatic content mineral oils (Low Toxicity Oil Based Muds), and later by so-called synthetic oil based muds, formed from either very highly refined oils, or non-petroleum products. Much of these changes have been driven by cost and performance, together with environmental restrictions on discharges. While the resulting move away from products with relatively high aromatic contents to relatively benign oils has been beneficial to operator health, current environmental discharge restrictions are encouraging so-called zero discharge operations, and with them a move back to cheaper, dirtier base oils. It has even been speculated that some operators may consider a move back to using diesel as a base fluid, which still shows appreciable cost/performance benefits over more technologically advanced fluids. Changes in the additives within drilling muds has been much less pronounced, with little change in the major components such as barite, bentonite, brine and fluid loss materials for the past 20 plus years. Opinion within the mud supply industry is that some of the more marked changes, such as the phasing out of chrome lignosulphonates and the use of glutaraldehyde, are representative of a general trend towards less harmful mud additives, although an assessment of overall trends in additive usage and changes in operator health risk requires further investigation.

With the implementation of COSHH offshore, substantial data on the health hazards of additives and their component chemicals is now available on Manufacturers' Safety Data Sheets. Thus a
framework is in place for the effective use of chemicals offshore with the minimal risk to users. However, there are a number of situations and operating practices within this framework which may potentially lead to inadequate assessment and control of chemicals offshore. There are a lack of data available on the impact of exposure to drilling chemicals in the field, and in particular the role that human factors have to play when adequate safety information is available. There are few current exposure limits for mud components and none for whole muds, and applicability of available exposure limits for some drilling mud components is in question. This is further complicated by the number of proprietary products in use within drilling muds. Drilling mud formulations currently tend to be tested for technical performance under downhole conditions, and as a rule little attention is paid to the formation of reaction products (unless they affect technical performance). In reality, this approach probably ensures that the generation of large quantities of breakdown components downhole is only a remote possibility. However, there has been concern that under some conditions harmful reaction products may be formed, and the possibility does exist of generating toxic substances at harmful levels that don’t affect technical performance. The risk is perhaps greater with water-based muds given the number of available additive combinations in a given situation. Oil-based muds are generally from a sole supplier, and formulated before shipping (package muds), thus reducing the risk of unexpected downhole reactions. In general, the mud components used in the greatest quantities such as bentonite, barite, brines and low toxicity or synthetic oils, are of relatively low toxicity. High risk chemicals used in small quantities such as sodium hydroxide are well documented, although mis-handling in the field is always a possibility. Assessment of more complex additives such as natural and synthetic polymers isn’t as straightforward. It is noted by suppliers that many of these products are used widely in the food industry, where available data indicate very low health risks, although this is presumably for ingestion rather than inhalation.

The health risk associated with using drilling fluids will depend on the accuracy and applicability of supplied hazard data in the field, factors governing the selection of mud formulations, and factors affecting the handling and use of muds and additives. This report covers the background to the role of drilling muds, their use, and available information on their associated health hazards.
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1 INTRODUCTION

The UK offshore industry is one in which large quantities of chemicals are used, both in the drilling and completion of wells, and in the production of oil and gas. The degree to which there is the potential for exposure to substances during drilling, whether by inhalation, dermal contact or ingestion, is relatively high. Anecdotally, the link between chemical exposure and ill health is well recognised, particularly in the use of downhole chemicals and the incidence of dermatitis. However, it is perhaps fair to say that with the balance of emphasis on safety rather than health in offshore operations, awareness of health hazards and the means of reducing the associated risks has been lower than in many onshore industries. This is changing, with operators and suppliers becoming increasingly aware of the need to assess the health risks when handling chemicals, partially as a consequence of the implementation of COSHH offshore.

Approximately 90% of all chemical agents supplied offshore are used during well drilling. Apart from a relatively small percentage used during cementing operations, the bulk of these agents form the drilling fluid used to remove cuttings and aid the drilling process. The potential risk of exposure to drilling mud and its separate components is relatively high. Dermal exposure during tripping is virtually unavoidable, and inhalation of mud aerosol and vapour during tripping and around mud pits and shale shakers may be significant. To a certain extent, the drive to minimise the environmental impact of drilling operations has raised awareness of the nature of drilling agents and driven the development and use of less harmful chemicals. However, it is not certain that the bias towards the environmental impact of drilling chemicals will benefit occupational health in the long term. Not only are chemicals being selected on their environmental impact with relatively little regard to their health impact, but environmental guidelines are beginning to encourage the use and handling of some agents that may potentially present a greater risk to worker health. To begin to redress the balance, an understanding of the nature, quantities and handling of offshore chemicals in the context of occupational health is essential. Although the chemicals used in drilling fluids aren’t the most harmful found offshore, they perhaps present the greatest risk to operator health. Production chemicals tend to be more harmful, but much better understood and respected from a hygiene point of view, as well as being used in well contained systems. Drilling fluids on the other hand are generally less harmful, and correspondingly less well respected, are selected in the main on economic and environmental grounds, and tend to be less well contained. The quantities used are also far in excess of those used during production. The emphasis of this report is therefore on the nature and use of drilling fluids offshore on the UK Continental Shelf (UKCS).

Within the offshore drilling industry there is a wealth of information on the composition and use of drilling fluids, or muds. Much of this is valuable for indicating the types and quantities of chemical agents operators may come into contact with, and trends in use. However, a lot of the information is either stored in company archives or forms part of the undocumented expert knowledge of operators and supply companies, and is not readily accessible. Accessibility is compounded by the expected degree of commercial mistrust between competitors! Acting as a non-commercial third party, the HSE has been granted limited access to drilling mud information held by the five offshore mud companies operating in the UK on a commercial in confidence basis. It is this information that forms the backbone of this report, augmented by general information in the public domain drawn from a range of sources.
2 DRILLING FLUIDS

2.1 BACKGROUND

A key requirement in any drilling operation is the means of removing cuttings from the hole. Early drilling operations used water to achieve this, with the use of continuous water circulation systems reported as early as 1845. However, the use of water alone as a drilling fluid was only partially successful at removing cuttings, and severely limited the achievable drilling depth. In 1901 a successful well was drilled in Texas using a drilling fluid with finely ground hole cuttings and sticky clay from surface deposits mixed into the water. The resulting gel formed by the clay suspension proved to be ideal for suspending cuttings, allowing them to be transported away from the bit and out of the hole more effectively, resulting in faster, deeper drilling capabilities. Apart from the development of pumps to supply mud to the drill bit, little changed in the drilling fluid industry until the discovery in the 1920's that the inclusion of a weighting agent into the drilling fluid prevented the incursion of high pressure formation fluids into the well. However it wasn't until 1935 that Hart introduced bentonite clay to suspend the weighting agent barium sulphate (barite) in the drilling fluid, and thus formed the foundation for the current drilling mud industry.

At the inception of the UK offshore drilling industry in the late 1960's, simple clay suspension water based muds (gel muds) were the dominant drilling fluid in use. While suitable for the early exploration work, they interacted to a significant degree with some formations - particularly the tertiary clay formations in the North Sea. They also suffered from poor temperature stability which became important as wells started to get deeper, and lacked the lubricity to achieve drilling at an incline. Initially, a wide range of water based mud systems using alternative gelling agents to bentonite (in particular cellulose based polymers) were used. However, as the necessary technical specifications became higher, the use of brine in oil (invert) emulsion muds to prevent formation interactions (i.e. inhibitive muds) became widespread. By using an oil base fluid instead of water, not only was the lubricity of the fluid significantly increased, but problems of shale interaction were virtually eliminated. Initially, diesel formed the continuous phase of the base fluid, but with increasing awareness of the health risks there was a move to low toxicity oils, and then, following environmental concerns, to either very highly refined petroleum based oils, synthesised oils and non-petroleum oils (all coming under the poorly defined terms of pseudo or synthetic oils).

2.2 FUNCTIONS

To cope with present day drilling requirements at ever increasing depths and inclines, as well as drilling through difficult formations, currently used drilling muds are complex formulations designed to have a number of physical and chemical properties. The base fluid may be either water or oil, with substances being added to this to achieve the desired technical performance. Although the functions that any particular mud formulation will be required to perform are diverse, the key functions may be summarised as follows:

Cuttings Removal. A drilling fluid must be capable of removing cuttings from the base of the hole, and return them to the surface. Drilling operations utilise a circulating drilling fluid system that has remained little changed since the 1930's. Fluid is pumped down the inside of the drill pipe, through orifices in the drill bit, and up to the surface via the annular space between the wall of the well and the drill pipe. Suspended cuttings are transported to the surface, where they are separated from the drilling fluid, which is re-circulated through the well. Cuttings removal requires sufficient viscosity in the fluid, together with a sufficiently high
circulation velocity, to ensure the cuttings remain suspended as the fluid is circulated up the annulus. Most water based muds rely on either bentonite clay or natural polymers to give the desired viscosity, and typically form up to 5% of the mud volume (section 2.4.1, table 1). Clays are also used as viscosifiers in oil based muds, but at much smaller volumes (section 2.4.2, table 2).

**Suspension of cuttings.** When drilling and fluid circulation is halted, the gel strength of the drilling fluid must be sufficient to maintain the cuttings in suspension. As lower viscosity and gel strength allow higher circulation rates and cutting rates, the ideal drilling fluid has a viscosity which is shear force dependent (i.e. shows high levels of thixotropy). The additives used to increase mud viscosity (bentonite clay, polymers) are also selected for their properties as gelling agents (sections 2.4.1, 2.4.2).

**Release of cuttings at surface.** Drilling fluids are used within semi-closed systems, with the returning fluid being cleaned and re-circulated. An important consideration with any fluid is therefore the ease with which cuttings are released before re-circulation. Again, cuttings release is largely governed by the viscosity and gel strength of the mud, although careful selection of additives is required to ensure the required balance between cuttings suspension and cuttings removal.

**Transmission of hydraulic power to the drilling bit.** Developments in the 1940’s demonstrated the relationship between cutting rate and the velocity of drilling fluid jets exiting the drill bit. By selecting fluid components to ensure that as much hydraulic pressure as possible is dropped across the bit, rather than in other sections of the circulation system, cutting rates may be substantially improved. Pressure drops arising from mud viscosity and friction with the drillpipe and bore walls reduce the available hydraulic power. Thus muds having high lubricity and low viscosity whilst in circulation are sought.

**Minimising formation damage.** Drilling fluids will interact with formations in a number of ways, depending on the composition of the fluid and the nature of the formation. At the most fundamental level, the hydrostatic pressure of the drilling fluid must be sufficient to prevent the ingress of formation fluids into the well, and prevent the wall of the well caving or sloughing. In the majority of cases a weighting agent such as barium sulphate (barite), or occasionally iron sulphate is added to the mud, to give it the required specific density. Heavy brines are also used to give the mud the necessary density. Damage will also occur when the drilling fluid reacts with the formation. This tends to be more prevalent with water based fluids, as the water interacts with salt-bearing and clay formations. The formulation of water-based fluids to minimise such interactions has in part led to the large array of additives available for such fluids. Interactions between oil based muds and formations are significantly reduced (i.e. the muds are more inhibitive), allowing simpler mud formulations with higher technical performance.

**Reducing filtration rate.** The danger of drilling fluid being lost into a formation is particularly important when drilling through porous and permeable formations where the rate of fluid loss (filtration rate) may be excessive. Fluid loss control products are designed to reduce the amount of filtrate lost to permeable formations and to produce a thin filter cake on the hole walls. Polymers in conjunction with bentonite achieve this in water based muds. Oil based muds are naturally inhibitive, and generally do not require such additives. Loss Circulation materials are generally different products designed to prevent or reduce the loss of whole mud to fractures or vugular porosity. Nut Plug, Mica and large flake material (cellophane and paper) are common products. A wide range of additives, ranging from shredded paper to proprietary polymers, are available to reduce filtration rates. Additives with large individual particles will block and fill cavities and pores.
Cooling and lubrication of the drill bit and drill string. Both cooling and lubrication of the drill bit and drill string are important for increased drilling rates, particularly at depth and when drilling at an incline. Heavy hydrocarbon emulsions and even polymer or glass microspheres may be added to water based fluids to increase lubricity, although the inherent lubricity of an oil based mud is significantly greater than can be achieved with a water based mud. Both water and oil are effective at cooling the drill bit. However problems occur when drilling at depth where the operating temperatures may exceed the safe operating limits of the fluid used. High temperature additives are available for water based muds (in particular high temperature polymers used for viscosity and gel strength), but such systems are still limited by the relatively low boiling point of water. Oil based muds can generally be used at higher temperatures.

Buoyancy support of the drill string. Drilling is always carried out with the drill string under tension rather than compression. Part of the role of the drilling fluid, particularly when drilling at depth, is to support some of the weight of the drill string though buoyancy, thus removing some of the strain on the supporting derrick and drilling line.

Corrosion prevention. Oxygen in a drilling fluid, and to a lesser extent hydrogen sulphide, are both responsible for corrosion of well bore casing and drill string components. Additives such as sodium hydroxide are used in water based drilling fluids to increase the pH to 9-10, thus inhibiting oxygen-linked corrosion. Oxygen and sulphide scavengers (e.g. ammonium bisulphate, iron oxide, zinc oxide) are also used.

Data Logging. A variety of instruments are used down-hole to monitor drilling progress. Drilling fluid properties need to be such that logging instruments used are able to accurately function and record the relevant well parameters. An increasing range of logging devices are able to operate within standard muds containing suspended solids. However in some cases there is still the need to use ‘clean’ fluids, usually consisting of solids-free heavy brines (such as zinc bromide).

2.3 BASE FLUIDS

The base fluid of a drilling mud forms the continuous phase in which all other components are carried. As such, the base fluid has a major influence over the properties and technical performance of a mud. Essentially, all muds may be categorised as being either water or oil based. Within these categories there are further distinctions. Water based muds tend to be categorised according to the type of gelling agent used, and according to addition of specific performance-enhancing components such as silicates or glycols. Oil based muds on the other hand are divided into those which use a base oil refined from crude oil, and those synthesised from separate components. Because of the natures of the base fluid types, the composition and performance of water based and oil based muds are very different.

2.3.1 Water Based Muds

On the basis of materials cost, water is always the first base fluid to be considered. Water used for most formulations is inexpensive, and readily available. Seawater based muds, or spuds, are used for the initial stages of the well, making this an exceptionally cheap option. However beyond the initial stages, increasingly tight control is required over the composition and chemistry of the mud, resulting in highly specified formulations. Typically, use of Water Based Muds (WBM) dominates the upper sections of a well, with an estimated use in the bottom well sections of less than 30% (although this varies from operator to operator). WBM’s are also used to a larger extent when drilling exploration wells. Salt, usually potassium chloride, is added to the water to act as an inhibitor for reactive clays, in combination with polymers. It also adds to the weight of the mud. Early water based muds were simple mixes of brine, bentonite (for gel
strength) and barite (for weight). However, there has been an increasing use of other gel strength agents, including lignosulphonates (particularly in the early years of offshore UK drilling) and both natural and synthetic polymers. Although complex in structure, the majority of these polymers are relatively innocuous. In fact many of the polymers used in the drilling industry are comparable with those used for similar purposes in the food industry.

Although water based muds are reasonably well suited to shallow vertical wells, their technical performance has led to difficulties in their use offshore. Interactions with formations (lack of inhibition) are a significant problem, particularly in some regions surrounding the UK. Control of fluid-formation interactions therefore becomes a major aspect of putting together a water based mud formulation, and as different formations are encountered, the formulation needs to be adjusted or changed as necessary. As a result, the available additives for water based muds is extensive (well in excess of 1000 in the UK market), and many are added to the mud on site as required. The use of polymers in water based muds has increased the overall performance regarding formation interactions to a certain extent. Cellulose based polymers have been in wide spread use in bentonite gel muds (for instance CarboxyMethyl Cellulose – CMC), and bentonite free Potassium Chloride/polymer muds (e.g. PolyAcrylic Cellulose – PAC) for some time. Xanthan gum is also widely used. Further improvements have been made with the addition of silicates and glycols to increase inhibition. Typically, these are based on a potassium chloride/polymer mud with around 5% glycol, or 5-6% silicate added. The additive results in a barrier being formed between the mud and the formation, thus increasing inhibition. Typically, a glycol system will be around 20% as effective as an oil based mud, and a silicate system around 60% or so as effective (with a standard water based system being around 5% as effective). Although neither of these technologies are new, the search for an alternative to oil based muds has pushed their development into a technically viable product. Glycol systems have been in use since 1994, and silicate muds have been generally available since 1997.

Although these developments in water based muds allow them to be used as viable alternatives to oil based muds in some circumstances, they still lack the lubricity and thermal stability of oil based systems. The thermal stability of water based systems has increased with the use of high temperature polymers and other additives. However, they are still of limited use in deep wells. Lubricity not only affects the drilling rate in vertical wells, but it is essential in determining the practicality of drilling at inclines away from the vertical. Despite the advances in increasing the thermal stability and inhibition of water based muds, no significant advances have been made in increasing lubricity to the point where wells at a significant incline can be drilled, leaving oil based muds as the only viable option in such cases.

Despite the disadvantages of water based systems over oil based system, their use in the UK has seen something of a resurgence in recent years. As yet there are no discharge limits on water based muds into the environment. Thus where the cost becomes prohibitive of either cleaning cuttings on site or transporting them for treatment or disposal when using oil based muds, water based muds have been seen as an economically viable alternative. With an effective ban on all oil based mud discharges coming into effect in 2001, it is predicted within the industry that the use of water based muds will continue to increase until economically viable methods of using oil based muds are in place and widely available.

2.3.2 Oil Based Muds

Although oil based muds are generally more expensive than water based equivalents, improved technical performance and drilling rates have generally led to them being the more economic option below a given depth. Compared with water based muds, oil based muds give an increased borehole stability, reduced washout, low filtration rates, low formation damage, good high temperature stability, high lubricity, high penetration rates and low corrosion. Because of
the minimal interactions between the base fluid and the formations being drilled, this is
achieved with significantly fewer additives compared with water based systems.

Significant use of oil based muds began offshore in the UK in the 1970’s, with diesel being
used as the main base fluid. This was relatively cheap and highly effective, but was undesirable from
an occupational hygiene viewpoint given the high aromatic compound content of diesel. The
health problems were recognised within the industry, and the use of diesel was phased out in the
early 1980’s, and its use offshore banned in 1984. Following the reduction in diesel use, there
was a gradual move to petroleum-based oils with a reduced aromatic content (Low Toxicity
Mineral Oils, or LTMO’s). Initially these had an aromatic content of around 3% - 5%, although
this has reduced significantly over the years. Since the early 1990’s, increasingly tight
guidelines on the discharge of LTMO on cuttings has led to the introduction and expansion in
use of synthetic oils. This is a description that has never been fully pinned down, but in general
refers to oils that are either not directly derived from crude oil, or are so far removed from their
origin via highly selective refining and cracking processes that they bear little or no connection
to it. Initially, as they weren’t mineral oils, they didn’t come under the same discharge
restrictions. Early synthetic oils were very expensive, and tended to have relatively poor
technical performance (specifically as characterised by their kinematic viscosity). The terms
first and second generation synthetic oils have therefore been coined to differentiate between
these early products, and cheaper, lower viscosity replacements that have subsequently been
introduced.

Although low toxicity mineral oils contain negligible aromatic compounds compared with
diesel, they are still a complex cocktail of hydrocarbons. The development and introduction of
synthetic oils allowed individual hydrocarbons with appropriate properties to be isolated, thus
allowing relatively biodegradable compounds to be used as base oils while eliminating the
general hydrocarbon background indicative of petroleum derivatives. First generation synthetic
base oils included esters, polyalpha olefins, ethers and acetal based fluids. These showed
improvements in biodegradability, biotoxicity and bioaccumulation over low toxicity mineral
oils. Ester, ether and acetal all contain oxygen in the structure, which contributes to active sites,
and thus their biodegradability. The two oxygen atoms in the ester molecule lead to an active
carbon site that is susceptible to either basic or acidic reactants, making it particularly
biodegradable. This, however, has been seen in an adverse light, with fears that rapid
degradation in the marine environment may lead to anoxic conditions. Both ether and acetal
oils show a slower degradation rate. Polyalpha olefins have much in common in their synthesis
and general structure with second generation synthetics, apart from the presence of alkene or
alkane side chains. These have the effect of raising the viscosity of the fluid, and thus lowering
its technical performance.

Second generation synthetic base fluids include linear alpha olefins, internal olefins, linear
paraffins and linear alkyl benzene. Although the introduction of linear alkyl benzene proved
highly successful in 1993, its use was phased out following extensive debates over the potential
for the release of free benzene (although this was not substantiated), together with its failure to
be awarded a category E rating (the least harmful to the environment) under the new Offshore
Chemical Notification Scheme (OCNS) classifications. The three remaining fluids have a
similar linear structure, and correspondingly lower viscosity’s than first generation fluids.
Although linear alpha olefins and internal olefins are obtainable from refining, followed by
purification, those currently in use offshore in the UK are synthesised products. Conversely,
although linear paraffin may be synthesised, those used in drilling muds in the UK offshore
industry are crude oil-derived. This at present forms the nub of the debate surrounding the
definition of a synthetic base oil. The linear paraffin based muds used offshore in the UK are
classed as synthetic based muds, and thus do not come under current mineral oil discharge
legislation. It has been argued that there is no definition of a synthetic base oil which is
stringent enough to distinguish between the source of currently available products. However,
companies not marketing the linear paraffin based mud argue that this is not a problem of definitions, but a problem of erroneous classification. At the heart of the current situation is the fact that the linear paraffin based mud has passed the same biotoxicity, bioaccumulation and biodegradability tests as the synthetic based muds, and therefore it has been argued that it should be included alongside them in the current classification scheme. Whether the same classification is relevant to the occupational health impact of the oil is uncertain. Certainly, the linear paraffin still retains traces of a wide range of other hydrocarbons that are absent from a truly synthetic product. Until the debate is resolved, products such as this derived through distillation and purification from a petroleum source are being termed enhanced mineral oils.

The use of synthetic oils as an alternative for low toxicity mineral oils is likely to be little more than a temporal aberration in an attempt to circumvent operating restrictions. As synthetics started to replace mineral oils, it began to be acknowledged that in many respects their properties weren’t as different to mineral oils as discharge limits appeared to imply. The exception being some ester based fluids, which were unique in not being based on petroleum products (e.g. palm oil), and in showing a significantly enhanced biodegradability over other synthetics. As a result, it was agreed between the industry and the DTI that between 1996 and 2000 oil on cuttings discharges of synthetic oil based muds (excluding esters) would be effectively phased out (a nominal unattainable limit of 1% oil on cuttings will apply from 2001). Whether esters should be included in this is still under debate. However, the overwhelming opinion from within the industry is that from 2001 Low Toxicity Mineral Oil Based Muds (LTMOBM) will be used in total containment drilling operations, and water based muds and ester based muds will be used where total containment isn’t an option.

2.4 DRILLING MUD ADDITIVES

Although the base fluid is important in determining the properties of a drilling mud, its primary role is acting as a carrier for additives that determine the mud's final properties. These allow the mud to be tuned to the formation being drilled, and the downhole conditions. In non-inhibitive water based systems the range, nature and quantities of additives needed to control the muds properties are extensive, with in excess of 1000 products available on the market. As oil based muds are by their nature inhibitive, the range of additives needed is significantly lower, having implications on how the mud is formulated, supplied and used.

2.4.1 Water Based Mud Additives

Although water forms a cheap plentiful base fluid for drilling, in many ways it is less than ideal for use at depth, and in the reactive shales found in many drilling locations around the UK. To compensate for its inadequacies, the list of property-modifying additives available is extensive. There are in excess of 1000 separate additives currently listed by UK drilling mud suppliers. As water based muds need to be modified or changed regularly according to drilling conditions, they tend to be mixed on site, with stockpiles of the most common components kept on the rig. The use of a wide range of trade names for generic products such as barite or bentonite, and many fluid loss additives, leads to the list indicating a greater complexity in the range of available additives than exists in practice. In addition, while agents such as barite and bentonite are used extensively, other agents such as sodium hydroxide, although essential, are used to a lesser degree, and many agents are used in comparatively minor quantities, as specific conditions dictate. Table 1 indicates the major components of a typical bentonite gel water based mud (although exact formulations will vary according to drilling conditions and mud weight required). A KCl/polymer mud would typically consist of a brine made up from around 30-35 pbh KCl, and a polymer such as PAC (PolyAnionic Cellulose) replacing the bentonite and CMC. Glycol and silicate muds are based around polymer muds, with around 5% or so
glycol or silicate added. It is also common to find gypsum and CMC used as the gelling agents in sea water to form an inexpensive mud for upper well sections.

Table 1
Composition of a typical bentonite gel water based mud, density 1300 kg/m$^3$. Components added to 1 barrel of water. (bbl: barrel; ppb: pounds per barrel)

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Mass (kg)</th>
<th>Volume (litres)</th>
<th>% Mass</th>
<th>% Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>1 bbl</td>
<td>159</td>
<td>158.99</td>
<td>65.33</td>
<td>84.92</td>
</tr>
<tr>
<td>Bentonite</td>
<td>20 ppb</td>
<td>9.1</td>
<td>9.07</td>
<td>3.73</td>
<td>4.85</td>
</tr>
<tr>
<td>Caustic Soda</td>
<td>0.5 ppb</td>
<td>0.23</td>
<td>0.22</td>
<td>0.09</td>
<td>0.12</td>
</tr>
<tr>
<td>Soda Ash</td>
<td>0.5 ppb</td>
<td>0.23</td>
<td>0.10</td>
<td>0.09</td>
<td>0.05</td>
</tr>
<tr>
<td>High Viscosity CMC</td>
<td>1.5 ppb</td>
<td>0.68</td>
<td>0.47</td>
<td>0.28</td>
<td>0.25</td>
</tr>
<tr>
<td>Low Viscosity CMC</td>
<td>3.5 ppb</td>
<td>1.59</td>
<td>1.09</td>
<td>0.65</td>
<td>0.58</td>
</tr>
<tr>
<td>Barite</td>
<td>160 ppb</td>
<td>72.58</td>
<td>17.28</td>
<td>29.82</td>
<td>9.23</td>
</tr>
</tbody>
</table>

Additives may be broadly grouped according to function, although the application of some chemical groups is so diverse that it is more appropriate to group them separately. The major groups are covered below, and broadly follow the functional categories used in offshore chemical usage and discharge returns (maintained on behalf of UKOOA and DTI by SCOPEC).

Weighting agents. Weighting agents are added to both water based and oil based muds to provide sufficient hydrostatic head to match formation pressures. By far the most prevalent agent is barium sulphate (barite). This is an extremely insoluble solid, with a specific gravity of 4.2. Finely divided, it can be added to both water based muds and oil based muds at up to 1800 kg/m$^3$ (630 ppb) to give mud densities of over twice that of water alone. Calcium carbonate (specific gravity 2.65) is also used to a limited extent, and very occasionally hematite (iron oxide) is used. The proportion of barite in the mud is continuously monitored to ensure hydrostatic pressure is slightly higher than formation pressure, but low enough to prevent fracturing of the formation.

Inorganic gelling products and viscosifiers. Clays added to water based drilling fluids (primarily bentonite) play a key role in determining viscosity, gel strength and filtration rate. The interaction between the water, clay particles and salts in the mud are complex, and play a major role in determining the properties of a specific formulation. In the presence of sodium ions, clay particles will disperse in the water. When fully dispersed, the particles give the mud a low gel strength, but allow the formation of a firm filter cake, thus reducing the filtration rate. If the particles are allowed to flocculate, gel strength increases, but filter cake efficiency reduces. By introducing high concentrations of calcium ions to the mud, the clay platelets form into smaller aggregates, that may flocculate or deflocculate to give similar properties as before. Other ions such as magnesium, potassium and ammonium may be added to alter further the properties of the clay suspension, and the formation. In this way, the properties of the water based mud, and its reaction with formations (particularly shales) are controlled. Where formation salts (or mud salts added for other purposes) lead to flocculation with bentonite, attapulgite clay is occasionally used as an alternative. Although early bentonite muds used the clay alone to give the correct gel properties, it is now more common to find the addition of an organic polymer such as CMC (see below, and table 1). In the upper stages of a well where mud composition isn’t critical it is also common to find gypsum used as a gelling agent, again usually with an organic polymer such as CMC. In a typical water based mud bentonite will be added at around 20 ppb (pounds per barrel)
Alkaline chemicals. Drilling muds are usually held in an alkaline condition (≈ pH 8 – 12.5) to stabilise clay suspensions, improve the solubility of various additives, and reduce corrosion of the drill pipe and casing. In a normal water-based mud, sodium hydroxide is added to maintain alkalinity (either as a solution, powder or pellets). In muds with a high calcium concentration, calcium hydroxide is used (in powder form) to maintain both pH and calcium concentration. In certain polymer muds, where both calcium and sodium ion concentrations are kept low and the dominant salt is potassium chloride, potassium hydroxide is used. In a bentonite mud, sodium hydroxide will be added at around 0.5 ppb.

Salinity chemicals. Inorganic salts are added to water-based muds to form brines which control the properties of suspended clay and formation clays, and prevent the dissolution of formation salts. Sodium chloride is used frequently in bentonite systems. However, in the UK offshore industry the majority of brines are potassium chloride based. In particular, polymer based muds are usually formed using a KCl brine. The KCl added to a KCl/polymer mud is around 30-35 ppb. In areas where formations have a high salt content (particularly in the southern sectors of the North Sea), saturated brines are used to prevent significant washout and fluid loss.

Lost circulation material. When large amounts of drilling fluid are lost into the formation, either through existing pores or voids, or through induced fractures, measures are taken to reduce the loss rate. In many cases, this takes the form of introducing solid material to the drilling fluid that will effectively plug the points in the formation where losses are occurring. A diverse range of materials are used, including crushed nut shells, shredded cellophane, graded calcium carbonate particles and diatomaceous earth. Most are supplied and added in a solid form as either a fine or coarse powder, or coarse fibres.

Defoamers. Foaming in drilling muds ranges from being a nuisance, (e.g. during mixing) to being a severe hazard when the release of formation gas is impeded. Lowering gel strength reduces the degree of foaming encountered, but will often compromise the cutting support and removal properties of the mud. The addition of defoaming agents such as aluminium stearate and alkyl phosphates is therefore used to eliminate the problem. Defoamers based on silicones and polyalcohols are also used, but are more commonly applied during production. Required treatment concentrations vary between 0.03 – 3 kg/m³.

Biocides. Biocides may be incorporated into starch and cellulose based polymers to prevent biodegradation or, more commonly, to prevent the growth of sulphate reducing bacteria (particularly in mud left behind casing during cementing, and in producing formations). In the past, the predominant biocide used has been glutaraldehyde. However, given its toxicity, most suppliers of drilling fluids are either replacing its use with safer alternatives or actively looking for alternatives, and generally reducing the biocide levels used during drilling. In general, a biocide will now only be added to a mud as necessary, for instance to a pill of fluid that will remain stationary for some time, rather than as a basic mud component.

Corrosion Inhibitors. Corrosion of the drill string and drill casing while using water-based muds is primarily caused by the presence of dissolved oxygen. In many cases this is controlled by maintaining fluid pH between 9 – 10, often with the addition of lime, sodium hydroxide or potassium hydroxide. Oxygen scavengers, which actively remove dissolved oxygen, may also be used. These are all forms of sulphates, which react with dissolved oxygen (e.g. ammonium bisulphate). Their use is not widespread during drilling, however, possibly as oxygen is introduced into the drilling mud each time it is circulated through the surface facilities. Hydrogen sulphide can also present severe problems at times, either due to release from formations, as a by-product of mud decomposition, or from sulphate-reducing bacteria. By maintaining the mud in an alkaline state, most of the sulphide is contained as soluble bisulphide ions. However, a drop in alkalinity will then result in the release of hydrogen sulphide. In this case sulphide scavengers such as iron oxide, zinc carbonate and zinc oxide are used to remove
both the gas and the bisulphide from the mud. The resulting metal sulphides are extremely insoluble, but will release hydrogen sulphide in the presence of a strong acid.

**Scale Inhibitors.** Scale inhibitors are occasionally added to water based muds to prevent the precipitation of calcium carbonates on surfaces within the circulation system. Typically, phosphate esters, phosphonates and a range of synthetic polymers are used in low concentrations to interfere with the crystal structure of scale deposits, thus inhibiting growth.

**Drilling Lubricants.** As well as sulphonated asphalts, a range of other heavy hydrocarbon emulsions are used in water based muds to reduce friction. Most of these are processed to remove aromatic and naphthenic compounds. Fatty acids, fatty acid salts and triglycerides are also used to improve lubricity. Microspheres of either glass or organic polymers are alternatives used to reduce downhole friction.

**Pipe release agents.** Differential sticking occurs where a positive pressure differential between the drilling mud and a formation leads to a static drill pipe to become embedded in the well wall. Pipe release agents may be delivered as a plug or pill of fluid (spotted) to the point of sticking to penetrate between the drill pipe and the formation, break up the filter cake, and lubricate the contact, thus allowing the pipe to be pulled free. The spotting fluid almost always contains an invert emulsion to give the necessary lubricity. It also requires a high level of detergency to break down and penetrate the filter cake. Emulsifier agents may be fatty acid salts, sulphonates and modified asphallic materials.

**Emulsifiers.** Emulsifiers are predominantly added to water based muds to disperse small amounts of oil, which arise from the formations being drilled or are added to increase lubricity. Water based mud emulsifiers are predominantly water soluble, and include fatty acids, sulphonates and polyoxylates.

**Shale inhibitors/encapsulators.** Polyacrylic type polymers and copolymers and some asphalt products are used to control and prevent interactions between shales and the drilling fluid, and are covered below. Potassium chloride is also widely used as a shale control agent.

**Thinners.** Chemicals added to water based muds to reduce the interaction between clay particles and platelets, and thus reduce viscosity and gel strength, include lignosulphonates, lignites and polyphosphates. Of these, the lignosulphonates and lignites dominate, as polyphosphates react with calcium and magnesium ions in hard and saline muds.

**Dispersants.** The term dispersant is used for a variety of water based mud chemicals that have different functions. However, in all cases, the role of the agent is to disperse or separate particles or droplets within the mud. Perhaps most commonly, the term is used to describe chemicals used to disperse clay particles and platelets (thinners), such as lignosulphonates and various salts. The term is also used for emulsifiers (see above).

**Lignosulphonates.** Lignosulphonates and modified lignosulphonates were widely used as dispersants within water based drilling muds in the 1970’s and 1980’s. Derived from the complex polymer lignin that occurs naturally in wood, they are a by-product of the sulphite paper manufacturing process. The precise nature of the lignosulphonates depends on the source wood pulp, and the resultant processing of the initial sulphonates. Soluble sulphonates are partially precipitated by lime to form calcium sulphonates, which are soluble enough to be used directly in drilling muds. Further processing to give iron, chrome, sodium, potassium and aluminium salts of many lignosulphonate low molecular weight copolymers may be used to increase solubility and develop specific properties.
Sometimes referred to as thinners, lignosulphonates aid clay particles to deflocculate by neutralising charges at the edges of the clay platelets. The resulting bonding between the lignosulphonate and the clay platelet is strong enough to result in an insoluble unit. Other chemicals may also be used as dispersants at low concentrations (e.g. sodium chloride and tannin), but become ineffective at high concentrations, or high salinity. Lignosulphonates are also used as emulsifiers, where they will form a semi-rigid film around oil droplets. The emulsion is difficult to break, and can increase viscosity and reduce fluid loss.

Chrome lignosulphonates were at one time widely used within water based drilling muds, but have largely been superseded by chrome-free lignosulphonates. Relatively few lignosulphonates are presently used in water based muds.

Lignite base chemicals. Lignite is a form of brown coal. The most common form, leonardite, is naturally oxidised on contact with air or oxygen-containing water near its surface to form humic acids (complex organic materials containing phenolic and carboxylic acid structures). These have only limited water solubility, and can help reduce fluid loss. By reacting the lignite with a base such as sodium hydroxide, they are converted to water soluble salts. Water solubility may also be increased by forming sulphonates or sulphonmethoxylates. In both cases, these soluble derivatives are primarily used as thinners (dispersants) to counter the viscosifying and gelling nature of clays.

Polymers. A wide range of naturally occurring and to a lesser extent synthetic polymers are used in drilling fluids, for a variety of functions. Polysaccharides such as starch (and derivatives), guar gum and xanthan gum are used extensively as viscosifiers. Both starch and guar gum, extracted from plants, exhibit thermal and biological decomposition, and are generally restricted to shallow drilling, with the presence of a biocide. Xanthan gum is produced by bacterial action on natural carbohydrates and acts as a very effective viscosifier at low concentrations.

Carboxymethyl cellulose (CMC) and Hydroxyethyl cellulose (HEC) are derived from naturally occurring cellulose, and their properties depend on the source of cellulose used. CMC is usually formed by reacting sodium hydroxide with cellulose to form the sodium salt. The resulting anionic polymer adsorbs strongly to bentonite particles, and thus acts as a fluid loss reducer. It is also an effective viscosifier, although becomes ineffective at higher temperatures. Low viscosity CMC is often used to reduce fluid loss without increasing viscosity significantly. HEC is similar, apart from solubility being retained by reacting the OH groups within the cellulose with ethylene oxide. The resulting polymer is non-ionic, so its properties are affected much less by salts. Formulations relying on a polymer additive alone for gel strength tend to use PolyAnionic Cellulose (PAC) in a KCl brine.

The diversity of synthetic polymer constructions has allowed the formulation of a range of function-specific additives. Key monomers include acrylonitrile, acrylamide, acrylic acid, polyvinyl alcohol, polyvinyl methyl ether, polymaleic acid and polyethylene oxide. Resulting polymers and copolymers are however as diverse as the reaction process used. Early polymer based muds used in the UK offshore drilling industry used PHPA (partially Hydrolysed Polyacrylamide polymer). However, indications are that the use of synthetic polymers in drilling fluids in the UK is currently not widespread.

The use of polymers in place of clays to provide gel strength has increased since the late 1970’s. Early systems used polymers such as xanthan gum or PHPA in a KCl brine. More recently typical KCl polymer muds have relied on PAC. As the polymers used perform the same function as those used in the food industry for giving products viscosity and gel strength, there is significant overlap between the industries, resulting in most mud polymers being non-toxic.
(via ingestion). The majority are not classifiable under CHIP, with the only applicable health warning being a nuisance dust warning.

**Asphalt base products.** Asphalts are highly complex hydrocarbons which are naturally occurring, and a by-product of petroleum refining. They can be added to water based muds to reduce shale reactivity. Blowing air through asphalts (air-blown asphalts) increases the content of asphaltenes – hard, crystalline materials – and forms a product widely used to reduce fluid loss in oil based muds. Reacting asphalts with sulphuric acid produces sulphonated asphalt, which can be neutralised to give sulphonate salts. These are easily dispersed in water, and act as a lubricant, reducing downhole friction. Gilsonite, a similar material to asphalt, is also added to water based muds to reduce fluid loss and stabilise reactive clays.

Asphalt products appear to be used relatively infrequently in large quantities within drilling muds at present, although they have been used extensively in the past.

### 2.4.2 Oil Based Mud Additives

As oil based mud systems are naturally inhibitive, the range of chemical agents added to achieve specific properties is much reduced compared to water based systems. An oil based mud as used offshore in the UK typically consists of a base oil, brine (at least 10%, but more usually 30%-40%, and occasionally up to 50%), primary and secondary emulsifiers, a viscosifier, a fluid loss control additive and a rheology modifier. Other components may be added in small quantities to deal with specific conditions. The role of specific components such as the

<table>
<thead>
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<th>Component</th>
<th>Quantity</th>
<th>Mass (kg)</th>
<th>Volume (litres)</th>
<th>% Mass</th>
<th>% Volume</th>
</tr>
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<tr>
<td>Base fluid</td>
<td>0.52 bbl</td>
<td>63.64</td>
<td>83.31</td>
<td>30.37</td>
<td>52.40</td>
</tr>
<tr>
<td>Viscosifier</td>
<td>5 ppb</td>
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<td>1.08</td>
<td>0.88</td>
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<tr>
<td>Emulsifier 1</td>
<td>0.8 gpb</td>
<td>2.89</td>
<td>3.02</td>
<td>1.38</td>
<td>1.90</td>
</tr>
<tr>
<td>Emulsifier 2</td>
<td>0.4 gpb</td>
<td>1.49</td>
<td>1.51</td>
<td>0.71</td>
<td>0.95</td>
</tr>
<tr>
<td>Lime</td>
<td>5 ppb</td>
<td>2.26</td>
<td>1.00</td>
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<td>0.63</td>
</tr>
<tr>
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<td>47.22</td>
<td>22.50</td>
<td>29.70</td>
</tr>
<tr>
<td>CaCl₂</td>
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<td>13.70</td>
<td>3.35</td>
<td>6.54</td>
<td>2.11</td>
</tr>
<tr>
<td>Barite</td>
<td>167.9 ppb</td>
<td>76.15</td>
<td>18.16</td>
<td>36.34</td>
<td>11.42</td>
</tr>
</tbody>
</table>

emulsifiers changes from supplier to supplier, with some also encompassing secondary roles such as fluid loss control. Table 2 indicates the main components of what may loosely be called a typical oil based mud. However, this will vary from supplier to supplier, as the various components are engineered to impart different properties to the mud. The formulation will also be adjusted to specific drilling conditions. Unlike water based muds, oil based muds are supplied ready mixed as a ‘package mud’ (although they may occasionally be made up offshore from the base oil, water and chemical additives. Consequently, additives for a particular mud will be specific to that system, resulting in all components (bar some bulk standard chemicals) being sourced from a single supplier. This has arisen in the main from the need for additives to be base oil-specific, although the current Offshore Chemical Notification Scheme (OCNS) also
requires oil based mud packages to be treated as a complete system. The situation is also aided by a single oil based mud formulation being sufficiently inhibitive to be applicable to a wide range of formations. The exact formulation of the mud will still depend on downhole conditions, with the supplied mud being mixed to the correct formulation prior to shipping. The major functional groups of additives in oil based muds are outlined below:

**Base Oil.** Although early oil based muds used diesel, base oils used within the UK offshore industry are currently exclusively formulated with either low toxicity mineral oils or synthetic oils. The low toxicity mineral oils tend to have broadly similar properties from one source to another, and in general a LTMOBM may be formulated with oil from one of a number of sources (appendix 2 of the OCNS List of Notified Chemicals lists approved low toxicity mineral oils for inclusion in OBM formulations). However the flash point of LTMO’s may vary from over 100°C to less than 80°C, and this may have significant impact on health and safety implications as the lower flash point oils will produce more fumes as well as presenting an increased fire risk. Synthetic base oils are highly specific individual products, and are less easily interchangeable. In general, a synthetic oil based mud package will be designed around one base oil. Initial Synthetic Oil Based Muds were based around esters, ethers, polyaromatic olefins and acetals. Of these, the first ester based mud (Petroleum) was claimed to be the only true synthetic product, being derived from palm oil rather than being petroleum based. Second generation synthetic base oils include linear alkyl benzene (LAB), linear alpha olefins, internal olefins and linear paraffins. LAB-based muds were used extensively on their introduction to the industry, given the low cost and high performance. However concern over the potential release of free benzene, although not seen by many as a realistic occurrence, resulted in them being phased out.

**Brines.** Most UK offshore oil based drilling muds are an invert emulsion of brine in oil, with the brine accounting for between 10% and 50% of the total oil volume. The proportion of brine has tended to increase from the introduction of early invert mud systems in the UK as higher performance emulsifiers have been developed. Inclusion of brine minimises interactions between the mud and formation clays and salts, together with adding density to the mud. The emulsion also tends to have a higher viscosity than either the oil or brine alone, thus increasing cutting carrying capacity. In most instances, potassium chloride is used to form the brine. However if formations are expected to contain specific salts, saturated solutions of those salts will be used.

**Weighting materials.** Weighting materials used in oil based muds are essentially identical to those used in water based muds – barite being the main agent. As in water based muds, up to 630 ppb may be added to the fluid to achieve the desired density.

**Lost circulation materials.** Again, many lost circulation materials commonly used with water based systems are used with oil based systems.

**Inorganic gelling products.** Both bentonite and montmorillonite clays can be used as gelling agents in oil based muds. However, they must first be reacted with organic amines to make them dispersible (organophillic). The amines are usually composed of carbon chains with between 12 – 18 atoms, and frequently they will be quaternary ammonium salts.

**Alkaline chemicals.** Lime is generally added to oil based muds to increase pH, minimising corrosion and converting some additives into oil soluble forms. Lime is used in preference to sodium hydroxide due to the high calcium content in the brine.

**Lignites.** Lignite-based chemicals are used in oil based muds for fluid loss control (leonardite is reacted with long chain amines or quaternary amines). These materials also help to stabilise invert emulsions as a secondary property.
Emulsifiers, detergents. Many oil based mud packages use a system of two emulsifiers to ensure a stable invert emulsion as the mud is contaminated by cuttings and formation fluids. Common primary emulsifiers include fatty acids, rosin acids and their derivatives. Secondary emulsifiers act to improve emulsion stability, particularly at high temperatures. They also act to oil wet the cuttings, thus ensuring good suspension and transport. Amines, amides, sulphonic acids alcohols and related copolymers are all used as secondary emulsifiers.
3 TRENDS IN MUD USE

3.1 LEGISLATIVE AND VOLUNTARY FRAMEWORK

Since the inception of the UK offshore drilling industry, chemical usage has been influenced by both Workplace Health and Safety, and Environmental legislation. Containment of hazardous substances offshore was initially covered by the Mineral Workings (Offshore Installations) Act 1971, with more general workplace practices being governed by the Health and Safety at Work Etc. Act 1974. The containment and use of chemical agents onshore was further tightened up by the introduction of the Control of Substances Hazardous to Health Regulations (COSHH) in 1988, and the Chemicals (Hazard Information and Packaging for Supply) (CHIP) regulations in 1996. Although it wasn’t until January 1995 that COSHH was applied offshore, many offshore operators were working along the same principles of COSHH well before this.

General Health and Safety legislation has laid down the basis for controlling exposure to hazardous substances and assessing the risks associated with their use. However, it has played a relatively small role in determining the selection of chemicals used downhole. Perhaps its greatest influence was in the restrictions placed on the use of diesel as a base drilling oil in the 1980’s. This was driven by the need to reduce worker exposure to the hazardous aromatics in diesel, as well as environmental concerns, and led to the implementation of low aromatic content oils, or Low Toxicity Mineral Oils.

Apart from the removal of diesel from drilling operations, the major changes in the chemicals used downhole since the late 1960’s have been driven by concerns over the environmental impact of operations. In 1979 a voluntary Offshore Chemical Notification Scheme (OCNS) was set in place whereby chemical usage and discharge were monitored, and substances graded between 0 and 3 according to their environmental impact; a category 0 substance being the most benign. In 1982, following concern over the environmental impact of discharging oil-coated cuttings, discharge guidelines were introduced of 5 g diesel per 100 g cuttings, and 15 g Low Toxicity Mineral Oil per 100 g cuttings. In 1988 the discharge limit for low toxicity oils was consolidated at 150 g per 1 kg of cuttings, leading to the search for unregulated alternatives, and the development of synthetic oil based drilling systems. This discharge limit for LTMO’s has been decreasing steadily - 100 g/kg cuttings for exploration, development and appraisal wells in 1992, 10 g/kg cuttings for exploration and appraisal in 1994 and 10 g/kg for all drilling operations in 1997. As this is practically unachievable, there has been an effective ban on mineral oil mud discharges since 1997. Up to this point there was a guideline discharge limit of 100 g/kg for synthetic bases muds. Following concerns that synthetic oils were having a similar effect on the environment as mineral oils, agreement was reached between industry and the DTI to reduce the discharge of synthetic based muds on cuttings by 25% per year between 1996 and 2000 to 10 g/kg (effectively stopping the discharge of synthetic based muds). Esters have so far been excluded from discharge limits as they show significantly increased biodegradability over other synthetic oils. Recent tests have indicated their effect on the environment to be comparable to other oil based muds. However, suppliers are arguing that the tests are misleading. Further tests are therefore being conducted, and it is still unclear whether a discharge limit will be applied to ester based muds.

Alongside discharge limits, the current Offshore Chemical Notification Scheme effectively restricts the use of chemicals that are indicated to be harmful to the environment. Substances that are deemed to pose little or no risk to the environment, as listed in the Oslo and Paris convention for the protection of the marine environment of the north-east Atlantic (OSPAR, previously known as PARCON), may be used freely. However substances not on this list are required to be tested for aerobic and anaerobic biodegradation, bioaccumulation and toxicity
tests to algae and zooplankton. If the substance is soluble, it is tested against fish, and if it is likely to end up on the seabed, it is tested against a sedimentary re-worker. Individual components of drilling muds are tested, and because of the package nature of oil-based mud systems, complete systems with the 'worst case' balance of components are also tested. In the current Offshore Chemical Notification Scheme, brought into play in 1994, agents are subsequently graded from A to E, with A being the most harmful to the marine environment, and E the least harmful. As the scheme is currently voluntary, this classification does not in itself present a restriction on the use of certain chemicals. However, the classification is used extensively by operators and the DTI in allowing or approving the use of specific chemicals. Before any drilling operation, approval is sought from the DTI, including approval of the drilling mud schedule (which is calculated in advance from lab tests on the formations to be drilled). At this stage justifications on technical grounds need to be given for the use of non-category E chemicals. As a result, operators are in the habit of specifying the use of category E chemicals alone in drilling operations. This approach has been recognised as being potentially harmful by the DTI, where the substitution of an A or B category substance by a category E substance that is used in significantly larger quantities to achieve the same effect, may be detrimental to the environment. As a result, guidance has been circulated to this effect. However, from the perception of the suppliers, operators are still avoiding the use of non-category E substances. This may change as an approach based on environmental risk assessment is explored in more depth. A model to predict the environmental hazard and risk of chemical usage offshore (CHARM) is currently under development in consultation with all interested parties. If successful, this should in principle move the emphasis away from hazard, and towards risk, and could form the basis of assessing operations in the future. However the is a degree of scepticism within the supply industry as to how effective the model will be in practice.

In August 1998 an additional Z category was added to the OCNS classification scheme. This refers to chemicals that will be used in zero discharge operations (resulting in no release to the environment), and does not require the usual battery of environmental impact tests. In the current list of notifiable chemicals, there are no category Z agents. However, it is predicted that in the next release of the list, a significant number of chemicals and mud systems used in zero discharge operations will be included in this category. In particular, low toxicity mineral oils that are currently stockpiled and not classified under the current scheme are likely to be assessed as category Z substances (these oils are likely to reflect the list of LTO's given in appendix 2 of the OCNS list of approved chemicals). It is worth noting that in these classifications, impact on occupational health has no bearing.

As a adjunct to the OCNS, the usage and discharge of all chemicals used offshore have been voluntarily recorded and reported since 1994. The scheme, run jointly by the UK Offshore Operators Association (UKOOGA) and DTI, is managed by the company SCOPEC, and collates all well completion records on chemical usage and discharge offshore. As the scheme is currently voluntary, it can not be relied on as an accurate indicator of chemical usage. However, the general consensus is that it gives a reasonable estimation of substance use, with the discharge figures being perhaps slightly less reliable.

Under the Paris and Oslo Convention, discharge limits are due to become mandatory in the year 2000. However, the mechanisms by which this will come about and operate within the UK are by no means clear.

3.2 HISTORICAL USAGE

The composition of drilling muds used offshore around the UK has largely been driven by technical necessity and environmental impact. The first well drilled in UK waters was in 1964,
although it wasn’t until the early 1970’s that significant drilling began. Up to the mid 1970’s most activity was concerned with exploration. Without the time and cost constraints of drilling production wells, operators could afford to use inexpensive but ‘slow’ water based mud systems. Traditional muds relying predominantly on bentonite (and lignosulphonates) as gelling agents were commonly used. As wells became deeper however, and difficult formations were encountered (particularly in the Forties), the use of inhibitive mud systems became increasingly necessary. Encapsulating polymers (starch, CMC, HEC, PHPA) were added to bentonite muds and used as gelling agents in KCL/polymer muds as the need for inhibitive systems increased. The use of diesel based muds as an inexpensive and technically superior alternative also began to increase, until at the end of the 1970’s the estimated split between diesel and water based muds was around 70:30. Despite the technical advantages of using diesel, resulting from its inhibitive qualities and its high lubricity, the impact on its use to operator health was reportedly severe, leading to an industry-led phasing out of its use in the early 1980’s, and its eventual ban in 1984. In a push to find a safer alternative, mud companies started to introduce muds based on low aromatic content Low Toxicity Mineral Oils.

Drilling mud usage through the 1980’s was dominated by LTMO systems, with the aromatic content reducing as new base oils were found. As the market for drilling mud oils is small compared to other petroleum product markets, these tended to be selected from products designed for other markets. In the search for ‘cleanliness’ it has been remarked that a number of food grade oils have been used. However, the late 1980’s saw increasing concern over the environmental impact of using oil based muds, dominated by the lack of biodegradation and dispersion into the sea. Discharge limits of 15% were placed on the LTMOBM solids content of cuttings in 1988. As the discharge limits on low toxicity oil based muds were tightened through the early 1990’s, there was an increased push to find alternative base fluids that escaped the limits imposed. The result was the introduction of so-called pseudo- or synthetic base oils in the early 1990’s. In essence these were oils that were either so highly refined that they bore little resemblance to their petroleum origins; oils commercially synthesised to give precisely controlled compositions; or oils that were derived from a non-petroleum source (such as the palm-oil based esters). There is still debate over the exact definition of a synthetic base oil. However the presently held view is that any oil that passes current DTI marine toxicity and bioaccumulation tests is treated as a synthetic base oil.

Changes to the base oils used in muds, changes were also made to the emulsifier packages. Early systems relied heavily on fatty acid emulsifiers and amine treated lignites to give a stable oil/brine invert emulsion. On the introduction of low toxicity mineral oils, the same emulsifiers were used. However, in the late 1980’s there was a move to more polymeric emulsifiers and lower oil/brine ratios in muds. The introduction of synthetics in essence kept the same emulsifier packages (although improvements are continually being made), with the solvent simply being changed to suit the base oil. The general feeling within the mud supply industry is that there have been few significant changes in emulsifiers made for over a decade.

Also coinciding with the shift away from low toxicity mineral oils was an increased effort to find viable water based mud alternatives. 1991 saw the first use of glycol as an additive to KCl/polymer muds (up to 15%) to increase inhibition, with their use increasing steadily in the late 1990’s. These were followed in the mid 1990’s with silicate containing water based muds (around 6% sodium silicate added). Trials were started around 1993/94, with general use in the field from around 1997. Both glycol and silicate water based muds improve the inhibition of the mud, with glycol achieving around 20% of the performance of an oil based mud, and silicates around 60%. However, their lubricity is only marginally greater than that of a more standard water based mud.

Gaining a clear picture of trends in mud usage is complicated by the incompleteness and disparity of available records. Since 1994, downhole chemical use and discharge has been
reported on a voluntary basis, and provides a valuable record of both quantities used and trends in usage. However, as the record is voluntary, it is both incomplete and inaccurate. Chemical names and functional groups tend to be mis-reported in the records (particularly if a component has multiple functions), making a quantitative analysis of chemical types impractical. However, it is possible to draw out indicative data on generic mud types from the data. Figure 1 gives an estimate of drilling mud use in the UK offshore drilling industry between 1994 and 1998, based on returns made to SCOPEC. Figures for low toxicity oil based muds and synthetic based muds are reasonably accurate, as the muds are supplied ready formulated, minimising the risk of recording errors. However, as the majority of water based muds are formulated from their constituent parts on the rig, there is no direct method of extracting their levels of use from the data. An estimate of water based mud use has therefore been made by assuming that where brine is recorded separately, it was used exclusively as the continuous medium for this mud type. Weighting agents were assumed to be reported for use in any mud type, and were therefore not included on the figures presented. Despite the qualitative nature of the information, there is a clear trend in the increased use of synthetic based muds, with a corresponding decrease in the use of low toxicity oil based muds. Interestingly, there is evidence for an increase in the use of water based muds before a significant increase in synthetic usage. This agrees with a perception within the mud supply industry of water based muds being used to fill the ‘gap’ between increasingly tighter discharge limits on synthetic muds, and the current scarcity of zero discharge options for low toxicity oil based muds.

Mud usage data before 1994 are available in the capping off reports of each well drilled, and are kept by the mud companies. The accessibility and informativeness of these records is variable — many are archived as paper records, and any analysis of mud use per well would be prohibitively time consuming. Figure 2 presents representative data of historic mud usage compiled from data supplied by UK mud companies. General trends within the industry are clear. Figure 2 demonstrates the dominance of water based mud systems before 1980. No substantial oil based mud use is indicated prior to this, which is at variance with some verbal information. However, data prior to 1980 are incomplete, and it is likely that the use of diesel between 1970 and 1980 is significantly underestimated. The significance of low toxicity mineral oil based muds in the 1980’s is apparent. 50:50 muds refer to the low oil/brine ratio muds that were used following the introduction of more polymeric emulsifier packages. It isn’t
until 1994/5 that synthetic based muds begin to make a significant appearance, tying in with the usage data in figure 1. Figure 2 also shows the slight increase in water based muds coinciding with the phasing out of low toxicity oil based muds around 1997 that is seen in figure 1.

![Bar chart showing mud usage from 1972 to 1998](chart.png)

**Figure 2**

Historical mud usage data 1972 – 1998, compiled from data supplied by the UK mud supply industry.

The above data do not cover the use of brines (as opposed to brine-containing muds) downhole. These are used primarily as completion fluids, to give a solids-free environment where logging can be conducted effectively. If detailed logging is required during drilling, they may also be used as a pill within a drilling mud. In deep wells, the specific gravity of the brine must be sufficient to ensure well stability, and thus heavy salts such as ZnBr are used. These are unpleasant to handle, and in recent years alternatives have been sought. Advances in logging technology have overcome many of the problems associated with logging within a mud, thus enabling a move away from brines to drilling fluids weighted with solids. Heavy formates (e.g. caesium formate) are also being explored. Thus although heavy brines are still used, they appear to be on the decline.

Biocide use within water based drilling muds has also seen a decline from the 1970’s and 1980’s, following increasing recognition of the toxicity of substances such as glutaraldehyde. The approach taken to biocide use over the years appears to have changed. Whereas at one time they were treated as an integral component of some muds (in particular those using starch or cellulose polymers), at present they tend to be used as and when necessary. They are still used extensively during completion and production, although use during drilling now appears to be minimised. Of the mud supply companies active in the UK, some are not supplying glutaraldehyde anymore, and those that are supplying it are actively looking for alternatives.

### 3.3 CURRENT USAGE

Drilling mud usage offshore in the UK is currently in a state of flux, and lies somewhere between the trends shown in the historic data, and the predictions made for future usage. From the SCOPEC usage returns, around 40% of drilling in 1998 has been carried out using water based systems, 45% with synthetic oil based systems, and 5% with low toxicity mineral oil based muds.
<table>
<thead>
<tr>
<th>Mud Component</th>
<th>Reported component usage (KiloTonnes)</th>
<th>% Usage 1998</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weighting Agents + Inorganic Gelling Agents</td>
<td>116.0026</td>
<td>161.8271</td>
</tr>
<tr>
<td>Brine, or brine salt</td>
<td>34.8647</td>
<td>38.3483</td>
</tr>
<tr>
<td>Oil Based Mud + Additives</td>
<td>36.2798</td>
<td>41.7314</td>
</tr>
<tr>
<td>Synthetic Based Mud and Additives</td>
<td>6.2600</td>
<td>9.3547</td>
</tr>
<tr>
<td>Water Based Mud + Additives</td>
<td>5.9859</td>
<td>7.5916</td>
</tr>
<tr>
<td>Gel</td>
<td>4.5337</td>
<td>5.5317</td>
</tr>
<tr>
<td>Lost Circulation Material</td>
<td>1.8982</td>
<td>1.8023</td>
</tr>
<tr>
<td>Shale Inhibitor/Encapsulator</td>
<td>2.7730</td>
<td>2.3598</td>
</tr>
<tr>
<td>Polymeric Viscosifiers and Fracture Reducers</td>
<td>1.8909</td>
<td>1.9209</td>
</tr>
<tr>
<td>Fluid Loss Control</td>
<td>1.2569</td>
<td>1.0479</td>
</tr>
<tr>
<td>Viscosifier</td>
<td>1.1320</td>
<td>1.1372</td>
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<tr>
<td>Emulsifier</td>
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</tr>
<tr>
<td>Carrier Solvents</td>
<td>0.5802</td>
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<tr>
<td>Detergent/Cleaning Fluids</td>
<td>0.3189</td>
<td>0.3797</td>
</tr>
<tr>
<td>Drilling Lubricants</td>
<td>0.4217</td>
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<tr>
<td>Corrosion Inhibitors</td>
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<tr>
<td>Asphalts and asphalt based products</td>
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<td>0.0452</td>
</tr>
<tr>
<td>Oxygen Scavenger</td>
<td>0.0807</td>
<td>0.1966</td>
</tr>
<tr>
<td>Gas Treatment</td>
<td>0.0092</td>
<td>0.0335</td>
</tr>
<tr>
<td>Lignosulphonates/Lignites</td>
<td>0.0637</td>
<td>0.0606</td>
</tr>
<tr>
<td>Dispersant</td>
<td>0.0622</td>
<td>0.0773</td>
</tr>
<tr>
<td>Biocides</td>
<td>0.0345</td>
<td>0.0371</td>
</tr>
<tr>
<td>Scale Inhibitor</td>
<td>0.0894</td>
<td>0.0255</td>
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<tr>
<td>Defoamers</td>
<td>0.0440</td>
<td>0.0384</td>
</tr>
<tr>
<td>Thinner</td>
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<td>0.0369</td>
</tr>
<tr>
<td>Anti-foaming (hydrocarbons)</td>
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<td>0.0141</td>
</tr>
<tr>
<td>Scale Dissolver</td>
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<td>0.0199</td>
</tr>
<tr>
<td>Pipe Release Agents</td>
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<td>0.0143</td>
</tr>
<tr>
<td>Flocculant (Water Injection)</td>
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<td>Laboratory Chemicals</td>
<td>0.0571</td>
<td>0.0004</td>
</tr>
<tr>
<td>Denufflizers</td>
<td>0.0056</td>
<td>0.0163</td>
</tr>
<tr>
<td>Coagulant/Decoilier</td>
<td>0.0059</td>
<td>0.0019</td>
</tr>
<tr>
<td>Dye</td>
<td>0.0001</td>
<td>0.0003</td>
</tr>
<tr>
<td>Cutting Wash Fluids</td>
<td>0.0010</td>
<td>0.0002</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>225.64</td>
<td>291.83</td>
</tr>
</tbody>
</table>

Table 3
Reported mud component usage 1994 – 1998 (extrapolated). The categories shown are as reported to SCOPEC in the OCNS notification scheme, and may not represent the material actually used. Approximately 2% of the total returns were not identified with a specific category.
These figures, shown in figure 1, are an extrapolation of reported data for the first quarter of 1998 to the whole year. The use of oil based muds has been minimised since the introduction of the effective ban on discharge in 1997. Since then, the progressive reduction in the use of synthetic based muds has also had an impact, although this is perhaps most noticeable in the overall reduction of wells drilled in 1998. Water based mud use in 1998 has been consistent with previous years (figure 1), although there are large margins of error in estimating water based mud figures from the SCOPEC data. Although data on water based mud types currently in use aren’t readily available, the indication is that the majority of fluids used are polymer based, with a significant number using glycol or silicate additives to increase inhibition. Table 3 presents the mud component usage returns made to SCOPEC between 1994 and the first quarter of 1998 (with the 1998 figures extrapolated to give an estimate for the whole year. These data are also presented in figure 3). Also shown is the percentage that each component forms of total mud use in 1998. These figures need to be treated with caution, as not all substances are correctly categorised. Confusion also arises where an additive may have

Figure 3
SCOPEC drilling mud component usage data 1994 – 1998 (extrapolated), showing the twenty four components with the highest levels of usage. Note that the categories shown are as reported in the notification scheme, and may not represent the material actually used. Approximately 2% of returns were not identified with a specific product category.

different or multiple functions, depending on circumstances. However, they do give a broad indication of the amount of each chemical grouping that has been physically placed downhole. Use is dominated by bentonite and barite (weighting agents and inorganic gelling agents), with this category forming 41% of the total drilling chemcials used. Synthetic based muds (19%) and brines, representing water based muds (12%) are the remaining two components, with oil based muds forming only 5% of the total chemical use. Polymeric viscosifiers are only recorded at 0.6%, although many may have been included in the water based mud category. Asphalts and asphalt based products form 0.06% of the total chemical use, while
lignosulphonates and lignites form only 0.02%. Total biocide use is low, at 0.02% of the total use, or 261 tonnes.

Whether mud usage around the UK can be characterised by the geology of the formations being drilled is debatable. Although specific areas around the UK do have specific features, the general applicability of oil based muds has tended to obscure the effect of any differences on mud formulation. Drilling in the South North Sea appears to have been dominated by oil based muds, with the balance veering towards synthetics over the rest of the North Sea, and being dominated by synthetics in the Atlantic Margin. However, this information is more likely to reflect the periods over which drilling has dominated in each of the sectors.

3.4 FUTURE TRENDS

Trends in drilling mud use over the next two to three years are relatively clear, and are almost entirely driven by environmental considerations. The key driving force is the agreed reduction in synthetic base fluid discharges by 25% per year between 1997 and 2000, leading to an effective ban on discharges of oil on cuttings (apart from esters) in the year 2001. The only

![Pie charts showing mud usage trends](image)

**Figure 4**
Predicted mud usage by type, 1998 – 2000. It is assumed that all zero discharge options (re-injection and skip & ship) will use low toxicity mineral oils. Source: Operator survey carried out by BW Muds plc.

options open to operators from 2001 will be either to use muds with no discharge limits (i.e. water based muds and ester based muds), or to operate total containment (zero discharge) regimes where cuttings are either re-injected, or shipped to shore (so-called skip and ship operations). The lack of discharge limits on ester based muds is likely to lead to an increase in the use of such muds initially. However, cost considerations will lead to the widespread use of more economically viable alternatives in the long term. The relatively high cost of synthetic muds is also likely to discourage their use in total containment operations, and it is the opinion of the industry that synthetic muds will not be used in such operations.
Projected mud usage figures from within the oil industry reflect this situation. Figure 4. Shows mud use predicted by operators between 1998 and 2000. In 1998, mud use has been dominated by synthetic based muds and water based muds, with esters making up 6% of usage, and low toxicity mineral oils in total containment operations making up 14% of total usage. In 1999 it is predicted that there will be a significant decrease in synthetic oil use, following tightening discharge limits. Correspondingly, ester use is predicted to rise, circumventing discharge limits, and the number of total containment operations is predicted to rise to 29%. By 2000, the use of oil based muds will be dominated by total containment operations. As the use of expensive synthetic oils in such operations makes little economic sense, nearly half of all operations are predicted to be using low toxicity oil based muds. No use of ester based muds is predicted, as the economics of freely discharging an expensive ester are far outweighed by the use of inexpensive low toxicity mineral oils in total containment systems. As total containment becomes the norm for oil based muds, water based muds are predicted to be used more frequently where possible, hence the rise in water based mud usage predicted for 2000.

Figure 5 breaks down predicted mud use further into well sections. Again, the relatively swift changeover to low toxicity oil based muds and water based muds is seen. Interestingly, the predicted increased usage of water based muds is particularly marked in the 17.5" section, presumably arising from the greater tolerance of upper sections to the use of less inhibitive and lubricious systems. It is also possibly driven by the unfavourable economics of applying zero discharge operations to the relatively high volume of cuttings arising from this section. Although volume of mud used will depend on section diameter, length and formation losses, the estimated figures in figure 5 indicate that the volume of water based muds used in 2000 is likely to significantly supersede the volume of low toxicity oil based muds. This ties in with the current research push on developing new water based mud systems that compare favourably with oil based systems. Apart from the introduction of glycol and silicate based muds, there has been relatively little progress in this area over the past 10 years. Even the use of these additives only addresses the inhibitive properties of the resulting muds, and not lubricity.

An alternative is the development of oil based muds that do not have the environmental problems associated with current oil based systems. One approach being examined is the use of glycol as the base fluid for synthetic based muds. Two types of glycol based synthetic mud are possible. First, a water-miscible system consisting of diethylene glycol and brine at ratios of around 80:20 may be used. Such systems show shale inhibition similar to oil based systems, and indicate a low level of marine toxicity. However, when discharged, they behave as water based muds, dispersing in the sea and in principle not leaving cuttings piles. The second approach is based on the same principle as Thermally Activated Mud Emulsion (TAME) glycol systems. TAME systems are designed to result in an emulsion of immiscible glycol at elevated temperatures. By reducing the activation temperature, muds may in principle be devised that form a stable invert emulsion at the surface and downhole, while forming a miscible system at the reduced temperatures below the surface of the sea (ocean-soluble inverts), encouraging dispersion and discouraging the formation of cuttings piles. At present, water miscible glycol muds are undergoing field trials, while ocean-soluble inverts are very much at the developmental stage.

A third option that may be developed and used further after 2000 is the use of reversible-emulsifier packages. These allow a stable invert emulsion to be formed under normal circumstances. However on treatment in an acid environment, they switch to an oil in water (direct) emulsion. As a result, mud discharged on cuttings may be dispersed more effectively following treatment, minimising environmental impact.

With the move back to low toxicity oil based muds, there is some speculation as to the base oils that will be used. Undoubtedly, mud suppliers will continue to use new base oils as supplies present themselves. However, there are significant stockpiles of low toxicity oils previously
used in muds held by the mud companies, and it is reasonable to assume that these will form the basis of the first phase of low toxicity oil based muds to be used. These oils are listed in appendix 2 of the OCNS list of approved chemicals.

Figure 5
Predicted mud usage in the UK Offshore Drilling industry up to 2000, as a function of well section. Source: Survey of operators carried out by BW Group plc.

3.5 ZERO DISCHARGE OPERATIONS

The reduction of oil discharge limits offshore to 1% oil on solids for low toxicity oils in 1997, and 1% oil on solids for synthetic oils in 2001, has led to widespread interest in cuttings processing operations within the industry over the past few years. Untreated cuttings typically contain 10% oil when using an oil based mud, and processing using conventional methods is unable to bring this down to the 1% limit, thus leading to an effective ban on oil based mud
discharges. A number of options are therefore being looked at by operators to allow the continued use of oil based muds past 2001.

On-site processing of cuttings has been under investigation since the early 1990's, with the aim of developing in-line cutting cleaning systems that can deal with between 30 to 40 MT/hour of solids. Two technologies have dominated: solvent extraction, and steam volatilisation. Trials using steam extraction systems in the early 1990's showed promise. However there were significant problems with residual solvent levels and machine downtime, leading to the effective abandonment of the technology offshore. The early 1990's also saw the development of the Torbed system, based on steam volatilisation of oil on cuttings. Cuttings are introduced to a toroidal bed and fluidised with high temperature (750°C), thus ensuring complete removal of volatiles. Pilot studies showed residual oil on cuttings to be as low as 0.5%, with the possibility of high throughput. Trials concluding in 1997 indicated that the technology was not viable offshore without significant modification, although there still appears to be interest within the industry.

The consensus in the industry is that after 10 years research, offshore/online cleaning of cuttings to bring residual oil levels to below 1% is not economically achievable at present. The alternatives to comply with discharge limits are to either re-inject cuttings offshore, or ship them to shore for reprocessing. Re-injection has been used within some sectors of the industry for some time now. In particular, it is used more extensively within the Norwegian sector. However, its success depends on drilling practices. On fixed production platforms there is easy access to wells for re-injection. The installation cost of re-injection equipment is high, but economically viable in some cases. For platforms where there are only a few remaining wells to be drilled the cost of installing the equipment becomes prohibitive, and in such circumstances the industry is very keen for inter-field transfer of cuttings to be allowed.

The use of sub-sea wellheads complicates re-injection substantially. Unlike fixed installations, there is little or no storage space for cuttings to be held in before re-injection, and the mechanics of transferring cuttings between wells are largely prohibitive. Until recently, difficulties in achieving re-injection into sub-sea wellheads had prevented implementation worldwide. However with the increasing pressure for zero discharge operations, this option is still being pursued.

Currently, the zero discharge option perceived as the most viable within the industry is shipping to shore for processing. In a survey carried out in 1997, around 40% of UK offshore operators saw shipping to shore as part of their future environmental strategy, with a further 30% prepared to consider it if the logistics could be simplified. At the time, current estimates of cuttings to be shipped were 6600 MT in 1997, 11400 MT in 1998 and 14400 MT in 1999, although these are likely to be underestimates. There are currently two cuttings reprocessing plants within the UK, one at Lowestoft and one in the Shetlands, with a third planned for the North East of Scotland. The logistics of shipping to shore for all but operations close to current plants are therefore immense. Drilling operations off the east coast of Scotland are planned for 1999 that will ship cuttings to Shetland. However, this is being carried out as a feasibility study, and at present it is unclear whether the cost of shipping and reprocessing will prove more costly than the use of dischargeable muds such as high performance water based muds and ester based muds.

It would be fair to say that, although environmental restrictions are forcing the adoption of zero discharge operations, mud supply companies are concerned with the possible consequences. Some concern has been expressed over the long term containment of re-injected cuttings. However it is the impact of transporting contaminated cuttings to shore, processing them and disposing of the waste that appears to raise the most concerns, with the feeling that environmental and health problems are simply being shifted to new areas, rather than being solved. There is some concern that high temperature processing of oil contaminated cuttings
will carry specific risks. One mud company is currently looking at the effect of processing cuttings, and although the study is currently in progress, there are indications that reclaimed oils show decreased flash points and increased vapour pressures. The use of high temperature reclamation processes also introduces the risk of thermal decomposition and cracking within the base oil (and additives), leading to potentially harmful by-products. Although this shouldn’t be a problem if each cuttings batch is treated appropriately, the likely impact of high throughput thermal processing plants appears not to have been investigated in depth.

Once processed, the environmental and health risks associated with clean cuttings is also under debate. The barite used to weight drilling fluids offshore has a small heavy metal content. Although the indications are that heavy metals attached to cuttings after processing are not bioavailable, it is accepted that this aspect of cuttings treatment and the subsequent usage and disposal requires further consideration. The final destination of cleaned cuttings is uncertain at present. The industry does not wish to take the cuttings to land-fill sites, and alternative uses are being looked at. Their use as road fill material has been considered, although the quantities involved are small by civil engineering scales.

In countries where onshore drilling operations are significant, disposal of contaminated cuttings has been an important issue for some years. Although the use of oil based muds onshore isn’t as prolific as it is offshore, the need to dispose of cuttings while minimising the impact on the environment and occupational health has led to a number of approaches to mud use and disposal. Relative ease in the storage and transportation of cuttings onshore have led to a wide range of disposal solutions. Key to many is the appropriate selection of drilling fluid, including synthetics with low boiling points to aid processing, and ‘chloride-free’ brines to reduce the environmental impact of direct disposal to land. Whether similar approaches will eventually be taken in zero discharge offshore operations remains to be seen.
4 HEALTH HAZARDS ASSOCIATED WITH MUDS

4.1 GENERAL HEALTH HAZARDS

In general terms, the majority of health hazards associated with drilling fluids arise from the manual handling of mud additives, and exposure to the mud, and particular chemical components. Manual handling used to be a significant problem when the use of off-shore formulated muds was widespread and additives were supplied in bulky packaging, with little or no handling assistance. However with the increasing use of package muds, together with the introduction of smaller sacks and automated systems/mechanical handling assistance, this is no longer seen as a major hazard.

Exposure to constituent chemicals and derivative compounds poses a health risk in many cases if appropriate controls are not in place. Exposure may be through inhalation, dermal contact or ingestion. Most solid additives are in the form of fine powders, and present an inhalation hazard. In many cases nuisance dust limits apply, but the potential for exposures up to and beyond the limits occur. Liquid components pose a dermal exposure hazard during formulation and drilling (during which there is also a risk of ingestion), and there is a risk of inhalation exposure where sprays, mists or vapour are formed. The vapour pressure and flash point of base oils is critical to the vapour concentration and fire risk in enclosed spaces such as around the shakers and mud pits. In the early days of LTOBM, base oils with reasonably high flash points (greater than 160° C) were generally used. Recently Operating Companies have been specifying lower flash point oils, with flash points as low as 75° C. These are preferred as they have a low inherent viscosity so that in mud’s with a lot of barite (for high pressure wells) the viscosity of the mud can be kept lower. The flash point of the mud will be greater than that of the oil but there is still likely to be greater amounts of vapour given off with potential for health problems and possibly increased fire risks.

4.2 AVAILABLE INFORMATION

A detailed examination of the links between drilling muds and other downhole chemicals used offshore and operator health is a complex subject, and beyond the scope of this review. However, given the dominance of environmental concerns in determining the use of downhole chemicals, there is a need to give an overview of the information available on associated health risks. This is particularly pertinent given the move towards zero discharge drilling operations, leading to a relaxation of usage constraints on environmental grounds, as well as increased worker contact with contaminated cuttings.

Under COSHH, all chemicals used offshore must be suitably assessed and adequately controlled. This requires an appropriate Manufacturers Safety Data Sheet, informing the user of active ingredients in the substance and their health classifications, together with an overall classification for the substance, and guidance on use, transport and handling. Hazard classifications are arrived at using standard tests, as with any other commercially available chemical. The framework is therefore in place for the effective use of chemicals offshore with the minimal risk to users. However, there are a number of situations and operating practices within this framework which may potentially lead to inadequate assessment and control of chemicals offshore.

Partly as a consequence of the dominance of environmental concerns, the health risks associated with chemical use are perhaps not as widely appreciated offshore as they are onshore. There is a lack of data available on the impact of exposure to drilling chemicals in the field, which
includes not only the lab-determined hazards, but also handling and usage regimes. This is further complicated by the relatively high number of proprietary products used in the field. Many of these are benign formulations of well-known generic groups. However, insufficient data are available on many of the primary drilling fluid constituents (e.g., synthetic oils and polymers) to carry out an exhaustive evaluation of health risk in the field. Dermatitis is anecdotally a significant problem when working with drilling muds, although the exact root of skin complaints is not always easily pinpointed. However, there is evidence within the industry that dermatitis directly resulting from prolonged contact with oil-based drilling muds has a basis in poorly understood handling procedures. In one instance, the introduction of a synthetic base oil led to widespread dermal problems among workers, despite the provision of a fully detailed MSDS. Repeated examination of the mud system, and repeated irritancy tests, failed to indicate the source of the problem. Finally, it was discovered that through a lack of education on the rig floor, the mud system was being handled inappropriately: Because word had got round that synthetic oils were more environmentally friendly than the low-toxicity oil equivalents, it was assumed that they also posed a negligible health hazard, resulting in appropriate precautions such as protective equipment and barrier creams not being used. Thus lack of information and education (or health and safety management) were predominantly at the centre of the problem. In general, this account is indicative of the role that human factors have to play in determining the health hazards associated with drilling fluids.

Not only does this case highlight the need to consider how a substance is used when assessing its health impact, but it also demonstrates the interest that mud companies take in the impact their products have on worker health. All UK mud companies run schemes to ensure that health effects associated with their products are logged and reported. Self-interest is a primary motivating factor, as an operator will have second thoughts about using a supplier whose chemicals lead to health problems, and as a consequence increased drilling costs. However, the feedback loop is a useful mechanism whereby the health risks associated with using downhole chemicals are minimised, and significant incidences of ill health are logged. These data are, in principle, available from the respective mud supply companies, although the data are obviously commercially sensitive, and not made freely available.

Apart from the handling and use of downhole chemicals, concerns arise over possible reaction products resulting from thermal (and pressure-induced) degradation, reactions between additives or mud/formation reactions. At high temperatures, oils will react with water under hydrolytic degradation, to form a range of reaction products, some of which may be toxic. Low-toxicity mineral oils and many synthetic oils have sufficiently high hydrolytic breakdown temperatures for thermal degradation not to be a problem. Esters are relatively unstable, with a breakdown point of 150°C, and for this reason are not ideal for drilling deep wells. Rape seed oil also has a relatively low hydrolytic breakdown temperature of 125°C, and acetals undergo hydrolytic breakdown between 180° - 200°C. Under normal drilling conditions however, downhole conditions are well documented beforehand (from experimental wells), allowing appropriate fluids to be used. Logging during drilling also ensures that conditions downhole are not allowed to exceed the tolerances of the fluid and equipment being used. To assess the impact of downhole conditions on oil-based drilling mud systems, mud companies carry out tests on specific system formulations. In most cases, the technical performance of a mud system will be assessed at elevated temperatures and pressures. One mud supply company questioned carries out a full analysis of reaction products (both liquid and vapour phase) after subjecting a sample to equivalent downhole conditions. Such tests demonstrate whether use of a mud system under specific conditions will lead to harmful reaction products. However, they are expensive, and it is more common for technical performance alone to be assessed. Although such tests do not explicitly generate health-related information, a view expressed by one supply company was that the generation of any reaction products under extreme conditions will almost definitely be at the detriment of technical performance, and thus a mud system is extremely unlikely to be used under such conditions. Whether this will be the case if relatively low levels of highly toxic
substances are generated is not clear, and there may be a case for examining the potential for the generation of low levels of toxic substances on breakdown, and the possibility of these reaching harmful levels before technical performance is compromised. The formation of reaction products within water based muds formulated on site is much more difficult to assess. Intuitively, severe problems are unlikely: major additives in water based muds tend to have a low toxicity; water based muds tend not to be used at extreme temperatures and pressures; knowledge of the effects of mixing additives is likely to be well understood. This is speculation however, and little information appears to be publicly available on the likelihood of harmful reaction products, or whether there is a perception of this type of hazard among operators. The indication is that among mud supply companies, the view is that the risks from noxious downhole reaction products are low. This is somewhat strengthened by the operating principle of one supply company being in control of the mud during a given operation. However, water based mud components may still be bought in from third parties, some of which are of unknown composition. Bringing in such products which either aren’t bulk standard additives such as bentonite or barite, or aren’t well understood, appears to be the exception rather than the rule in the current working environment.

There is some debate as to whether current MSDS’ on downhole products provide sufficient data to assess the health impact of substances. CHIP lays down clear guidelines on what information should be included in an MSDS, and how detailed this information should be. There is a general consensus amongst mud suppliers that this is sufficient to give a clear picture of the health hazard inherent in any substance used. However, it was noted that for many mud components, safety data is passed on from the initial supply company, and to a large extent mud suppliers have to assume this information is correct. There was concern that tests on some supplied agents were carried out under old guidelines that may not be sufficiently rigorous for present day classifications. However, there was an indication that if safety data from a supply company did not appear to agree with what was known about a chemical, the safety data were challenged and, if necessary amended in the mud supply company MSDS for the final product.

Chemical and environmental toxicological data for all OCNS approved chemicals are held by the MAFF agency CEFAS. These data are commercial in confidence and contain detailed information on the chemicals used offshore. Such detail may not be appropriate for the purposes of an MSDS but could be useful in other areas e.g. exposure surveys, epidemiology studies. From table 3, the bulk of chemical use during drilling offshore consists of weighting agents, brine and oil based muds. Of these, the composition of the weighting agents (predominantly barite), although complex, is relatively well understood, and certainly widely available. The composition of the brines is self-explanatory. Although the low toxicity mineral oil based muds will use oil sourced from a variety of places, such oils may be treated as belonging to the same generic grouping, the overall composition of which is readily accessible. Synthetic oils are diverse, according to their narrowly defined structures, and hence have a range of properties. It is perhaps this group of chemicals more than any other where detailed chemical data could reasonably be requested over and above that supplied in the MSDS’.

Of the chemicals used in smaller quantities, polymeric gelling agents make up the bulk. The exact nature of most of these chemicals is obscured by the complex nature of the polymers, and by commercial interests. However, many of the polymers based on natural products (starch, cellulose, xanthan) are widely used in the food industry, and are believed to be harmless. This assessment is based on ingestion however, and may not be relevant in all cases to inhalation. Of the remaining groups, many additives are self-explanatory of their composition, and many are used in such small quantities that exposure to them as a component of the drilling mud is likely to be minimal (although the same may not apply when handling the neat chemical). While there are specific additives within the numerous products used offshore that appear not to be well characterised, the logistics of categorising all additives would suggest that a better cause of action may be to look at specific low usage components as and when the need arises.
are specific additives within the numerous products used offshore that appear not to be well characterised, the logistics of categorising all additives would suggest that a better cause of action may be to look at specific low usage components as and when the need arises.

4.3 COMPONENT SUBSTITUTION

One approach to minimising the risk of exposure to hazardous agents during drilling may be to encourage the substitution of higher risk components with lower risk components in the drilling mud formulation. For such an approach to be successful, it is important to understand the process of drilling mud selection, and where best to target increased awareness. Before beginning drilling, an operator will send out an invitation to tender for supplying drilling fluids. Mud Supply Companies will then bid against a detailed specification for the well(s). The specification will generally detail expected downhole conditions, as well as restrictions the operator feels justified in placing on the types of chemicals used (for instance, insisting that only OCNS category E chemicals are specified). The successful company will then develop a detailed mud programme based on lab assessments of downhole conditions, which is then authorised by the DTI. Only then will drilling begin. While a mud engineer will tweak the mud schedule slightly as required during drilling, changes are extremely uncommon, and require the authorisation of the operator and the DTI. Thus once the mud schedule has been set, substitution of components is not a viable option in the majority of cases.

The point in this process where the selection of components posing the least risk to operator health is most viable, is at the point of bidding for supply contracts. From the mud supply company’s point of view, substitution will only be viable if there are no cost or performance penalties within the specification outlined by the operator. It is the operator therefore who has the greatest influence over the selection of mud formulations that are finally used, and thus the operator where awareness of health issues should be raised. At present, operators are specifying the use of products that will minimise the environmental impact of drilling operations (either through the specification of category E substances, or through environmental impact assessment). It isn’t clear to what extent a similar approach is used to minimise the health risks of substances used, although it is evident from the supply companies that they are encouraged to provide mud solutions that aren’t detrimental to operators’ health. However, if product substitution is to be pursued, encouraging operators to include minimising health risks as a requirement of mud supply tenders is a possible way forwards.
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