



Drilling fluids and health risk management

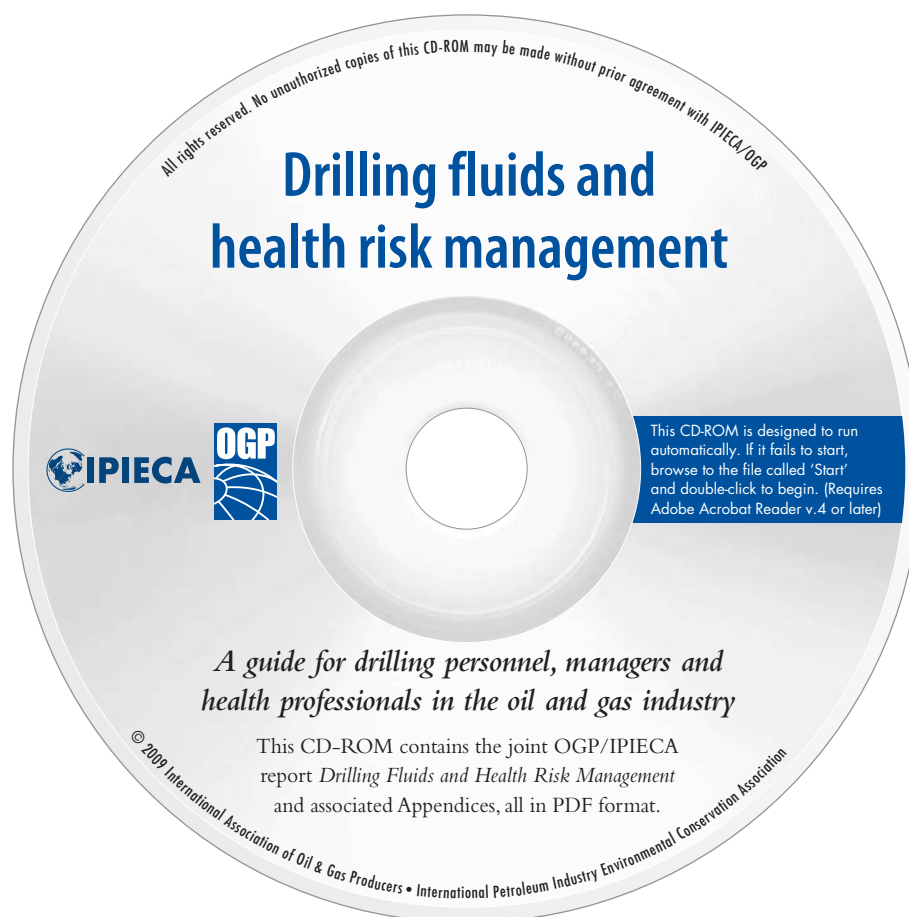
*A guide for drilling personnel,
managers and health professionals
in the oil and gas industry*



‘Drilling fluids and health risk management’ on CD-ROM

This document is also included on the attached CD-ROM in PDF format[†]. The file includes links to the associated Appendices which are also included on the CD-ROM. The links are represented in this printed version by the [blue highlighted text](#).

[†]Requires Acrobat Reader™ — available from the Adobe website: www.adobe.com/products/acrobat/readstep2.html



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Drilling fluids and health risk management

*A guide for drilling personnel,
managers and health professionals
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This electronic version of the OGP/IPIECA guide to *Drilling Fluids and Health Risk Management in the Oil and Gas Industry* includes hyperlinks throughout the document to facilitate access to the 11 associated Appendices (included on the CD-ROM) and to related information on the Internet. The bookmarks on the left are also provided to facilitate navigation between the files on the CD-ROM.



Introduction

Drilling fluids are used extensively in the upstream oil and gas industry, and are critical to ensuring a safe and productive oil or gas well. During drilling, a large volume of drilling fluid is circulated in an open or semi-enclosed system, at elevated temperatures, with agitation, providing a significant potential for chemical exposure and subsequent health effects. When deciding on the type of drilling fluid system to use, operator well planners need to conduct comprehensive risk assessments of drilling fluid systems, considering health aspects in addition to environmental and safety aspects, and strike an appropriate balance between their potentially conflicting requirements. The results of these risk assessments need to be made available to all employers whose workers may become exposed to the drilling fluid system.

This document provides some general background on drilling fluids and the various categories of base fluids and additives currently in use. It outlines potential health hazards associated with these substances, looks at opportunities for human exposure presented by drilling operations, and introduces risk management methods and monitoring processes aimed at reducing the risk of harmful health effects.

This guidance is evidence-based and aims to define and discuss best practices for reducing exposures and subsequent health effects through a risk-based management process.

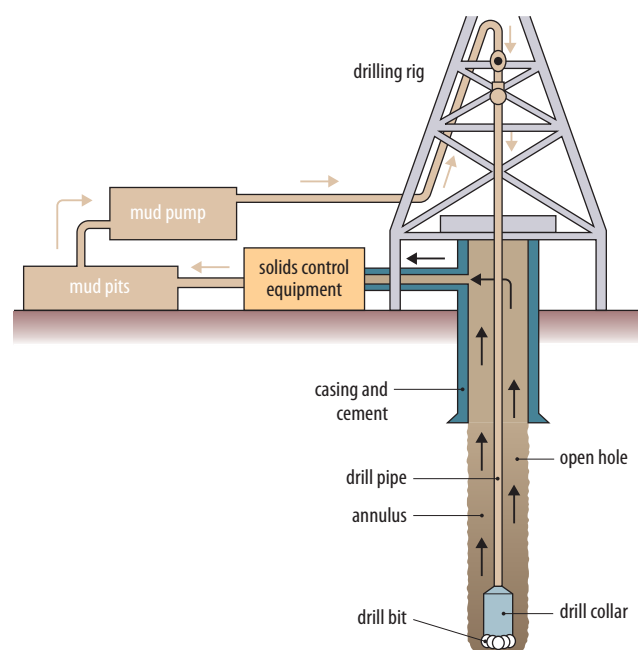
The document is designed to be of use to operator and drilling personnel, managers, Health, Safety and Environment managers, drilling fluid specialists, rig-site medical staff, and occupational health and hygiene professionals.

Functions of drilling fluids

Drilling fluids are a key requirement in the vast majority of drilling operations. The main functions performed by drilling fluids are to:

- provide a barrier for well control;
- remove cuttings from the well bore as they are produced;
- maintain drill cuttings in suspension when drilling circulation is stopped;
- transmit hydraulic power to the drilling bit;
- maintain formation stability;
- maintain pressure on the formation;
- control fluid loss through filtration;
- cool and lubricate the drill bit and string; and
- facilitate data logging—drilling fluids characteristics need to be controlled so that logging instruments can accurately provide information about the well and formations being drilled.

Figure 1 Fluids circulating system of a rig and well



Functions of drilling fluids

Although the most primitive systems used water only, drilling performance was enhanced by using other materials, e.g. clays as filtrate reducers, viscosifying agents and dispersants for rheology control. As drilling became more complex, especially in long sections, with increased temperatures and when drilling more reactive formations, the use of additives has increased rapidly in number and in complexity. By the 1980s, the base fluid for the now complex emulsion had evolved from water to hydrocarbon-based fluids, and the number of chemicals used in the drilling fluids industry numbered in the thousands. For more

information on the historical development of water-based and non-aqueous based fluids, reference should be made to [Appendix 1](#).

It is common practice to use both water-based drilling fluids (WBFs) and non-aqueous drilling fluids (NAFs) when drilling various sections of the same well. WBFs are generally used in the upper hole sections of the well, while NAFs tend to be used in the more technically demanding hole sections.

For more detailed information on the functions of drilling fluids, reference should be made to [Appendix 2](#).

General composition of drilling fluids

Drilling fluids have a continuous liquid phase and are modified with various chemical additives, both liquid and solid, to align the performance of the drilling fluid to the drilling conditions. However, all fluid types must possess some common characteristics. These are described below.

Density

The density of the fluid will vary according to the formation pressures encountered in the well bore. It is critical to the stability of the well bore that the formation pressures are correctly balanced with the drilling fluid to prevent the formation fluids from flowing into the well bore, and to prevent pressurized formations from causing a well blowout.

Viscosity

Drilling fluids must be able to suspend drilled cuttings, weighting materials such as barite

(barium sulphate) and other chemical additives under a wide range of conditions. The viscosity of the drilling fluid must also be such that the removal of drilled solids at the surface using solids control equipment is possible.

Fluid loss control

Some additives may be required to help establish a strong impermeable filter cake on the well bore to limit the loss of the drilling fluid filtrate to porous formations being drilled. This improves the stability of the well bore and prevents a number of drilling and subsequent production problems.

Shale inhibition

When using a WBF, the addition of shale inhibition chemicals is required to prevent the formation clays from swelling and sticking, which would result in significant drilling problems. NAF drilling fluids do not allow the



formation clays to be exposed to water. These types of fluids are therefore innately inhibitive.

The choice of a WBF or NAF depends on the formation to be drilled and the particular technical requirements needed to drill the well successfully, e.g. temperature, pressure, shale reactivity. In addition, local environmental regulatory requirements and waste disposal considerations may determine which type of drilling fluid system will be used, as well as economic factors.

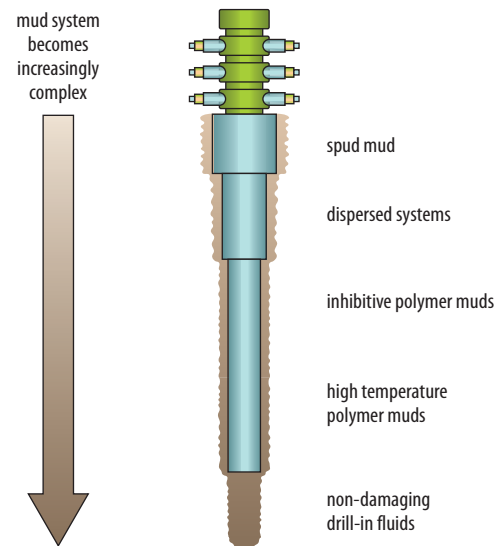
Many different types of drilling fluid systems are used in drilling operations. Basic drilling fluid systems are often converted to more complex systems as the well deepens and the well bore temperature and/or pressure increases. Several key factors affect the selection of the types of drilling fluid systems for a specific well.

As the technical performance requirements of the fluid increase, there may be a need to add a variety of specific chemicals to ensure acceptable characteristics, for example: lubricity; stuck pipe prevention; bit balling; accretion; shale/clay inhibition; temperature stability; and formation damage prevention. To maintain the integrity of the well bore and fluid it may also be necessary to add other chemicals such as biocides, oxygen scavengers and corrosion inhibitors.

Water-based fluids

More than one WBF system is typically used when drilling the same well because various formulations of fluids are required to be able to accurately meet the technical physiochemical properties required in each section of the well. The fluid composition may also need to be continually modified within each hole section, as shown in Figure 2.

Figure 2 Water-based drilling fluids—composition requirements

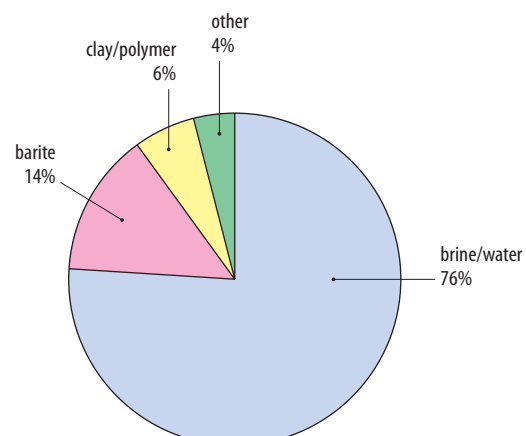


Water-based fluid composition

WBFs have water as the primary phase, which is either freshwater, seawater or brine. A combination of salts may be used to provide specific brine phase properties.

The pie chart in Figure 3 shows the general proportions of the liquid phase and chemical content of the water-based fluid types as a percentage by weight. This information has been averaged for global use from industry sales volumes and fluid types used.

Figure 3 Water-based drilling fluids—chemical components, by weight (%)



General composition of drilling fluids

Non-aqueous fluids

NAFs can be split into three groups based on their aromatic hydrocarbon content (see Table 1)¹:

Group I: high-aromatic content fluids. This category includes crude oil, diesel and conventional mineral oils. These fluids are refined from crude oil and contain levels of total aromatics between 5 and 35 per cent.

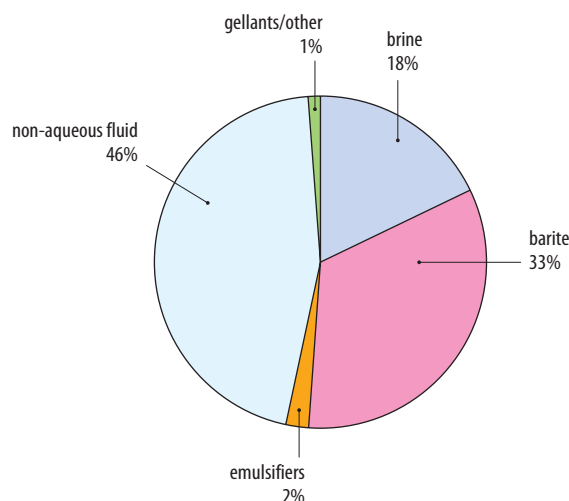
Group II: medium-aromatic content fluids. This category contains products produced from crude oil with levels of total aromatics between 0.5 and 5 per cent and is often known as ‘low toxicity mineral oil’.

Group III: low/negligible-aromatic content fluids. This group includes fluids produced by chemical reactions and highly refined mineral oils which contain levels of total aromatics below 0.5 per cent and polycyclic aromatic hydrocarbon (PAH) levels below 0.001 per cent, according to the OGP definition.

Non-aqueous fluid composition

The pie chart in Figure 4 shows the general proportions of the liquid phase and chemical content of non-aqueous fluid types as a percentage by weight. This information has been averaged for global use from industry sales volumes and fluid types used.

Figure 4 Non-aqueous drilling fluids—chemical components, by weight (%)



Selection of non-aqueous base fluid

There are a number of different physical properties which need to be assessed in the selection of a NAF base fluid with regard to technical, health, safety and environmental characteristics. [Appendix 3](#) lists the most important physical properties which are commonly considered in the selection process. Two key variables are the vapour pressure and boiling point of the base fluid, especially at elevated temperatures.

[Appendix 4](#) provides generic information on the chemical characteristics of key non-aqueous drilling fluid additive groups, summarizing:

Table 1 Classification of non-aqueous fluids¹

Non-aqueous category	Components	Aromatic content
Group I: high-aromatic content fluids	Crude oil, diesel oil, and conventional mineral oil	5–35%
Group II: medium-aromatic content fluids	Low-toxicity mineral oil	0.5–5%
Group III: low/negligible aromatic content fluids	Ester, LAO, IO, PAO, linear paraffin and highly processed mineral oil	<0.5% and PAH lower than 0.001%



- their functions in the drilling fluid system;
- how commonly the additives are used;
- generic examples of hazard classifications of the product types; and
- the types of products which may have particular hazards, e.g. silicon dioxide (SiO_2) content.

For relevant definitions, reference should be made to [Appendix 5](#).

Additives common to water-based and non-aqueous based fluids

There are a number of chemical products which can be used either in a water-based or a non-aqueous drilling fluid to achieve the necessary technical properties. To give an indication of the range and variability of these types of components, [Appendix 6](#) provides generic information on key products and their basic functions. This table is not exhaustive and is included only to give an indication of the degree of variation and complexity that may be required.

Contamination of drilling fluids

Potentially hazardous substances can arise from the formations being drilled. This is not always predictable. This section introduces some examples of more common contaminants.

Hydrocarbon-based contaminants

As the purpose of drilling a well is to produce hydrocarbons, one known source of hydrocarbon contamination will be from the reservoir formation. Often, however, the formations drilled through to the reservoir also contain hydrocarbons, but not of producible or commercial quantities. These hydrocarbon sources can introduce oil, condensate and gas contamination in a drilling fluid. Gases from formations are primarily composed of methane.

Non-hydrocarbon gases

Formations can contain hydrogen sulphide (H_2S) gases and H_2S -containing water samples. These gases must be closely monitored and treated to eliminate hazardous exposure to personnel. Both H_2S gas and water contaminants in a drilling fluid system must be treated out, as the H_2S can degrade the metal piping and tubulars of the circulating system.

Other gases

Carbon monoxide can be present particularly when coal beds are drilled. This occurrence is, however, extremely rare.

Low specific activity (LSA) radioactive scale contamination

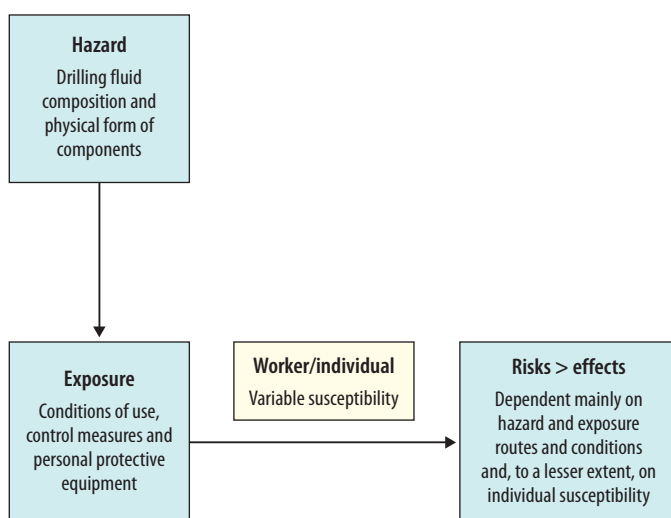
LSA scale contamination of a circulating fluid can occur during scale clean-out operations, or when abandoning production wells. Operators should be conscious of this risk and control exposure as appropriate. Reference should be made to OGP report no. 412, *Guidelines for the Management of Naturally Occurring Radioactive Material (NORM) in the oil & gas industry*⁴⁰.

These contaminants are either removed or treated in the drilling fluids used. Therefore, even though there may only be limited exposure from these contaminants, their identification and remediation at the earliest opportunity is important.

Exposure to chemical hazards

The risk of adverse health effects from drilling fluids is determined by the hazardous components of the fluids and by human exposure to those components (Figure 5). This section examines the hazardous components of drilling fluids and additives, and their associated health effects.

Figure 5 The relationship between health hazard, exposure and risk



Health effects associated with drilling fluids

The most commonly observed health effects of drilling fluids in humans are skin irritation and contact dermatitis. Less frequently reported effects are headache, nausea, eye irritation and coughing⁴. The effects are caused by the physico-chemical properties of the drilling fluid as well as the inherent properties of drilling fluid additives, and are dependent on the route of exposure (dermal, inhalation, oral and other) as detailed below.

Dermal

When drilling fluids are circulated in an open system with agitation, there is a high likelihood of dermal (skin) exposure. The

potential dermal exposure is not limited to the hands and forearms, but extends to all parts of the body. Actual exposure depends on the drilling fluid system and the use of personal protection equipment (PPE).

Irritation and dermatitis

Upon dermal exposure to drilling fluids, the most frequent reported effects are skin irritation and contact dermatitis¹⁴ (see Figure 6). Contact dermatitis is one of the most common chemically-induced occupational illnesses, probably accounting for 10–15 per cent of all occupational illnesses. Symptoms and seriousness of the condition vary and are dependent on the type and length of exposure to drilling fluid and the susceptibility of the individual.

Petroleum hydrocarbons will remove natural fat from the skin, which results in skin drying and cracking. These conditions allow compounds to permeate through the skin leading to skin irritation and dermatitis. Some individuals may be especially susceptible to these effects.

Skin irritation can be associated with petroleum hydrocarbons, specifically with aromatics and C8–C14 paraffins²⁵. Petroleum streams containing these compounds, such as

Figure 6 Contact dermatitis after repeated dermal exposure to mineral oil





kerosene and diesel (gasoil), are clearly irritating to skin²⁶. This is suggested to be caused by the paraffins, which do not readily penetrate the skin but are absorbed into the skin, hereby causing irritation²⁷. Linear alpha olefins and esters commonly used in drilling fluids are only slightly irritating to skin, whereas linear internal olefins are not irritating to skin^{28,29,30}.

In addition to the irritancy of the drilling fluid hydrocarbon constituents, several drilling fluid additives may have irritant, corrosive or sensitizing properties^{14,31}. For example calcium chloride has irritant properties and zinc bromide is corrosive^{30,32,33} whereas a polyamine emulsifier has been associated with sensitizing properties^{13,34}. Although water-based fluids are not based on hydrocarbons, the additives in the fluid may still cause irritation or dermatitis.

Excessive exposure under conditions of poor personal hygiene may lead to oil acne and folliculitis.

Carcinogenicity (dermal exposure)

Olefins, esters and paraffins commonly used in drilling fluids (Group III, negligible-aromatic content fluids) do not contain specific carcinogenic compounds and are not carcinogenic in animal tests. These compounds are not therefore associated with tumour formation upon dermal exposure. However, Group I (high-aromatic content fluids), especially diesel fuel, can contain significant levels of PAH. Diesel fuels that contain cracked components may be genotoxic due to high proportions of 3-7 ring PAH. Although no epidemiological evidence for diesel fuel carcinogenicity in humans exists, skin-painting studies in mice show that long-term dermal exposure to diesel fuels can cause skin tumours, irrespective of the level of PAH. This effect is attributed to chronic irritation of the skin³⁴. In humans, chronic irritation may cause small areas of the skin to thicken, eventually

forming rough wart-like growths which may become malignant.

Inhalation

Drilling fluids are often circulated in an open system at elevated temperatures with agitation that can result in a combination of vapours, aerosol and/or dust above the mud pit. In the case of water-based fluids the vapours comprise steam and dissolved additives. In the case of non-aqueous drilling fluids the vapours can consist of the low boiling-point fraction of hydrocarbons (paraffins, olefins, naphthenes and aromatics), and the mist contains droplets of the hydrocarbon fraction used. This hydrocarbon fraction may contain additives, sulphur, mono-aromatics and/or polycyclic aromatics. However, knowledge about the detailed composition and size of the aerosol droplets is limited. It should be noted that although the hydrocarbon fraction may contain negligible amounts of known hazardous constituents such as BTEX (see page 26) at low boiling point, these will evaporate at relatively higher rates potentially resulting in higher concentrations in the vapour phase than anticipated. Occupational exposure limits for several compounds may be



Exposure to chemical hazards



specified in occupational health and safety regulations and exposure should not exceed these levels.

Odour

An issue indirectly related to health, but directly related to the working environment is the odour of drilling fluids. Some drilling fluids may have an objectionable odour caused by the main constituents or specific additives. During operations the drilling fluids may be contaminated with crude oil and drilling cuttings, which may change the odorous properties of the drilling fluid. Measurements of headspace^a volatiles during drilling operations have indicated the presence of, amongst others, dimethyl sulphide and isobutyraldehyde. Both compounds have a pungent odour and may create unpleasant working conditions⁵.

Neurotoxicity

Inhalation of high concentrations of hydrocarbons may result in hydrocarbon-induced neurotoxicity, a non-specific effect resulting in headache, nausea, dizziness, fatigue,

lack of coordination, problems with attention and memory, gait disturbances and narcosis. These symptoms are of a temporary nature and are only observed at extremely high concentrations^b. Exposure to high levels of n-hexane may result in peripheral nerve damage, an effect observed after prolonged exposure to high concentrations¹⁶ (repeated dose studies in rats with a light naphtha stream containing up to 5 per cent n-hexane did not show neurotoxic effects¹⁷).

Pulmonary effects

The most commonly observed symptoms in workers exposed to NAF and aqueous fluid aerosols are cough and phlegm^{18,19}. Epidemiological studies of workers exposed to mist and vapour from mineral oils indicated increased prevalence of pulmonary fibrosis⁶. More recent inhalation toxicology studies show that exposures to high concentrations of aerosols from mineral-based oils resulted mainly in concentration-related accumulation in the lung of alveolar macrophages laden with oil droplets²⁰. Inflammatory cells were observed with higher aerosol concentrations, consistent with the clinical literature from highly exposed workers. These pulmonary changes appeared to be a non-specific response to the presence of deposited aerosol and are not related to vapour exposure. The results on various petroleum mineral oils support the ACGIH[®] TLV of 5 mg/m³ for mineral-oil mist. It should be noted that

^b In animal studies, some aromatics such as trimethylbenzene and xylenes have been associated with specific neurotoxic effects after longer-term exposure to high hydrocarbon concentrations; however epidemiological studies have not shown neurological effects after exposure to petroleum streams containing significant levels of aromatics. In addition, studies in rats exposed to a high-aromatic petroleum stream did not show neurotoxic effects¹⁵.

^c Inhalation studies with aerosols from an olefin (polybutene) also resulted in elevated numbers of pulmonary macrophages and increased macrophage vacuolization. In addition, high-level (700 mg/m³) exposure to polybutene was lethal to three of four animals, due to pulmonary oedema²¹.

^a The term 'headspace' refers to the vapour phase associated with, and in equilibrium with, a respective substance or blend of substances, liquid and/or solid, under defined conditions.



extremely high concentrations of low viscosity hydrocarbon aerosols can either be aspirated, or be deposited in droplets in the lungs, causing chemical pneumonitis potentially resulting in pulmonary oedema, pulmonary fibrosis and, in occasional cases, death^{22,23}.

In some cases, occupational exposure to drilling fluids is associated with respiratory irritation². It is likely that this is caused by additives in the drilling fluid and/or the physico-chemical properties as water-based drilling fluids have a typical pH of 8.0–10.5^d.

Carcinogenicity (inhalation exposure)

The olefins, esters and paraffins commonly used in drilling fluids (Group III, negligible aromatic content fluids) do not contain specific carcinogenic compounds such as benzene or PAHs^e.

Group II (medium-aromatic content) and especially Group I (high-aromatic content) fluids may contain minimal amounts of benzene.

^d Studies on sensory irritation during exposures of lab animals to mineral oils indicate possible effects only with very high aerosol concentrations.

^e Tests in laboratory animals have shown that Group III substances are not genotoxic or carcinogenic through inhalation.



Note that all drilling fluids may be contaminated by crude oil from the reservoir, generating trace contamination with benzene, which is not necessarily expected. Due to the low vapour pressure of benzene, the concentration in the vapour phase may be higher than expected. Benzene exposure at levels well above the current OEL of 0.5 ppm is specifically associated with acute myeloid leukaemia²⁴. Current evidence is that exposures are generally well below 0.5 ppm TWA.

Oral

As drilling fluids are not intended for ingestion, oral exposure is unlikely and negligible as compared to the other routes of exposure. Oral exposure however should not be ignored where contaminated hands are used to handle food or to smoke. Good hygiene practices should be followed.

Other routes or combined routes of exposure

A more likely scenario is drilling fluid coming into contact with the eyes. Hydrocarbon compounds of Group I, II and III drilling fluids are not, or are slightly, irritating to the eye. However, specific additives in both aqueous and non-aqueous drilling fluids may be irritating or corrosive to eyes.

On occasions, if drilling fluid or base fluid is under high pressure, fluid may be injected through the skin. As drilling fluids are generally of low systemic toxicity, the main effect expected is skin irritation.

Reprotoxicity

Compounds associated with reprotoxicity are n-hexane^f and toluene^g. These compounds may be present in small quantities in Group II drilling fluids and in larger quantities in Group I fluids. However, a study involving

^f Limited evidence in animals for affecting fertility.

^g Limited evidence in animals for causing developmental toxicity.

Exposure to chemical hazards

1,269 men employed as offshore mechanics, offshore operators and offshore drilling personnel showed that paternal exposure to hydrocarbons in the occupations studied did not seem to have had a major influence on time to conception or the incidence of spontaneous abortion among the wives of the men exposed to oil products³⁵. The olefins, esters and paraffins commonly used in drilling fluids (Group III, negligible-aromatic content fluids) do not affect fertility nor cause developmental toxicity in animals.

Particle size as an influencing factor

Particle size is a critical influencing factor when it comes to health effects. Particle size can influence aerodynamic behaviour resulting in varying degrees of penetration and differing areas of deposition within the respiratory system. Reference should be made to [Appendix 7](#) for further information.

Potential exposure to drilling fluids

Workers may be exposed to drilling fluids either by inhaling aerosols and vapours or by skin contact. The preparation and use of drilling fluid systems may generate airborne contaminants, dust, mist and vapour in the workplace. The potential for inhalation of dust is mainly in association with mixing operations. The highest potential for inhaling mist and vapour exists along the flow line from the bell nipple to the solids-control equipment, which can include the shale shakers, desanders, desilters, centrifuges and the fluid pits. However, the shakers themselves are often washed with high-pressure guns using a hydrocarbon-based fluid as the washing medium. This operation generates mist in the immediate working environment.

High hydrocarbon mist and vapour exposure levels have been reported in shale shaker rooms, particularly when cleaning and changing screens on the shale shakers. This generates both respiratory and skin exposure potential. Under circumstances where the removal of aerosols and vapour have relied on open atmospheric ventilation, personal





exposure to total hydrocarbon compounds has been reported to be up to 450 mg/m³ for some momentary tasks at the shale shakers when drilling with non-aqueous drilling fluids². On a drilling installation with a higher level of enclosure of the drilling fluid systems, reported exposures were significantly lower³.

Several factors such as drilling fluid temperature, flow rate, well depth, well section and the kinematic viscosity of the NAF might be expected to influence the exposure levels in the working atmosphere, but the relative contributions of these factors have not yet been published. Little is known about the impact from geological hydrocarbon-bearing formations on the composition of hydrocarbon mist produced in the fluid processing areas. While it has been suggested that droplets are generated by both the vibrating screens of the shale shakers and condensation of vapour, no studies have been performed to support these theories^{4,5}.

Exposure will be a function of duration and frequency. When the temperature of the circulated drilling fluid rises, vaporization of the light components will occur and vapour is generated. (Some mineral base oils can evaporate at a rate of 1 per cent by volume per 10-hour period at 70°C.) When the hydrocarbon vapour is cooled down it will condense to mist. There is limited knowledge regarding the resultant particle size but it is estimated to be less than 1 micron. In addition, the shale shakers will mechanically generate mist that will contain both light and heavier fractions of the drilling fluid components and this effect increases with temperature.

Headspace measurement shows that the gas phase over fluid quantity will increase with temperature. For example, a diesel base fluid will produce 100 parts per million (ppm) at 20°C and 1,000 ppm at 80°C.

Controlling the amount of vapour in the workplace is important. There is a common

belief that most vapours in the working areas come from the non-aqueous base fluid, because the base fluid is the largest constituent, generally in excess of 50 per cent by volume. Studies have shown this belief to be erroneous³. The total hydrocarbon vapour from non-aqueous drilling fluids also includes vapour contributions from drilling fluid additives which can be highly volatile and possibly from hydrocarbon-bearing formations which have been drilled with the fluid. When formulating a suitable drilling fluid therefore, it is important to minimize hazardous components in the formulations. Generally it is the lighter hydrocarbon components that are most hazardous to personnel. The traditional approach to minimizing the concentration of organic vapour in the atmosphere has involved improving the characteristics of the NAFs. However, field studies have shown that reducing the vapour concentration in the headspace above a pure base oil from 100 ppm to 10 ppm does not necessarily lead to the same percentage reduction of vapour being issued from the drilling fluid into the working environment³. Knowledge of exposure is important in evaluating the health risk for exposed workers.



Exposure scenarios and influencing factors

This section provides an overview of likely exposure types and durations associated with tasks encountered in a typical drilling operation, as well as influencing factors. Reference should also be made to [Appendix 8](#).

One of the most influential factors in personal exposure is the duration of exposure. The duration of exposure can be significantly increased by the contamination of inappropriate protective equipment, which may actually prolong contact with contaminants, particularly for dermal exposure, e.g. fabric gloves soaked in hydrocarbon or impermeable gloves contaminated on the inside.

Shaker house

High hydrocarbon mist and vapour exposure levels have been reported in shale shaker rooms. Workers may be exposed to drilling fluids either by inhaling aerosols and vapours or by skin contact. Main exposure opportunities are:

- washing with high-pressure guns using a hydrocarbon-based fluid;
- cleaning and changing screens; and
- checking the shaker screens for wear.

Several factors can be identified that might be expected to influence the exposure levels in the working atmosphere: drilling fluid

temperature; flow rate; well depth; well section; and the kinematic viscosity of the NAF.

Mixing hopper

The mixing hopper also provides an opportunity for exposure to chemicals and products as this is the point at which powdered products or liquid additives are introduced to the operation through a conical shaped device. Typically the narrow bottom section of the cone has a fluids circulating pipe passing through it. A choke provides a jetting action within the pipe which draws the materials added into the fluid being circulated.

The products and the associated additives are usually handled manually at the hopper. This can give rise to dust or splashing. Both of these conditions are potentially hazardous. More modern facilities enable powdered products to be handled mechanically even to the point of removing and disposing of the packaging. Liquid additives can be pumped into the hopper instead of manually poured.

The handling of powdered sacked products and liquid products from drums or cans, and the mixing of bulk powders such as barite, can cause exposure. Primarily this will be inhalation exposure as there may be dust associated with the movement of products in the storage area or with mixing products into the hopper. However, skin contact can also occur, particularly with powdered materials.

Alternatively, products and additives can be handled in bulk form from pre-loaded containers and added to the drilling fluid system from a remotely operated control zone, minimizing exposure at the rig site.

Fluids pit system

Personnel working over or around the fluids pit system can be exposed to high humidity resulting from the very warm drilling fluid forming condensate on contact with the cooler





atmosphere. Persons in this area are generally required to perform less complicated tasks but on a regular basis (every 15 minutes or so) with the potential for inhalation and skin contact.

Sack store

The handling of powdered sacked products, of liquid products from drums or cans and the mixing of bulk powders such as barite can cause exposure both by skin contact and by inhalation.

Drill floor

Contact with drilling fluids as well as lubricants, pipe dope, hydraulic oils, etc. by personnel on the drill floor is predominantly dermal contact which can be prolonged and repetitive due to the manual nature of the work involved. Contact may be through manual handling of unclean equipment surfaces, sprays, and spills from cleaning operations and high pressure washing.

Deck operations

Exposure can occur through contact with contaminated surfaces, spilled materials, handling of drilling fluid contaminated wastes, e.g. cutting containment and/or transportation systems.

Laboratory

During drilling, the drilling fluid is tested or checked by the mud engineer many times each day. This process requires sampling from a pit or flow line and using various forms of testing equipment to gain the necessary information about the fluid for analysis and remedial treatment purposes. One testing unit operates at high temperature to boil off the fluid fractions—oil and water. This test creates gases which can be uncomfortable to a person in the non-vented vicinity. Some regulations require the use of fume hoods and extract ventilation systems in the fluids testing laboratory.

More recent projects concern the development of drilling fluids testing apparatus. The benefit of this development will be that it removes personal contact with the respective fluids systems when testing for the fluids' characteristics. Potential exposure when testing is more likely to be by skin contact than by inhalation.

Due to the very limited quantities of drilling fluids and the controlled conditions which are typically involved in testing procedures, this is not considered further in the following tables. Extract ventilation systems are recommended.

Tables 2–7 contain generic information on likely exposure types and durations for these and other key tasks typically encountered in a drilling operation, as well as factors which may influence the level of exposure. This information is provided as a guide only—specific workplaces should be thoroughly assessed on a case-by-case basis.

Exposure scenarios and influencing factors

Table 2 Shaker house

General influencing factors: ambient temperature; indoors or outdoors; space and layout of the work area; general or local exhaust ventilation; HSE culture of the workforce, e.g. PPE discipline.

Task	Purpose	Exposure duration	Type of exposure	Influencing factors
Sampling	<ul style="list-style-type: none"> Mud weight and funnel viscosity measurements (before and after the shakers) 	<ul style="list-style-type: none"> Routine operation High frequency >15 minutes per hour 	<ul style="list-style-type: none"> Skin contact with fluid (hands) Inhalation of vapour/mist 	<ul style="list-style-type: none"> Fluid flow-line temperature Fluid characteristics and composition
	<ul style="list-style-type: none"> Cuttings sampling/ collecting (sample taken from the shaker) for oil on cuttings or for geological analysis of the rock formations 	<ul style="list-style-type: none"> Intermittent routine operation Up to 15 minutes per hour when sampling required 	<ul style="list-style-type: none"> Splashes of fluid (face/hands/body) Skin contact with fluid (hands) Inhalation of vapour/mist 	<ul style="list-style-type: none"> ROP and cuttings loading on screens Fluid flow-line temperature Fluid characteristics and composition
Maintenance	<ul style="list-style-type: none"> Changing shaker screens (shaker not operating) 	<ul style="list-style-type: none"> Intermittent routine operation; Up to 5 minutes per hour (guide only) 	<ul style="list-style-type: none"> Inhalation due to general work environment Skin contact with fluid contaminated surfaces 	<ul style="list-style-type: none"> ROP Shaker design Ergonomics Screen durability
	<ul style="list-style-type: none"> Routine maintenance of shakers 	<ul style="list-style-type: none"> Intermittent routine operation 	<ul style="list-style-type: none"> Inhalation due to general work environment Skin contact with fluid contaminated surfaces 	<ul style="list-style-type: none"> Shaker design Ergonomics
	<ul style="list-style-type: none"> Breakdown repair of shakers 	<ul style="list-style-type: none"> As required 	<ul style="list-style-type: none"> Inhalation due to general work environment Skin contact with fluid contaminated surfaces 	<ul style="list-style-type: none"> Shaker design and reliability Ergonomics
	<ul style="list-style-type: none"> Cleaning operations <ul style="list-style-type: none"> • screens • general workplace • header box/possum belly 	<ul style="list-style-type: none"> As required 	<ul style="list-style-type: none"> Inhalation due to general work environment and mist/aerosol from cleaning methods/ materials Skin contact with fluid contaminated surfaces Splashes to face/body/hands 	<ul style="list-style-type: none"> Cleaning methods/ equipment/ agents Ergonomics
<ul style="list-style-type: none"> Inspection/ monitoring 	<ul style="list-style-type: none"> Gas trap/ header box 	<ul style="list-style-type: none"> Routine operation High frequency >15 minutes/hour 	<ul style="list-style-type: none"> Inhalation due to general work environment Splashes to hands 	<ul style="list-style-type: none"> ROP dependent Ergonomics Design and layout of equipment
	<ul style="list-style-type: none"> Shaker operation or screens e.g. monitoring for screen blinding, damage to screen mesh 	<ul style="list-style-type: none"> Routine operation High frequency >5 minutes/hour 	<ul style="list-style-type: none"> Inhalation due to general work environment Splashes to face/body/hands 	<ul style="list-style-type: none"> Ergonomics Design and layout of equipment Solids characteristics/ volume Screen selection



Table 3 Mix area

General influencing factors: design and type of mix equipment; indoors or outdoors; space and layout of the work area; general or local exhaust ventilation; HSE culture of the workforce, e.g. PPE discipline; ambient temperature.

Task	Purpose	Exposure duration	Type of exposure	Influencing factors
Introducing solid chemicals to the drilling fluid system	<ul style="list-style-type: none"> Mixing through a venturi hopper 	<ul style="list-style-type: none"> Variable, hours to days 	<ul style="list-style-type: none"> Drilling fluid system additives: inhalation and skin contact of dust Skin contact with contaminated surfaces 	<ul style="list-style-type: none"> Venturi hopper design Packaging type Bulk transfer tanks Solid material characteristics Volume to be mixed
	<ul style="list-style-type: none"> Direct to mix tank/pit 	<ul style="list-style-type: none"> Variable, several hours 	<ul style="list-style-type: none"> Drilling fluid system additives: inhalation and skin contact of dust Skin contact with contaminated surfaces Splashing 	<ul style="list-style-type: none"> Mix system configuration Packaging type Solid material characteristics Volume to be mixed
	<ul style="list-style-type: none"> Through automated mixing system 	<ul style="list-style-type: none"> Variable, several hours possibly days 	<ul style="list-style-type: none"> Normal operations, no dust/ splashing exposure, as fully contained system 	<ul style="list-style-type: none"> Reliability of the system Suitability of products for use in the system Suitability of packaging
<ul style="list-style-type: none"> Introducing liquid chemicals to the drilling fluid system 	<ul style="list-style-type: none"> Mixing through a venturi hopper 	<ul style="list-style-type: none"> Variable, hours 	<ul style="list-style-type: none"> Drilling fluid system additives: skin contact with contaminated surfaces, potential for splashing 	<ul style="list-style-type: none"> Venturi hopper design Ergonomics Packaging type Liquid material characteristics Volume to be mixed
	<ul style="list-style-type: none"> Direct to mix tank/ pit 	<ul style="list-style-type: none"> Variable, hours 	<ul style="list-style-type: none"> Drilling fluid system additives: skin contact with contaminated surfaces, potential for splashing 	<ul style="list-style-type: none"> Mix system configuration Packaging type Liquid material characteristics Volume to be mixed
	<ul style="list-style-type: none"> Through automated mixing system 	<ul style="list-style-type: none"> Variable, hours 	<ul style="list-style-type: none"> Drilling fluid system additives: skin contact with contaminated surfaces 	<ul style="list-style-type: none"> Reliability of the system Suitability of products for use in the system Suitability of packaging
<ul style="list-style-type: none"> Handling packaging 	<ul style="list-style-type: none"> Containment and handling of waste packaging materials, sacks, big bags, drums, intermediate bulk containers 	<ul style="list-style-type: none"> Hours, continuous during mixing operations 	<ul style="list-style-type: none"> Drilling fluid system additives: skin contact with contaminated surfaces Dust and vapour inhalation from handling waste 	<ul style="list-style-type: none"> Packaging type Chemical characteristics Chemical compatibility Waste collection, storage and disposal methods

Exposure scenarios and influencing factors

Table 4 Sack store

General influencing factors: design and type of storage area; indoors or outdoors; space and layout of the work area; general ventilation; HSE culture of the workforce, e.g. PPE discipline; ambient temperature; weather conditions; design and type of mechanical handling equipment.

Task	Purpose	Exposure duration	Type of exposure	Influencing factors
Storage of chemical additives	<ul style="list-style-type: none"> Sack and drum storage of chemical additives to be used in mixing process 	<ul style="list-style-type: none"> Short term, intermittent 	<ul style="list-style-type: none"> Skin contact with contaminated surfaces Dust and vapour inhalation from handling damaged packaged materials 	<ul style="list-style-type: none"> Packaging type Chemical characteristics Layout and design of storage area
Manual handling of chemical additives	<ul style="list-style-type: none"> Movement of sacks and drums of chemical additives to and from mix area 	<ul style="list-style-type: none"> Short term, intermittent 	<ul style="list-style-type: none"> Skin contact with contaminated surfaces Dust and vapour inhalation from handling damaged packaged materials 	<ul style="list-style-type: none"> Packaging type Chemical characteristics Ergonomics
Mechanical handling of chemical additives	<ul style="list-style-type: none"> Movement of packaged chemical additives to and from mix area 	<ul style="list-style-type: none"> Short term, intermittent 	<ul style="list-style-type: none"> Dust and vapour inhalation from handling damaged packaged materials 	<ul style="list-style-type: none"> Packaging type Chemical characteristics

Table 5 Mud pits

General influencing factors: design and volume of pit storage area; indoors or outdoors; space and layout of the surrounding work area, i.e. open or enclosed tanks; general ventilation; local exhaust ventilation; HSE culture of the workforce, e.g. PPE discipline; ambient temperature; weather conditions.

Task	Purpose	Exposure duration	Type of exposure	Influencing factors
Use of tanks	<ul style="list-style-type: none"> Storage of bulk fluids 	<ul style="list-style-type: none"> Continuous 	<ul style="list-style-type: none"> Inhalation of vapour/mist 	<ul style="list-style-type: none"> Temperature of fluid Fluid surface area exposed Design and size of pits Workplace design
Manual pit cleaning	<ul style="list-style-type: none"> Removal of fluids/solids and cleaning of tank interior surfaces manually 	<ul style="list-style-type: none"> Continuous during cleaning operations 	<ul style="list-style-type: none"> Splashes, contact with contaminated surfaces, inhalation of vapour/mist 	<ul style="list-style-type: none"> Temperature Ergonomics Confined spaces Cleaning equipment design and operating methods Lighting
Automated pit cleaning	<ul style="list-style-type: none"> Removal of fluids/solids and cleaning of tank interior surfaces mechanically 	<ul style="list-style-type: none"> Limited to set up or removal of equipment 	<ul style="list-style-type: none"> Contact with contaminated surfaces, inhalation of vapour/mist 	<ul style="list-style-type: none"> Configuration of the tank Tank design Cleaning equipment design
Pit transfers or circulating	<ul style="list-style-type: none"> Movement of bulk fluids between pits, possibly using flexible hoses and pumps Agitation of fluid within tank 	<ul style="list-style-type: none"> Limited to connection and transfer time 	<ul style="list-style-type: none"> Contact with contaminated surfaces, inhalation of vapour/mist. Potential for splashing 	<ul style="list-style-type: none"> Transfer/agitation equipment design Operating methods Tank design Ergonomics



Table 6 Drill floor

General influencing factors: space and layout of the work area; general ventilation; HSE culture of the workforce, e.g. PPE discipline; ambient temperature; weather conditions; PPE type and suitability.

Task	Purpose	Exposure duration	Type of exposure	Influencing factors
Pipe handling	<ul style="list-style-type: none"> Casing handling, tripping, making connections, completion strings 	<ul style="list-style-type: none"> Continuous during tripping operations 	<ul style="list-style-type: none"> Skin contact with contaminated surfaces or pipe dope Splashes Inhalation and skin contact from vapour/mist 	<ul style="list-style-type: none"> Characteristics of pipe dope Degree of automation of drill floor activities Fluid temperature
Cleaning	<ul style="list-style-type: none"> Removal of fluid contamination 	<ul style="list-style-type: none"> During operations, intermittent 	<ul style="list-style-type: none"> Splashes, skin contact with contaminated surfaces Inhalation of vapour/mist aerosol 	<ul style="list-style-type: none"> Type of cleaning equipment and agents used

Table 7 Deck operations

General influencing factors: space and layout of the work area; design of equipment used; general and/or exhaust ventilation; HSE culture of the workforce, e.g. PPE discipline; ambient temperature; weather conditions; PPE type and suitability; ergonomics.

Task	Purpose	Exposure duration	Type of exposure	Influencing factors
Cuttings handling	<ul style="list-style-type: none"> Cuttings containment systems, cuttings conveyance 	<ul style="list-style-type: none"> Continuous 	<ul style="list-style-type: none"> Skin contact with contaminated surfaces Splashes Inhalation and skin contact from vapour/mist 	<ul style="list-style-type: none"> Temperature Volume and characteristics of material Design and operating methods of conveyance equipment
	<ul style="list-style-type: none"> Cuttings skip filling operations and skip storage 	<ul style="list-style-type: none"> Continuous during drilling 	<ul style="list-style-type: none"> Skin contact with contaminated surfaces Potential for splashes Inhalation and skin contact from vapour/mist 	<ul style="list-style-type: none"> Design and operating methods of skip filling equipment Ergonomics Space and layout of the work area Volume and characteristics of material
Cuttings treatment	<ul style="list-style-type: none"> Cuttings slurrification and re-injection, including sampling and analysis 	<ul style="list-style-type: none"> Continuous during drilling and re-injection operations 	<ul style="list-style-type: none"> Potential for splashes Inhalation and skin contact from vapour/mist 	<ul style="list-style-type: none"> Temperature Volume and characteristics of the slurry Equipment design
	<ul style="list-style-type: none"> Thermal processing of cuttings 	<ul style="list-style-type: none"> Continuous during treatment 	<ul style="list-style-type: none"> Inhalation from emissions Dust inhalation from treated cuttings 	<ul style="list-style-type: none"> Temperature Design and operating methods of the treatment equipment Space and layout of the workplace

Exposure scenarios and influencing factors

Exposure monitoring

Workplace monitoring to assess the level of exposure in the work area or to a particular individual is a critical aspect of the risk management process and should be carried out regularly to assess the effectiveness of the controls in place and drive improvements.

Air monitoring

Monitoring for dust, aerosol and vapour is a good way to accurately assess the level of drilling fluid component products present in the working atmosphere. The methods that need to be used to collect samples will vary with the chemical constituents of the drilling fluid systems in use and the duration of the sample. Common methods include:

- colorimetric detector tubes;
- passive and active adsorption samplers;
- filters;
- direct reading instruments; and
- adsorption methods.

(See [Appendix 9](#) for further information.)

Skin monitoring

A common and effective approach to personal monitoring is skin monitoring. Methods of skin monitoring include:

- passive dermal monitoring;
- visual examination;
- trans-epidermal water loss; and
- skin moisture level measurement.

(See [Appendix 9](#) for further information.)

Workplace health surveillance

Workplace health surveillance is a process designed to systematically detect and assess the early signs of adverse health effects on workers exposed to certain health hazards. Methods can be simple or more complex depending on the risks to workers from the job hazards and the substance, for example:

- monitoring for signs of skin irritation when a worker is potentially exposed to a substance that can cause dermatitis or sensitization;
- medical surveillance including biological monitoring to check for the presence of toxins in the body, e.g. testing blood or urine for benzene or heavy metals.

For workplace health surveillance to be applicable, there are criteria which should be considered:

- There is an identifiable disease or other identifiable adverse health outcome.
- The disease or health effect is related to exposure.
- There is a likelihood that the disease or health effect may occur.
- Valid techniques exist for detecting indications of the disease or health effects.

Further information on specific methods which can be used for health surveillance associated with drilling fluids is provided in [Appendix 10](#).

Health records

Where health surveillance information such as lung function test data is documented, records may have to be maintained for a minimum number of years if specified by legislation. In the absence of legislation, OGP/IPIECA Report No. 393³⁹ suggests maintaining health records for a minimum of 40 years after the individual leaves employment.

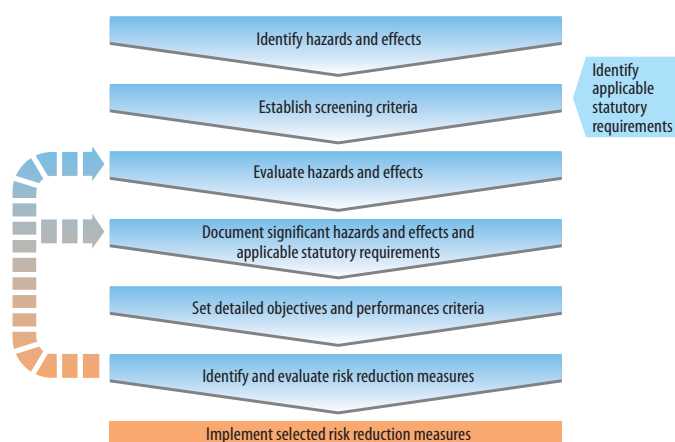


Risk management

The best way to minimize occupational exposure to hazardous substances is through the adoption of risk management principles, which are the key to identifying successful workplace HSE controls.

The risk management process is an iterative process of continuous improvement and should continue throughout the lifecycle of the drilling operation (see Figure 7³⁶). In order to identify the potential hazards it is imperative that persons with the responsibility for the design and selection of drilling fluid systems make information regarding all the constituents of those systems available to those responsible for the risk management process.

Figure 7 The risk management process



Hierarchy of risk controls

At each stage of a drilling operation, if hazardous components of drilling fluids have been identified, together with a risk of exposure, the following hierarchy of controls should be considered:

- Elimination
- Substitution
- Engineering controls
- Administrative controls (hygiene measures, working hours, awareness and training)
- Personal protective equipment.

Elimination

A goal of all operations should be to avoid the use of hazardous substances, and to avoid procedures which may cause exposure. Various brands of additives and chemical products may be at hand for personal preference reasons or as recommended by a particular manufacturer in cases where an alternative common additive could be used. Numerous chemicals with identical properties and functions may therefore be available on site, which may be unnecessary and could impede risk management. Every operation should strive to reduce the number of chemicals being used to an absolute minimum.

Substitution

The hazard presented by a drilling fluid not only depends on the main constituent but also on the additives used. The primary observed effect after repeated exposure to drilling fluid is dermal irritation and dermatitis. Dermal irritation may be caused by C9–C14 paraffinic and aromatic hydrocarbons, as well as by some additives. Use of an aqueous drilling fluid or a non-aqueous drilling fluid based on Group III hydrocarbons (such as esters, alpha olefins or linear internal olefins) may decrease the irritation hazard.

Drilling fluids with a high aromatic content may contain minimal amounts of benzene and a significant level of PAH, and may form a carcinogenic hazard. In addition, diesel-based



Risk management

drilling fluids may form a carcinogenic hazard due to chronic skin irritation. Using aqueous drilling fluids or fluids with a low aromatic content will decrease the carcinogenic hazard.

Engineering controls

Ideally the design of the workplace will incorporate the engineering controls required to provide a workplace which minimizes exposure of hazardous substances to the workforce. Certain older rigs cannot always accommodate the larger ventilation systems or modified flow lines that serve as engineering controls to minimize personnel exposure to certain drilling fluid systems. The ability of the rig to accommodate, or be modified to accommodate, the engineering controls needed to reduce personnel exposure to acceptable limits should be considered in the contracting process.

Over recent years many new technologies have been developed to address inferior work environment conditions. Some examples are given below.

Managed pressure drilling (MPD) and under-balanced drilling (UBD)

Both MPD and UBD practices require that bell nipple areas and flow lines to the shakers be enclosed and that they are able to tolerate greater than atmospheric pressures. These practices ensure that gases, vapours and condensation issuing from the drilling fluid circulated from the well bore are contained. Such practices are not common to all drilling operations but mainly used when these specific drilling techniques are employed.

Shale-shaker ventilation canopies

While improvements and experience with effective ventilation technologies are being realized, ventilation canopies enclosing shakers are being used more often.



Bulk handling and enclosed mix systems

More modern facilities enable powdered products to be handled mechanically even to the point of removing and disposing of the packaging. Liquid additives can be pumped into the mixing system instead of manually poured. Alternatively, products and additives can be handled in bulk form from pre-loaded containers and added to the drilling fluid system from a remotely operated control zone.

Use of sensors in closed drilling fluid tanks

The use of sensors has allowed drilling-fluid tanks to be completely enclosed, with control panels used to monitor tank levels (rather than visual inspection). This reduces the emission of gases, vapours and condensate to the work environment.

Introduction of real-time measurements

Automatic sampling and/or testing devices can reduce exposure through avoidance of the need to sample drilling fluids from open hatches/open tanks.

Administrative controls

Hygiene measures

Laundry practices

Protective clothing as well as skin becomes contaminated by chemicals, and it is essential that this should be washed frequently. One of the most common sources of skin irritation at



the well site has been due to the ineffective washing of coveralls and safety clothing. If not laundered properly, work clothing will retain fluid residue that can cause skin irritation the next time the clothing is worn. The following procedures are recommended when washing clothing soiled with NAFs:

- Do not overload washers.
- Designate one washer for drilling-fluid saturated clothing. Clothing that is not soiled with NAF fluid should always be washed in a separate washer.
- When washing contaminated clothes, run the clothes through at least two wash cycles using hot water and detergent. Additional cycles may be needed if the clothing is extremely soiled with drilling fluid.
- If it is not possible or practical to wash repeatedly, pre-soak the contaminated clothing in a laundry detergent solution for one to two hours before laundering.

Washing facilities

Removing all dirt and contaminants from the skin at the end of a day and during work breaks is extremely important, requiring the provision of adequate washing facilities. These include, as a minimum, an adequate supply of hot and cold running water, nail brushes and clean towels.



Rinsing in warm (not hot) running water and complete drying of the skin will help to reduce further the incidence of dermatitis; clean towels are preferable to air driers because the latter can de-fat the skin, and the time taken to dry the skin often leads to them not being properly used. The skin should be properly dried to avoid the risk of chapping, particularly during cold weather. Clean towels should therefore be available at all times; dirty towels mean exposing the skin to more dirt and bacteria, and to the risk of infection. The washing water available on a rig-site can be variable, with the hardness and pH being dependent on the source of the water; these factors can also contribute to a general drying of the skin.

Skin cleansing

Washing with soap and water is the most effective way of removing dirt and grime, provided the skin is not heavily soiled. However, choice of the correct soap is important: a quality soap that gives a good lather with a particular water supply will provide safe and often adequate cleansing.

The use of solvents and abrasives should be avoided. They tend to remove too much of the skin's natural grease, making it more vulnerable to other irritants, and can also cause dermatitis or other harm to the skin. Special skin cleansers are now widely available which allow safe and effective removal of dirt and irritants without upsetting the structure of the skin or its functions.

For external sites where no piped water supply is available, there are special waterless skin cleansers and cleansing wipes.

Barrier cream

General-purpose barrier creams are designed to protect against either water-soluble or solvent-soluble irritants. Their efficiency is limited and they cannot in any way be regarded as a substitute for good occupational hygiene practice and good skin cleansing and

Risk management

reconditioning practices. The main advantage of a barrier cream is that it facilitates the removal of contamination from skin.

The cream should be properly applied to the skin surface in hygienic conditions. Even when properly applied, its effectiveness will reduce after only 2 to 3 hours and it should be re-applied; the cream should also be re-applied after washing the hands. Barrier creams offer no effective protection for a person who has already been sensitized, because in such a case the person would react to very low amounts of the sensitizer. Some people can react to the ingredients of barrier creams and the use of these creams, especially under protective impermeable gloves, can in itself cause skin irritation. Barrier creams should be provided in hygienic wall-mounted dispensers at each changing area, with an alternative for use by personnel who may experience a reaction to a particular brand.

Skin reconditioning

The use of a reconditioning cream is often the most important stage in skin care, and generally the one which is not performed at all. The use of a conditioning cream at the end of the working day helps to replace the natural fats and oils which have been stripped from the skin by contact with chemicals and frequent cleansing. The reconditioning cream also helps to replace damaged skin cells and minimize infection of any cuts, scratches or abrasions of the skin. Reconditioning cream should be applied to clean, dry skin in the same way as barrier cream.

The installation of specially designed dispensers for use with liquid and gel skin cleansers and creams is strongly recommended. Such dispensers reduce to a minimum the risk of cross-infection and cream contamination that can occur if a number of people use the material from an open or communal container. Such dispensers should also be used in shower cubicles.

Working hours

A useful administrative control is to modify shift patterns and rotate jobs, thus limiting hours of exposure to potential hazards.

Awareness and training

Awareness and training on the hazardous materials, potential exposures and their health effects are critical.

- Material Safety Data Sheets should be provided for drilling fluid systems, components and additives.
- Material Safety Data Sheets for all drilling fluid system components and additives should be reviewed with personnel prior to working with these chemicals.
- Personnel should be trained in the recommended handling procedures; the selection, maintenance and storage of appropriate PPE; rig health and safety equipment; and procedures for reporting occupational illnesses such as skin irritations and for reporting to operation supervisors drilling practices that may be increasing exposure levels.
- Medical personnel should be selected giving consideration to their experience and expertise in the diagnosis and initial treatment of acute occupational illnesses related to the handling of these chemicals.





Emergency situations

Emergency situations, such as a major spillage or release, should be considered when designing administrative controls for normal activities.

Personal protective equipment

One of the most significant factors in effective personal protective equipment (PPE) usage is personal comfort. People will not wear personal protective equipment properly if it is uncomfortable or if their movement is restricted.

The use of protective clothing is advised to prevent direct contact with chemicals. PPE may include chemical splash goggles, appropriate chemical-resistant impermeable gloves, rubber boots, coveralls, and for roughnecks, slicker suits, when performing tasks such as tripping wet pipe or in work environments that are heavily contaminated with oil mist³⁷.

Wearing chemical resistant gloves and clothing is usually the primary method used to prevent skin exposure to hazardous chemicals in the workplace. Glove and protective clothing

selection is usually based on manufacturer's laboratory-generated chemical permeation data. This is unlikely to reflect actual conditions in the workplace, e.g. elevated temperatures, flexing, pressure and product variation between suppliers³⁸.

To minimize worker exposure to heat stress in areas where the ambient temperature is very high, disposable chemical-resistant coveralls can be utilized instead of slicker suits. Regular changes of these disposable suits and/or chemical resistant gloves may be required depending on breakthrough time and level of contamination.

When working with drilling fluids, if ventilation is not adequate it is recommended that goggles and self-contained respirators are worn at all times. Respiratory protective equipment (RPE) is considered to be a last resort. RPE should only be considered when exposure cannot be adequately reduced by other means. It is vital that the RPE selected is adequate and suitable for the purpose. It should reduce exposure to as low as reasonably practicable, and in any case to below any applicable occupational exposure limit or other control limit. To make sure that the selected RPE provides adequate protection for individual wearers, fit testing of RPE including full-face masks, half-face masks and disposable masks is strongly recommended. This will help to ensure that inadequately fitting face masks are not selected.

Positive pressure is not a substitute for adequate fit, it only provides an additional margin of protection. Combination filters with organic vapour cartridges should be used when performing activities where there is the potential for hydrocarbon exposure.



Conclusions and summary of recommendations

Personnel involved in drilling operations may be exposed to hazardous components of drilling fluids. Therefore, the principles of risk management and risk control should be implemented where possible, with the aim of minimizing occupational exposure to hazardous substances.

Key principles are as follows:

- Understand the constituents of drilling fluids and their health effects.
- Understand exposure routes and influencing factors.
- Manage the risks by adopting the standard risk control hierarchy:
 - Elimination
 - Substitution
 - Engineering controls
 - Administrative controls
 - Personal protective equipment.

Monitor exposures and health effects, and review controls regularly for continued effectiveness.

Best practices include:

- The selection of effective and reliable control options which could minimize exposure to chemicals and substitute hazardous chemicals with substances less hazardous to health.
- The design of engineering controls and operating processes to minimize emission, release and spread of substances hazardous to health.
- Control measures proportionate to the health risk. Controls should take into account all relevant routes of exposure.
- Monitoring to quantify exposure in the work environment.
- Provision of information and training to workers related to the hazards and the effective use of control measures.
- The application of relevant health surveillance practices.
- Auditing and reviewing the effectiveness of control measures.
- Continuous improvement.





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Abbreviations

ACGIH®	American Conference of Governmental Industrial Hygienists	OEL	Occupational exposure limit
BTEX	Benzene, toluene, ethylbenzene and xylenes	OGP	International Association of Oil & Gas Producers
HSE	Health, safety and environment	PAH	Polycyclic aromatic hydrocarbons
IO	Internal olefins	PAO	Poly-alpha olefins
LAO	Linear alpha olefins	PPE	Personal protective equipment
LP	Linear paraffin	ppm	parts per million
LSA	Low specific activity scale contamination	ROP	Rate of penetration (drilling)
mg/m ³	milligrammes per cubic meter	TLV	Threshold limit value
NAF	Non-aqueous fluids	TWA	Time-weighted average
NIOSH	National Institute of Occupational Safety and Health, USA	WBF	Water-based fluid



Glossary of terms

Aerosols	Suspension of variable size particles capable of remaining airborne.	Gases	Substances which normally exist in gaseous form at standard pressure and temperature.
Biological monitoring	Testing for the presence of a hazardous substance, its metabolites or a biochemical change in a person's body tissue, exhaled air or fluid.	Hazard	The hazard presented by a substance is its potential to cause harm.
Carcinogenic	Capable of causing cancer.	Hazardous substance	A chemical or other substance that can affect workers health, causing illness or disease; and any substance for which the supplier, manufacturer or importer must provide a current material safety data sheet. Since September 1997, hazardous substances include those with carcinogenic, mutagenic and teratogenic effects, and cytotoxic drugs.
Chemical name	The scientific or technical name of a substance.		
Code of practice	A systematic collection of rules, standards and other information relating to the practices and procedures followed in an area.		
Control measures	Ways of preventing or minimizing a person's exposure to a hazardous substance. A hierarchy of controls ranks measures taken to prevent or reduce hazard exposure according to effectiveness.	Health surveillance	The monitoring (including biological monitoring or medical examination) of a person in relation to the person's exposure to a hazardous substance. Surveillance is for the purpose of identifying changes in health status due to exposure.
Corrosive	Capable of destroying materials or living tissue (e.g. skin) on contact.	Hierarchy of controls	Ranking of measures taken to prevent or reduce hazard exposure according to effectiveness. That is from the most effective measures that eliminate hazards to the least satisfactory that achieve only limited protection.
Cytotoxic	Having the property of being destructive to living cells.		
Dusts	Caused by mechanical abrasion or fragmentation of solids, the size of particles is 0.1–100µm (microns).	Mists and fogs	Condensation or liquid particles, which produce liquid aerosols.
Exposed	A person is exposed to a hazardous substance if the person absorbs, or is likely to absorb the substance by ingestion or inhalation or through the skin or mucous membrane.	Smokes	Suspension of solid particles produced by incomplete combustion of organic materials; size of particle usually less than 0.5mm and particles do not settle readily.
Fumes	Produced by combustion, sublimation or condensation of volatile solids, the size of particle is usually less than 0.1 mm but fumes have a tendency to flocculate and produce larger particles as the aerosol ages.	Vapours	Gaseous form substances normally liquid at standard pressure and temperature.

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International Association of Oil & Gas Producers (OGP)

OGP represents the upstream oil and gas industry before international organizations including the International Maritime Organization, the United Nations Environment Programme (UNEP) Regional Seas Conventions and other groups under the UN umbrella. At the regional level, OGP is the industry representative to the European Commission and Parliament and the OSPAR Commission for the North East Atlantic. Equally important is OGP's role in promulgating best practices, particularly in the areas of health, safety, the environment and social responsibility.

International Petroleum Industry Environmental Conservation Association (IPIECA)

The International Petroleum Industry Environmental Conservation Association was founded in 1974 following the establishment of the United Nations Environment Programme (UNEP). IPIECA provides one of the industry's principal channels of communication with the United Nations.

IPIECA is the single global association representing both the upstream and downstream oil and gas industry on key global environmental and social issues. IPIECA's programme takes full account of international developments in these issues, serving as a forum for discussion and cooperation involving industry and international organizations.

IPIECA's aims are to develop and promote scientifically-sound, cost-effective, practical, socially and economically acceptable solutions to global environmental and social issues pertaining to the oil and gas industry. IPIECA is not a lobbying organization, but provides a forum for encouraging continuous improvement of industry performance.




Appendix 1: Historical developments in drilling fluid design

Water-based fluids (WBFs)

Figure 1 shows the development trend of water-based drilling fluids from very simple systems to highly complex chemical compositions. The technical advances in composition have primarily been to:

- prevent the softening and sticking of clay cuttings to the drill-string and pipe assembly;
- improve lubricity to reduce drilling torque and drag; and
- enable environmental compliance while allowing discharge of drill cuttings.

Figure 1 History of water-based drilling fluid development




Fresh water—bentonite. Dispersed gel muds (gel / lignosulphonate, gel / CMC)	1950s
Gypsum or lime-treated gel muds (gyp-FCL or gel / seawater)	
Non-dispersed polymer system with KCl	1970s
CaCl ₂ / polymer system	
KCl / polyacrylamide systems	1980s
New generation of polymer Water-based fluids glycol inhibited, silicate inhibited	1990s
Latest version of polymer Water based fluids polyamine inhibited	2000s

These improvements in technical specification have been required as environmental legislation and well design have become more demanding.

Non-aqueous fluids (NAFs)

Figure 2 expresses the development trend of hydrocarbon-based drilling fluids. The recognition of their benefit in the earliest years was to prevent the softening and sticking of clay cuttings to the drill string and pipe assembly. Later the benefit of lubricity was realized as well designs became more challenging. More recently, technical, environmental and health considerations have influenced the development of the various types of NAF.

Figure 2 Trends in non-aqueous drilling fluids formulation



1920	Engineering	Environmental	Health/safety	To date
Group I	Group I	Group I (early)	Group II	Group III (late)
C ₂ and up Crude oil Naphthenes PAH	C ₈ and up Diesel oil Naphthenes	C ₁₁ – C ₂₀ Mineral oil Naphthenes	C ₁₁ – C ₂₀ Low toxicity mineral oil Paraffins	Man-made C ₁₅ – C ₃₀ Esters, ethers PAO, acetals LAB, LAO, IO, LP Highly refined paraffins
High aromatics FP 20–90°F	Aromatics 15–25% FP 120–180°F	Aromatics 1–20% FP 150–200°F	Aromatics <1% FP >200°F	No aromatics FP >200°F

Appendix 2: Functions of drilling fluids

A schematic of the drilling fluid circulation system for well and rig is shown in Figure 1. The functions of drilling fluids include the following:

Barrier for well control

The drilling fluid is recognized as a primary barrier in a well for controlling down hole pressures and for the consequential avoidance of uncontrolled gas or fluid intrusions from the formations being drilled or exposed.

Cuttings removal

Drilling fluids must be able to remove cuttings from the well bore as they are produced. Drilling fluid is pumped down the drill string and out through the bit, circulating cuttings to the surface up the annulus where they are removed by solids removal equipment. The fluid is then re-circulated through the hole. This process is repeated as drilling progresses. To lift the cuttings out of the hole effectively, the fluid must have some viscosity. Clays and polymers can provide this viscosity.

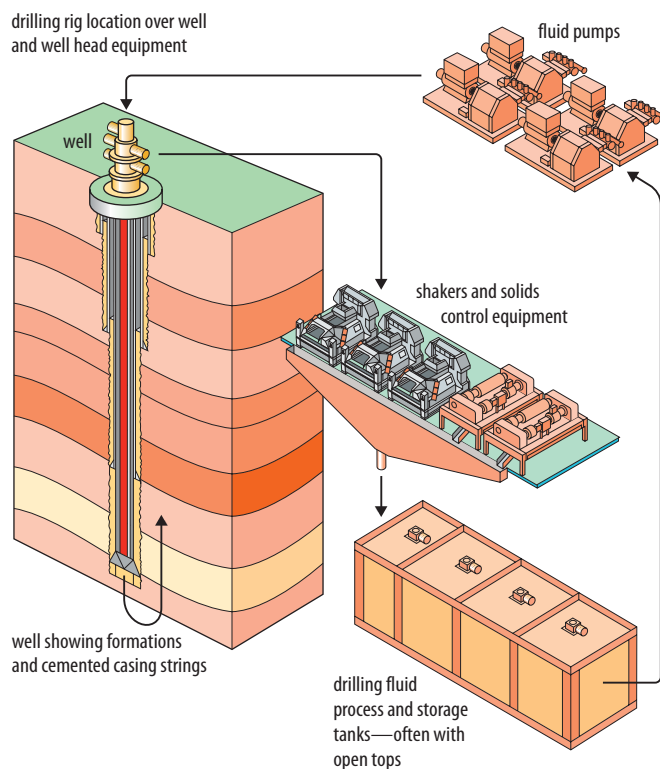
Suspension of cuttings

When drilling fluid circulation is stopped, the instantaneous gel strength of the drilling fluid must be sufficient to maintain the cuttings in suspension for a reasonable period of time. The additives used to increase drilling fluid viscosity, such as clays and polymers, are also selected for their properties as gelling agents.

Transmission of hydraulic power to the drilling bit

There is a relationship between the rate of penetration (ROP) and the hydraulic power of the drilling fluid exiting the drill bit. By selecting fluid components to ensure that optimized hydraulic pressure is expended across the bit, rather than in other sections of the circulation system, the ROP may be substantially improved. Pressure losses arising from viscosity and friction with the drill-pipe and bore walls reduce the available hydraulic power to the bit and bottom hole drilling assembly. Drilling fluids having high lubricity coefficients and low viscosity characteristics while in circulation may thus be required.

Figure 1 Fluids circulating system of a rig and well



Maintaining formation stability

Depending upon the drilling fluid and the formation contacted, fluids may interact with formations. Formation damage is more prevalent with water-based fluids, as the water may interact with salt bearing and clay formations. The formulation of new inhibitive water-based fluids has led to a wide selection of suitable additives which provide less formation damage potential than traditional water-based drilling fluids. Interactions between non-aqueous fluid (NAF) based drilling fluids and formations are significantly reduced as the drilling fluids are more inhibitive, reduce water contact with the formation, and allow less complex drilling fluid formulations of higher technical performance.

Maintaining pressure on the formation

The hydrostatic pressure of the drilling fluid must be sufficient to prevent inflow of formation fluids into the well, and also prevent the wall of the well collapsing. In the majority of cases a weighting agent is added to the drilling fluid, commonly barium sulphate (barite), or occasionally hematite or ilmenite to give the necessary density.

Filtration loss control

Drilling fluid loss can occur when drilling through porous and permeable formations. A wide range of materials as simple as shredded paper and straw to more complex blends, or proprietary polymer products are used to control filtration rates. Control of fluid loss is important both for maintaining pressure control and reducing damage to the formation.

Cooling and lubrication of the drill bit and drill string

Cooling and lubricating the drill bit and drill string are important, especially when drilling in deep or highly deviated wells where temperatures are hotter and the torque on the drill is higher. Hydrocarbons, graphitic or

microspheres may be used to increase lubricity in water-based fluids. NAF-based drilling fluids have an inherently low coefficient of friction. Both water and NAF-based systems are effective at cooling the drill bit. NAF-based drilling fluids can generally be used at higher temperatures due to the adverse reactions of many water-based products when exposed to higher temperatures.

Data logging

Drilling fluids characteristics need to be controlled so that logging instruments can accurately provide information about the well and formations being drilled.

Appendix 3: NAF-based fluids technical data

Table 1: NAF-based fluids technical data

Name	SG	Flash point (°C)	Pour point (°C)	Aromatics (%)	Viscosity 20 °C	Viscosity 40 °C	Aniline point (°C)	Boiling point range (°C)
ACETAL	0.84	129						
BP 8313	0.781	78	-40	2	2.36	1.67	82	195
BP 83HF	0.79	95	-10	5		2.4	88	220
CLAIRSOL	0.77	104		0	2.5		93	
CLAIRSOL 350M	0.7–0.81	72	-35	3	1.7–2.1		76	210–280
CLAIRSOL 350 MHF	0.818	100	-18	2		2.3	78	215–305
CLAIRSOL 370	0.79	100	-29	0.6–1.0	3.3	2.4	80	225–290
CLAIRSOL 400	0.794	98		3.8	3.7	2.5		235
CLAIRSOL 430	0.79–0.816	100		5	3.7	2.8–3.2	82	225–355
CLAIRSOL 450	0.815	93		4.4		3.4		225
CLAIRSOL 500	0.814	130		7.7		3.7		274
CLAIRSOL NS	0.82	122	-18	<0.5		3.4	84	261–293
CLAIRSOL NT	0.76	>90	-6	<0.1		1.8	91	
CLAIRSOL 2000 *	0.767	91	-6			1.8	93	>250
CONDRIIL A	0.796	69		4.6	1.88	1.56		176
DF1	0.82	75	-50	0.15	2.4	1.7	73	198–254
DIESEL	0.865	65	0	60			130	176
DIESEL	0.845	56	-21			3		
DIESEL No.2	0.8	54		45		1.9–3.4		204–337
DMF 120	0.82	74		3	2.44	1.72	73	185
DMF 120V	0.813	77		2.85	3.86	2.56	82	200
DMF 120 HF	0.8	100	-10	3.9	4.5	2.9	82	200
EDC 95-11	0.814	115	-27	<0.1		3.5	91	250–335
EDC99DW	0.811	100	-51	<0.01		2.3	80	230–270
EMO 4000	0.81	103	-30	0.55		2.2	77.4	236
ENERGOL HP0	0.784	66		1		1.7	82	195
ESCAID 110	0.804	70	-20	0.4		1.64	72	192–245
ESCAID 120	0.818	101	-24	0.9		2.36	78	235–270
ESCAID 300	0.76	97				2.4		221–248
EVCO LT4	0.82	130		8		3.8		266
FINA ISO 8267	0.82	60				1.5		
FINALAN	0.81	77		0.7				
HDF 100	0.808	95	-45	5		2.8	83	215
HDF 150	0.808	95	-45			2.7	84	215
HDF 200	0.814	100	-30	6	5	3.2	86	230
HDF 2000	0.803	105	-22	1		3.5	89	230
HDF 2000 PLUS	0.808	>102		<1				

continued ...

Drilling fluids and health risk management

A guide for drilling personnel managers and health professionals in the oil and gas industry

Appendix 3: NAF-based fluids technical data

Name	SG	Flash point (°C)	Pour point (°C)	Aromatics (%)	Viscosity 20 °C	Viscosity 40 °C	Aniline point (°C)	Boiling point range (°C)
HDF 250	0.815	105	-30			3.3	86	245
HDF 300	0.812	125	-20	5		3.6	90	260
HFD MF	0.822	101	-18	2.4		2.99		225
HT40N	0.83	126	-33	<2.2		3.4	79	256
IL 2803	0.81	103	-30	0.55		2.2	77.4	236
IL 2832	0.83	115	-20	3.8	7.5	4.4	81	242
IL 3000	0.815	100	-30	4		2.9		
KL 55	0.86	142		3.9		6.6	78	294
KL 66	0.834	80	-24		5.9	3.5	80	220
Lamium 11	0.805	80	-24	1		2		205
LA 12	0.816	74	-12		5.5	3.3	81	178
LAB	0.86	126			4			
LAO	0.78	113			2.28			
LVT200	0.814	94	-46	0.5		2.1	78	216
LVT52	0.808	93	-60	3		1.56		179
MDF300	0.81	>93	<-4	<0.1		3		
MOSSPAR H	0.8	90	-30			<7		220–380
PAO	0.8	160						
PETROFREE	0.86	179	-30	0	6		0	
PUREDIL HT-30	0.81	95	-18	<0.9		2.9	95	
PUREDIL IA-35	0.835	120	-57			3.5	90	
PUREDIL IA-35LV	0.816	96	-63	<0.1		2.64	82	
RAD 564	0.77	85		0.05		1.69	80	
RAD 569	0.82	80	-21	3	3.1	2.1	75	220
RAD 569M	0.805	59	-21	6	2.9	2	77.5	175
SARALINE 185	0.783	>85	3		2.6			175–360
SARALINE 200	0.783	>95	<8		3.7	<0.05		200–360
SARAPAR 103	0.73	75	-18		1.6			
SARAPAR 147	0.76	120	<9		2.5			225–300
SASOL		80	-8	0.1		<3		
SAFRASOL D80	0.787	81		0.1			78	207
SHELLSOL D70	0.79	72	-30		2.1	1.5	75	194
SIP 1	0.825	102	-35	0.3		2.3	80	230–310
SIP 2\0	0.7605	92	-7	<0.1		1.76	88	>211
SIP 4\0	0.8275	132	-57	0		3.8	92	>249
SIPDRIL 4.0	0.82	104	-51	<0.01		2.7	84	230–310
SURDYNE B140	0.796	95	-30		2.7	2.1	78	220–275
SURDYNE B200		114	-6		3.1	2.1		245–290
TSD 2832	0.83	109		4.1		4.6	87	242
XP-07	0.767	91	-6			1.8	93	>250

Drilling fluids and health risk management

A guide for drilling personnel managers and health professionals in the oil and gas industry

Appendix 3: NAF-based fluids technical data

Table 2: Physical and chemical characteristics of commonly used NAF base fluids

Base fluid type	Diesel	Total HDF-200	Total DF-1	Total EDC 95/11	Total EDC99DW	Carless XP-07	Carless Clairsol NS	SIP 1	SIP 2/0	SIP 4/0	Escaid 110	Escaid 120	Escaid 300
OGP NAF Classification Group	I	II	III	III	III	III	III	III	III	III	III	III	III
Odour	Characteristic		slight	none	faint	mild	mild						
Density as SG at 15 °C	0.845	0.812	0.82	0.814	0.811	0.761	0.827	0.825	0.7605	0.8275	0.804	0.818	0.76
Kinematic viscosity in cSt at 40°C	3.0	3.2	1.7	3.5	2.3	1.7	3.2	2.3	1.76	3.8	1.64	2.36	2.4
Flash point in Pensk.M as °C	56	93	75	115	100	92	122	102	92	132	70	101	97
Pour point as °C	-21	-30	-50	-27	-51	-9	-18	-35	-7	-57	-20	-24	
Boiling range as °C		230–325	198–254	250–335	230–270	215–255	261–293	220–310	211–235	243–352	192–245	235–270	221–248
Aromatics as % weight	20	<1	0.15	<0.1	<0.01	< 0.1	<0.5	0.3	< 0.1	0.00	0.4	0.9	
Sulphur content as ppm		3,120		0	0			< 5	< 1				
Skin irritation—OECD 404 test			Non-irritant	Non-irritant	Non-irritant	Mild irritant	Mild irritant	Non-irritant	Non-irritant	Non-irritant			
Vapour pressure (Pa) @ 20 °C			13	0.3	2.7	4.8	0.25	<100			17.7	1.5	
Vapour pressure (Pa) @ 60 °C	1,650 @50 deg	284 @50 deg	214,900	10.3	59.3	105.5	12.2		478				
Vapour pressure (Pa) @ 80 °C	3,330 @75 deg	685 @75 deg	689,200	42.3	205,200	359	55		1,620				
Vapour pressure (Pa) @ 100 °C	10,600	3,804	1,885,100	145,600	631,100	1,110	285		4,200				

Appendix 4: Characteristics of non-aqueous drilling fluids additives

Physical characteristics of non-aqueous fluids					
Primary product function	Type of material	Requirement in NAF	Hazardous classification	Hazardous components	Handling and PPE recommendations
Weighting agent	Barite, ilmenite, hematite, calcium carbonate	Generally barite, almost always	Not classified, dust hazard	May contain SiO ₂ , respiratory hazard. Mechanical irritation of skin or eyes.	Wear appropriate dust mask/ respirator with filter suitable for the particle size of the dust. Wear safety goggles to protect from mechanical eye irritation. Gloves to protect from mechanical skin irritation.
NAF base fluids (OGP Group III)	Linear paraffins, synthetic iso-alkanes, highly refined mineral oils, olefins	Yes, from 50–95% by volume	Harmful, may cause lung damage if swallowed, some may cause dryness of skin on prolonged or repeated contact	Hydrocarbon aspiration risk if viscosity is <7cSt @ 40 °C. Hydrocarbon may cause skin dryness.	Safety goggles to protect from mist and splashing to the eyes. Organic vapour mask/respirator to protect from inhalation of hydrocarbon mist/vapour. Oil resistant gloves, boots and slicker suits to protect from prolonged skin contact. Effective ventilation systems are essential.
Primary emulsifier (generic)	Hydrophilic and hydrophobic compounds in a carrier fluid - soaps, amines, imidazolines, fatty acid derivatives	Yes, always	May be harmful to skin, eyes, by inhalation or if swallowed. Irritating to skin and eyes. May have aspiration risk, viscosity dependent.	Surfactant fatty acids/ amine derivatives, tall oil reaction products. Hydrocarbon based carrier fluid. Check the MSDS for specific details.	Safety goggles to protect from splashing to the eyes. Organic vapour mask/ respirator if atmosphere heavily contaminated. Chemical/ oil resistant gloves and slicker suits or aprons to protect from prolonged skin contact.
Secondary emulsifier (generic)	Hydrophilic compounds with a positive end in a carrier fluid— polyamides, soaps, amines, imidazolines, fatty acid derivatives	Dependent on NAF type	Irritating to skin and eyes. May have aspiration risk, viscosity dependent.	Surfactant fatty acids/ amine derivatives, tall oil reaction products. Hydrocarbon based carrier fluid. Check the MSDS for specific details.	Safety goggles to protect from splashing to the eyes. Organic vapour mask/ respirator if atmosphere heavily contaminated. Chemical/oil resistant gloves and slicker suits or aprons to protect from prolonged skin contact.
Wetting agent	Hydrophilic compounds primarily—sulphonic acid, amides, polyamides	Dependent on NAF type	Generally irritating to skin and eyes	Surfactant fatty acid derivatives. May contain hydrocarbon carrier fluid. Check the MSDS for specific details.	Safety goggles to protect from splashing to the eyes. Organic vapour mask/ respirator if atmosphere heavily contaminated. Chemical/oil resistant gloves and slicker suits or aprons to protect from prolonged skin contact.
Viscosifiers	Organophilic montmorillonite, attapulgite or hectorite, synthetic polymers—amine treated	Yes, usually montmorillonite	Not classified as hazardous, dust hazard and SiO ₂ hazard depending on composition	May contain SiO ₂ , respiratory hazard, depending on the material. Mechanical irritation to skin/ eyes.	Wear appropriate dust mask/ respirator with filter suitable for the particle size of the dust. Wear safety goggles to protect from mechanical eye irritation. Gloves to protect from mechanical skin irritation.

continued ...

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Appendix 4: Characteristics of non-aqueous drilling fluids additives

Physical characteristics of non-aqueous fluids (continued)					
Primary product function	Type of material	Requirement in NAF	Hazardous classification	Hazardous components	Handling and PPE recommendations
Rheological modifier	Hydrophobic or polymeric compounds, typically fatty acids in liquid products or acrylate co-polymers in powder products	Infrequently, these products tend to be environmentally unacceptable	Not classified as hazardous for liquid products, or for powder products dust hazard only	Fatty acid derivatives may contain hydrocarbon carrier fluid. Check the MSDS for specific details.	Safety goggles to protect from splashing to the eyes. Organic vapour mask/ respirator if atmosphere heavily contaminated. Chemical/oil resistant gloves and slicker suits or aprons to protect from prolonged skin contact.
Brine phase	Fresh water primarily with calcium chloride; see Table 1 for list of alternatives and hazard classifications	Calcium chloride is used in greater than 95% of NAF formulations	Irritating to eyes and skin, prolonged exposure can result in severe skin irritation.	Calcium chloride salt, other salts may be more or less irritating. Check the MSDS for specific details; also see Table 2 in Appendix 6.	Safety goggles and full face shield to protect from splashing, protect from skin/eye irritation. Chemical resistant/impervious gloves, boots and clothing to protect from prolonged exposure
Filtration control	Asphalt, lignite, gilsonite	Not always needed, dependent on mud type and purpose	Not classified, dust hazard	May contain SiO ₂ , depending on the material. Check the MSDS for specific details.	Wear appropriate dust mask/ respirator with filter suitable for the particle size of the dust. Wear safety goggles to protect from mechanical eye irritation. Gloves to protect from mechanical skin irritation.
Lime	Lime (Calcium hydroxide)	Yes, to activate the emulsifiers in particular	Severe eye irritant, may cause permanent damage. Skin irritant, may be corrosive if skin is moist.	Calcium hydroxide reacts with moisture to be extremely irritating/ corrosive on prolonged contact.	Wear appropriate dust mask/ respirator with filter suitable for fine dust. Wear safety goggles/ face shield to protect from skin/eye irritation. Chemical resistant gloves, boots and clothing to protect from skin irritation and prolonged contact.
Thinners	Liquid products may contain fatty acids. Powder products include lignites, lingo-sulphonate and tannins	Very seldom	Liquid products may be irritating to eyes and skin. Powder products, dust hazard	Liquid products may have a hydrocarbon carrier fluid. Mechanical dust hazard May contain SiO ₂ , depending on the material, check MSDS.	Safety goggles to protect from splashing to the eyes. Organic vapour mask/ respirator if atmosphere heavily contaminated. Chemical/oil resistant gloves and slicker suits or aprons to protect from prolonged skin contact.
Lubricating agent	Ester oils, asphalts, graphite cannot be grouped into one hazard	Seldom, but as deemed necessary	May be a dust hazard for powder products. Ester oils hazards as per NAF base fluids.	Powder products may contain SiO ₂ .	Powdered products as per weighting agents. Ester—as per NAF Base fluid.
Lost circulation materials	CaCO ₃ , graphite, walnuts shells, mica, almost any solid plugging material available, cross linking pills sometimes resin based	Added only when required, More recent NAF loss prevention procedures can use CaCO ₃ and graphite maintained in the circulating system	Not classified, dust hazard	May contain SiO ₂ , depending on the product, check MSDS	Wear appropriate dust mask/ respirator with filter suitable for the particle size of the dust. Wear safety goggles to protect from mechanical eye irritation. Gloves to protect from mechanical skin irritation.

Appendix 5: Definitions of technical NAF base fluid properties

Vapour pressure

If a substance is contained in an evacuated, closed container, some of it would evaporate. The vapour pressure of a liquid is the pressure exerted by its vapour when the liquid and vapour are in dynamic equilibrium, i.e. the number of molecules vaporizing equals the number returning to the liquid phase. The pressure in the space above the liquid would increase until it stabilizes at a constant value, known as the vapour pressure. It is important to specify the temperature when stating a vapour pressure because vapour pressure increases with temperature, due to the molecules having more energy to vaporize. Liquids that are not in a closed container still have a vapour pressure; these materials will eventually evaporate or vaporize (turn into a gas) completely.

Vapour pressure is important in the selection of a non-aqueous base fluid because the vapour pressure gives an indication of the quantity of hydrocarbon vapour which may be released into the working environment at various operating and flow line temperatures. As the temperature increases, the vapour pressure increases. If that vapour is flammable, a fire or explosion could result with an ignition source such as an electrical device, a pilot light, or even static electricity. Other materials may emit enough vapour to exceed the occupational exposure limits for inhalation. The use of NAF-based fluids for drilling which have a low vapour pressure is desirable to reduce the exposure to possible hazardous components in the working atmosphere and to reduce explosive potential.

Boiling point

The boiling point of a liquid is the temperature at which the vapour pressure of the liquid equals the environmental pressure surrounding the liquid. The higher the vapour pressure of a liquid at a given temperature, the lower the normal boiling point (i.e. the boiling point at atmospheric pressure) of the liquid.

The boiling point has an equivalent importance as mentioned above for vapour pressure.

Flash point

The flash point of a flammable liquid is the lowest temperature at which it can form an ignitable mixture in air. At this temperature the vapour may cease to burn when the source of ignition is removed. The flash point is not related to the temperature of the ignition source or of the burning liquid, which are much higher. The flash point is often used as one descriptive characteristic of liquid fuel, but it is also used to describe liquids that are not used intentionally as fuels. The flash point is an empirical measurement rather than a fundamental physical parameter. The measured value will vary with equipment and test protocol variations. The testers and protocols are specified in standards such as DIN 51758, ASTM 93, and Determination of flash point: Closed cup equilibrium method (ISO 1523:2002).

The flash point is used as an indication of safety for the selection of NAF base fluids and may be influenced by regulatory issues such as the transportation of bulk fluids by sea, road or rail. The use of a NAF base fluid for drilling with a high flash point is desirable to reduce the potential for the generation of explosive atmospheres.

Density

The density is mass per unit volume, i.e. the ratio of the amount of matter in an object compared to its volume. In some cases the density is expressed as a specific gravity, in which case it is expressed in multiples of the density of some other standard material, usually water.

The non-aqueous liquids used to formulate NAF drilling fluids are much more compressible than water. Their density increases with increased pressure, they also expand with increased temperature so that the two effects somewhat counteract each other under down hole conditions, but not uniformly. Therefore the equivalent down hole density of a fluid will be different from the surface measured density.

Kinematic viscosity

Viscosity is a measure of the resistance of a fluid to being deformed by either shear stress or extensional stress. It is commonly perceived as 'thickness', or resistance to flow. Viscosity describes a fluid's internal resistance to flow and

may be thought of as a measure of fluid friction. Thus, water is 'thin', having a lower viscosity, while vegetable oil is 'thick' having a higher viscosity. Kinematic viscosity is a measure of the resistive flow of a fluid under the influence of gravity.

The viscosity of the non-aqueous base fluid directly influences the plastic viscosity (PV) of the drilling fluid. The plastic viscosity of a drilling fluid is the theoretical viscosity of a fluid at an infinite shear rate; the PV is always required to be as low as reasonably practicable. The viscosity of non-aqueous base fluids varies with temperature, the viscosity decreasing as the temperature increases. It should be noted that very low viscosity fluids (kinematic viscosity <7 cSt @ 4° C) may be aspirated upon ingestion. However, ingestion is not considered a likely route of exposure for a NAF base fluid.

Pour point

The pour point of a liquid is the lowest temperature at which it will pour or flow under prescribed conditions. It is a rough indication of the lowest temperature at which oil is readily pumpable.

Base fluids with high pour points may have unacceptably high viscosities at lower temperatures which may make them impractical to use in some geographic areas.

Appendix 6:

Examples of additives common to WBMs and NAFs

Table 1: Additives common to WBMs and NAFs

Additive	Primary functional potential
Water	
Fresh water	WBM—primary phase; dilution: NAF—internal phase
Sea water	WBM—primary phase; dilution
Brine (see salts)	WBM—primary phase; dilution; formation stability: NAF—internal phase
Saturated NaCl	WBM—primary phase; formation stability
Osmotic—salts	
CaCl ₂	WBM—primary phase; well control; formation stability: NAF—internal phase
KCl	WBM—primary phase; formation stability
ZnBr/ CaBr	WBM—primary phase; generally a completion fluid
Formates	WBM—primary phase when drilling and for completion operations
Density	
Barite (barium sulphate)	WBM and NAF—fluid density control
Calcium carbonate	WBM and NAF—fluid density control; bridging/plugging agent
Iron carbonate	WBM and NAF—fluid density control
Hematite	WBM and NAF—fluid density control
Ilmenite	WBM and NAF—fluid density control
Viscosity	
Bentonite (or other clays)	WBM—viscosity; fluid loss control
Organophilic clay	NAF—amide modified clay for viscosity control
Biopolymers	WBM—viscosity control; hole cleaning; fluid friction reduction
Carboxymethyl cellulose	WBM—viscosity control; hole cleaning
Polyanionic cellulose	WBM—viscosity control; shale stabilization; hole cleaning; fluid loss control
Guar gum (polysaccharide)	WBM—viscosity
Synthetic polymers	WBM—viscosity often for high temperatures: NAF—viscosity
Dispersants	
Modified polyacrylates	WBM—shale control; fluid loss control
Lignosulphonates	WBM—solids dispersant; limited shale control
Tannins	WBM—solids dispersant
Fluid Loss	
Synthetic polymers	WBM—viscosity often for high temperatures: NAF—viscosity
Carboxymethyl cellulose	WBM—viscosity control; hole cleaning
Polyanionic cellulose	WBM—viscosity control; shale stabilization; hole cleaning; fluid loss control
Starch	WBM—fluid loss control
Bentonite	WBM—fluid loss control but largely dependent on dispersants
Modified lignites	WBM and NAF—fluid loss control
Asphalt	WBM and NAF—fluid loss control; limited lubricity improvement
Resins	WBM—fluid loss control; limited shale stabilization
Gilsonite	WBM and NAF—fluid loss control; limited lubricity improvement

continued ...

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Appendix 6: Examples of additives common to WBM and NAFs

Table 1: Additives common to WBM and NAFs (continued)

Additive	Primary functional potential
Inhibition	
Salts (KCl)	WBM—primary phase; shale control and stability
Glycols (polyglycols)	WBM—shale control
Silicate	WBM—shale control
Gypsum	WBM—shale control; some fracture plugging benefits
Polyacrylamides (partially hydrolysed)	WBM—shale control; some filter cake benefits stabilizing the formation
Modified PAC and other	WBM—shale control; some filter cake benefits stabilizing the formation
pH Control	
NaOH / KOH	WBM—NaOH being used less owing to its volatile and hazardous character
Ca(OH) ₂	WBM—used for specialized purposes
Citric acid	WBM—used to reduce alkalinity
NaHCO ₃	WBM—used to reduce alkalinity; sequester calcium content
Other	
Bactericides	WBM—control or prevent bacterial development
Lubricants	WBM and NAF—for enhanced lubricity of metal/metal or metal/formation contact
Lost circulation material	WBM and NAF—selected plugging and sealing products used only as required
Polymer stabilizers	WBM—stabilize for excessively high temperatures, salt and specific chemicals concentrations, bacteria
Corrosion control (oxygen scavengers, filming agents)	WBM—specialized application for numerous conditions

Table 2: Brine types and characteristics

Brine type	Formula	Max density (ppg)	Hazard classification
Seawater		8.6	Not classified
Potassium chloride	KCl	9.5	Not classified
Sodium chloride	NaCl	10	Not classified
Sodium formate	NaCOOH	10.8	Not classified
Calcium chloride	CaCl ₂	11.3	Eye irritant
Potassium formate	KCOOH	13.1	Not classified
Sodium bromide	NaBr	12.5	Not classified
Calcium bromide	CaBr ₂	14.2	Not classified
Zinc bromide	ZnBr ₂	19.2	Corrosive
Caesium formate	CsCOOH	19.2	Harmful/irritant

Appendix 7:

Particle Size as an influencing factor for inhalation effects

Substances which can be inhaled or are respirable include gases, vapours and aerosols: aerosols are particles and may have gases or vapours adsorbed onto their surface or dissolved into them. These substances can be defined as follows:

- Gases: substances which normally exist in gaseous form at standard pressure and temperature.
- Vapours: gaseous form substances normally liquid at standard pressure and temperature.
- Aerosols: suspension of variable size particles capable of remaining airborne.
- Dusts: caused by mechanical abrasion or fragmentation of solids; the size of particles is 0.1 microns (μm) to 100 μm .
- Fumes: produced by combustion, sublimation or condensation of volatile solids, the size of particle is usually less than 0.1 μm , but fumes have a tendency to flocculate and produce larger particles as the aerosol ages
- Smokes: suspension of solid particles produced by incomplete combustion of organic materials; size of particle usually less than 0.5 μm and particles do not settle readily.
- Mists and fogs: condensation or liquid particles, which produce liquid aerosols.

Particle size will determine where in the respiratory tract particles will dispose. Larger particles (>10 microns) will generally dispose in the upper respiratory tract whereas smaller particles (<10 microns) will generally dispose in the lower respiratory tract such as the bronchial and the alveoli.

The fraction smaller than 10 μm which is able to reach the alveoli is called the respirable fraction.

Particle deposition in the respiratory tract	
Aerodynamic diameter (size in μm)	Behaviour
>100	Unlikely to be inhaled.
100–30	Can be inhaled at the smaller end of the range but unlikely to be absorbed into the body unless the particles are very soluble.
30–10	Will penetrate into the bronchial part of the respiratory system but will gradually be cleared. Some absorption into the rest of the body may occur due to the long residence time unless very insoluble.
10–1	Particles in this aerodynamic size range will be carried into the alveoli.
<1	At less than one micron a substantial percentage will remain suspended in the air and will be breathed out.

Appendix 8:

Detailed health hazard information on drilling fluid components

Information has been provided on generic chemical materials used in drilling fluid compositions; for specialty trade name products, reference must be made to the manufacturer's data for the specific product.

Table 1: Health hazards of drilling fluid components

Component	Human health hazard
Base fluid	
Crude	<p>Crude oil is raw petroleum extracted in its natural state from the ground and containing predominantly aliphatic, alicyclic and aromatic hydrocarbons. It may also contain small amounts of nitrogen, oxygen and sulphur compounds.</p> <p>Crude oil is of low acute toxicity with dermal and oral LD50 values greater than 2000 mg/kg. Inhalation toxicity expected to be low. Light crude oils may pose an aspiration hazard and may also cause symptoms of central nervous system depression. Upon repeated exposure, some light crude oils may cause skin dryness or cracking. Available data indicate that crude oil is not a sensitizer. Data available indicate that crude oils are carcinogenic.</p>
Diesel (gasoil)	<p>Gas oils contain straight and branched chain alkanes (paraffins), cycloalkanes (naphthenes), aromatic hydrocarbons and mixed aromatic cycloalkanes (cycloalkanoaromatics). Most commercial gas oils contain polycyclic aromatic compounds (PAC's). In straight-run gasoil components these are mainly 2 and 3-ring compounds; with relatively low concentrations of 4 to 6-ring PAC's. The use of heavier atmospheric, vacuum or cracked gasoil components is likely to result in an increase in the content of 4 to 6-ring PAC's, some of which are known to be carcinogenic.</p> <p>Skin exposure to diesel fuel will remove natural fat from the skin; repeated or prolonged exposure can result in drying and cracking, irritation and dermatitis. Excessive exposure under conditions of poor personal hygiene may lead to oil acne and folliculitis. A serious potential health hazard related to diesel fuel utilization concerns the possible risk of skin cancer under conditions of prolonged and repeated skin contact and poor personal hygiene. No epidemiological evidence exists for humans, but it has been demonstrated with mice that skin cancer can result in paint tests with light diesel oil and gas oils irrespective of the percentage of PAC's present. This effect is due to (chronic) irritation of the skin. The diesel fuels/gas oils that contain cracked components may also be genotoxic because of high proportions of 3-7 ring PAC's and their carcinogenicity may be much greater. Diesel fuels may contain 10% (w) or more PAC's.</p>
Highly refined mineral oil	Highly refined mineral oils are of low acute toxicity and are not irritating or sensitizing. Data available indicate that highly refined mineral oils are not mutagenic, carcinogenic or reprotoxic.
Synthetic paraffin	Synthetic paraffins are of low acute toxicity. Data show that synthetic paraffins are not irritating or sensitizing. Based on their composition, synthetic paraffins are not expected to be mutagenic, carcinogenic or reprotoxic.
Linear alpha olefins	Based on screening level tests, alpha olefins are of low toxicity upon acute oral, dermal and inhalation exposure. Alpha olefins are slightly irritating to the skin and eyes of rabbits. In repeated dose studies alpha olefins of different chain length have shown comparable levels of low toxicity to female rats and male rat-specific kidney damage that is likely associated with the alpha2u-globulin protein. Based on screening level testing, alpha olefins appear not to be neurotoxic, produce no adverse effects on reproduction or foetal development, and are not genotoxic. As a result, all the above tested endpoints indicate a low hazard potential for human health.
Internal olefins	Olefins (alkenes) ranging in carbon number from C6 to C24, alpha (linear) and internal (linear and branched) demonstrate low acute toxicity by the oral, inhalation and dermal routes of exposure. Repeated-dose studies, using the inhalation (C6 alpha), dermal (C12-C16), or oral (C6 alpha and internal linear/branched; C8 and C14 alpha; and C16, C18 and C20-C24 internal linear/branched) routes of exposure, have shown comparable levels of low toxicity in rats. Based on evidence from neurotoxicity screens included in repeated dose studies, internal olefins are not neurotoxic. Based on evidence from reproductive/developmental toxicity screens in rats internal olefins are not expected to cause reproductive or developmental toxicity. Based on the weight of evidence alpha and internal olefins are not genotoxic. No carcinogenicity tests have been conducted on alpha or internal olefins; however, there are no structural alerts indicating a potential for carcinogenicity in humans. These materials are not eye irritants or skin sensitizers. Prolonged exposure of the skin for many hours may cause skin irritation. The weight of evidence indicates alpha and internal olefins with carbon numbers between C6 and C24 have a similar and low level of mammalian toxicity, and the toxicity profile is not affected by changes in the location of the double bond or the addition of branching to the structure.

continued ...

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Appendix 8: Detailed health hazard information on drilling fluid components

Table 1: Health hazards of drilling fluid components (continued)

Component	Human health hazard
Base fluid	
Poly alpha olefin (PAO)	Poly alpha olefins are of low acute toxicity and are not irritating to eye and skin.
Esters	<p>Data on C8-C16 fatty acid 2-ethyl hexanol ester indicate that this ester is of low oral acute toxicity. In an acute skin irritation test in rabbits, minimal skin irritation was observed. The ester is not primarily eye irritant.</p> <p>The ester was non-genotoxic in a micronucleus test. Results from an oral repeated dose study in rats indicate that the ester is not toxic at up to 1000 mg/kg.</p>
Water	
Fresh water	Fresh water is generally considered to be not hazardous to human health.
Sea water	Sea water has a low hazard potential for human health upon inhalation and dermal exposure.
Brine (see salts)	See Table 2 in Appendix 6, and below (osmotic—salts)
Osmotic—salts	
Calcium chloride (CaCl ₂)	<p>The acute oral and dermal toxicity of calcium chloride is low. The acute oral toxicity is attributed to the severe irritating property of the original substance or its high-concentration solutions to the gastrointestinal tract. In humans, however, acute oral toxicity is rare because large single doses induce nausea and vomiting. Irritation/corrosiveness studies indicate that calcium chloride is not/slightly irritating to skin but severely irritating to eyes of rabbits. Prolonged exposure and application of moistened material or concentrated solutions resulted in considerable skin irritation. The irritating effect of the substance was observed in human skin injuries caused by incidental contact with the substance or its high-concentration solutions. A limited oral repeated dose toxicity study shows no adverse effect of calcium chloride on rats fed on 1000–2000 mg/kg bw/day for 12 months. Calcium and chloride are both essential nutrients for humans and a daily intake of more than 1000 mg each of the ions is recommended. Genetic toxicity of calcium chloride was negative in the bacterial mutation tests and the mammalian chromosome aberration test. No reproductive toxicity study has been reported. A developmental toxicity study reveals no toxic effects on dams or fetuses at doses up to 189 mg/kg bw/day (mice), 176 mg/kg bw/day (rats) and 169 mg/kg bw/day (rabbits). (from: SIDS. <i>Screening Information Data Set for High Production Volume Chemicals</i>. (2005)).</p>
Potassium chloride (KCl)	<p>Potassium chloride is an essential constituent of the body for intracellular osmotic pressure and buffering, cell permeability, acid-base balance, muscle contraction and nerve function. Acute oral toxicity of KCl in mammals is low. In humans, acute oral toxicity is rare because large single doses induce nausea and vomiting, and because KCl is rapidly excreted in the absence of any pre-existing kidney damage. The toxicity upon repeated dose exposure is low. A threshold concentration for skin irritancy of 60 % was seen when KCl in aqueous solution was in contact with skin of human volunteers. The threshold concentration when applied to broken skin was 5%. No gene mutations were reported in bacterial tests, with and without metabolic activation. However, high concentrations of KCl showed positive results in a range of genotoxic screening assays using mammalian cells in culture. The action of KCl in culture seems to be an indirect effect associated with an increased osmotic pressure and concentration. No evidence of treatment-related carcinogenicity was observed in rats administered up to 1,820 mg KCl/kg body weight/day through the food in a two-year study. A developmental study revealed no foetotoxic or teratogenic effects of KCl in doses up to 235 mg/kg/day (mice) and 310 mg/kg/day (rats). Gastro-intestinal irritant effects in humans caused by KCl administered orally have been reported at doses from about 31 mg/kg bw/day. One epidemiological investigation among potash miners disclosed no evidence of predisposition of underground miners to any of the diseases evaluated, including lung cancer. (from: SIDS. <i>Screening Information Data Set for High Production Volume Chemicals</i>. (2004)).</p>
Sodium chloride (NaCl)	<p>Sodium chloride is an essential nutrient for the normal functioning of the body. It is important for nerve conduction, muscle contraction, correct osmotic balance of extra cellular fluid and the absorption of other nutrients. Although rare, acute toxicity may be caused by ingestion of 500–1,000 mg sodium chloride/kg body weight. Symptoms include vomiting, ulceration of the gastrointestinal tract, muscle weakness and renal damage, leading to dehydration, metabolic acidosis and severe peripheral and central neural effects. Long-term effects of high (>6 g/day) dietary sodium chloride include the development of hypertension, and may increase the risk of kidney stone formation and left ventricular hypertrophy. In rodents, extremely high doses of sodium chloride during pregnancy caused musculoskeletal abnormalities, foetotoxicity and foetal death and post-implantation mortality and abortion. Sodium chloride has been demonstrated to be a gastric tumour promoter</p>

continued ...

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Appendix 8: Detailed health hazard information on drilling fluid components

Table 1: Health hazards of drilling fluid components (continued)

Component	Human health hazard
	in experimental animals and high sodium chloride intakes have been associated with incidence of stomach cancer in human populations with traditional diets of highly concentrated, salted foods. (Expert Group on Vitamins and Minerals (2003), www.food.gov.uk/science/ouradvisors/vitandmin/evmpapers)
Zinc bromide (ZnBr ₂)	<p>Zinc bromide inhalation can cause severe irritation of mucous membranes and upper respiratory tract. Symptoms may include burning sensation, coughing, wheezing, laryngitis, shortness of breath, headache, nausea and vomiting. High concentrations may cause lung damage. Ingestion of zinc bromide can cause severe burns of the mouth, throat, and stomach. Can cause sore throat, vomiting and diarrhoea. Ingestions are usually promptly rejected by vomiting, but sufficient absorption may occur to produce central nervous system, eye and brain effects. Symptoms may include skin rash, blurred vision and other eye effects, drowsiness, irritability, dizziness, mania, hallucinations, and coma.</p> <p>Causes severe skin irritation with redness, itching and pain. May cause burns, especially if skin is wet or moist.</p> <p>Can cause severe eye irritation or burns with eye damage.</p> <p>Repeated or prolonged exposure by any route may cause skin rashes (bromaderma). Repeated ingestion of small amounts may cause central nervous system depression, including depression, ataxia, psychoses, memory loss, irritability and headache.</p>
Calcium bromide (CaBr ₂)	Calcium bromide brine is a highly concentrated aqueous solution of calcium bromide and calcium chloride. It is used extensively in the oil industry. This solution and its components are recognized as causes of skin injury and information is available from the manufacturers on their safe use and handling. Two patients who were injured following unprotected skin exposure to this solution and one patient who was injured following exposure to calcium chloride powder are reported. All sustained skin injuries characterized by an absence of pain and a delayed clinical appearance of the full extent of the injury. Furthermore healing was complicated by graft loss or was slow. Although organic bromine compounds are recognized as a cause of skin injuries, no previous reports of such injuries to humans secondary to calcium chloride or bromide exposure were found in the medical literature. Our experience with these patients is described. (Saeed <i>et al.</i> , Burns; 23 (7–8) ³² . 1997. 634–637)
Sodium bromide (NaBr)	Sodium bromide is of low acute oral toxicity. Sodium bromide is expected to be a slight to moderate eye irritant. Repeated or prolonged skin contact may cause irritation and superficial burns. Available data indicate that sodium bromide may act as a teratogen (behavioural effects).
Sodium formate (NaCOOH)	Sodium formate is of low acute oral toxicity (LD ₅₀ oral rat > 3000 mg/kg). Data show that sodium formate is slightly irritating to the eye. Based on read-across from caesium formate, sodium formate is expected to be slightly irritating to skin. Sodium formate is not expected to be a skin sensitizer. Sodium formate at 1% in drinking water did not produce clinically adverse effects in rats after administration for approximately 18 months. Sodium formate is not genotoxic <i>in vitro</i> or <i>in vivo</i> . Based on read-across with calcium formate, sodium formate is not expected to be reprotoxic or carcinogenic.
Potassium formate (KCOOH)	Potassium formate is of low acute oral toxicity (LD ₅₀ oral mouse 5500 mg/kg). Data show that potassium formate is slightly irritating to the eye. Based on read-across from caesium formate, potassium formate is expected to be slightly irritating to skin. Potassium formate is not expected to be a skin sensitizer. Repeated-dose toxicity tests are not available; however, the metabolite formic acid did not cause significant toxicity to rats when administered in their drinking water at 0.5 and 1% for 2 to 27 weeks. Based on read-across with calcium formate, potassium formate is not expected to be reprotoxic or carcinogenic.
Caesium formate (CsCOOH)	Caesium formate solution (83%) is harmful upon ingestion (LD ₅₀ = 1780 mg/kg in rats), with clinical signs including depression, convulsions, respiratory distress, ataxia, and excessive salivation. Caesium formate monohydrate had low dermal (LD ₅₀ >2000 mg/kg) toxicity in rats, with signs of erythema noted at sites of application. Caesium formate solution (83%) was a slight skin irritant and a moderate eye irritant. Aqueous caesium formate (80% w/v) was not sensitizing to guinea pigs in a Buehler test. Repeated-dose toxicity tests are not available; however, the metabolite formic acid did not cause significant toxicity to rats when administered in their drinking water at 0.5 and 1% for 2 to 27 weeks. The caesium cation is not expected to produce significant chronic toxicity. Caesium formate was not mutagenic in different <i>in vitro</i> assays. (National Industrial Chemicals Notification and Assessment Scheme (NICNAS), Australia, 2001).

continued ...

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Appendix 8: Detailed health hazard information on drilling fluid components

Table 1: Health hazards of drilling fluid components (continued)

Component	Human health hazard
Density (weighting agents)	
Barite (Barium sulphate)	<p>Studies in rats using a soluble salt (barium chloride) have indicated that the absorbed barium ions are distributed via the blood and deposited primarily in the skeleton. The principal route of elimination for barium following oral, inhalation, or intratracheal administration is in the faeces. Following introduction into the respiratory tract, the appearance of barium sulphate in the faeces represents mucociliary clearance from the lungs and subsequent ingestion. In humans, ingestion of high levels of soluble barium compounds may cause gastroenteritis (vomiting, diarrhoea, abdominal pain), hypotassaemia, hypertension, cardiac arrhythmias, and skeletal muscle paralysis. Insoluble barium sulphate has been extensively used at large doses (450 g) as an oral radiocontrast medium, and no adverse systemic effects have been reported. No experimental data are available on barium sulphate; however, due to the limited absorption of barium sulphate from the gastrointestinal tract or skin, it is unlikely that any significant systemic effects would occur. The acute oral toxicity of barium compounds in experimental animals is slight to moderate. Barium nitrate caused mild skin irritation and severe eye irritation in rabbits. The lack of reports of skin or eye irritation in humans, despite its widespread use, suggests that barium sulphate, often used as a contrast medium, is not a strong irritant. Long-term studies of barium exposure in laboratory animals have not confirmed the blood pressure, cardiac, and skeletal muscle effects seen in humans and laboratory animals orally exposed to acutely high levels. Inhalation exposure of humans to insoluble forms of barium results in radiological findings of baritosis, without evidence of altered lung function and pathology. Animal studies involving respiratory tract instillation of barium sulphate have shown inflammatory responses and granuloma formation in the lungs; this would be expected with exposure to substantial amounts of any low-solubility dust, leading to a change in lung clearance and subsequently to lung effects. Currently available data indicate that barium does not appear to be a reproductive or developmental hazard. Barium was not carcinogenic in standard National Toxicology Program rodent bioassays. <i>In vitro</i> data indicate that barium compounds have no mutagenic potential. The critical end-points in humans for toxicity resulting from exposure to barium and barium compounds appear to be hypertension and renal function. The NOAEL in humans is 0.21 mg barium/kg body weight per day. (www.inchem.org/documents/cicads/cicads/cicad33.htm, Concise International Chemical Assessment Document 33, Barium and barium compounds.)</p>
Calcium carbonate	<p>Acute effects may include irritation of skin, eyes, and mucous membranes. Based on an oral LD50 in rats of 6,450 mg/kg, calcium carbonate is of low oral acute toxicity. There is no adequate evidence for a tumour-promoting or genotoxic action of calcium carbonate. Effects on reproduction have not been shown. High dietary levels inducing maternal toxicity resulted in decreased fetal weights and delayed skeletal and dental calcification in rats and/or mice. There may be a silicosis risk in using impure limestone or chalk containing (3–20%) quartz. No adverse health effects have been reported in the literature among workers using calcium carbonate. High oral doses did not produce systemic toxicity in laboratory animals. (Health Council of The Netherlands, 2003, calcium carbonate.)</p>
Iron carbonate	<p>Most data from iron compounds are derived from read-across with the ferrous salt iron sulphate. Ferrous sulphate has a low to moderate acute toxicity with a LD50 (rat) of 319–1,480 mg/kg. As ferrous sulphate is used in humans for the treatment of anaemia, human data are also available. These indicate that the human LD50 is in the range of 40–1,600 mg/kg. Fatal doses are associated with gastric injury. Irritation data are scarce and indicate that ferrous sulphate may be irritating to skin and eyes. Ferrous sulphate is not a sensitizer. Genotoxicity data on ferrous sulphate are ambiguous. However, the overall weight of evidence from genotoxicity studies shows that ferrous sulphate is not genotoxic. Carcinogenicity is not expected. Ferrous sulphate is not a reprotoxicant. A study in calves fed up to 4000 ppm ferrous carbonate in diet shows that the calves were not affected. The tolerance for ferrous carbonate was higher than for ferrous sulphate.</p>
Hematite	<p>There are little data on hematite (or Fe₂O₃) available. The acute oral toxicity LD50 (rat) for Fe₂O₃ is greater than 10 g/kg. Upon eye contact some mechanical eye irritation may occur (dust). A carcinogenicity study in miners shows that haematite mining with low-grade exposure to radon daughters and silica dust was not associated with excess lung cancer in a relatively large cohort.</p>
Ilmenite	<p>There are no toxicity data available for ilmenite, or iron titanium oxide. It is expected that ilmenite is of low toxicity. There are no known hazards resulting from accidental ingestion of ilmenite sand as may occur during normal handling. Swallowing a large amount may result in irritation to the digestive system due to abrasiveness. Ilmenite dust may cause mechanical irritation of the eye. Ilmenite dust is regarded as general nuisance dust, but can be irritating if inhaled at high concentration. May cause symptoms such as coughing or sneezing.</p>

continued ...

Table 1: Health hazards of drilling fluid components (continued)

Component	Human health hazard
Manganese tetroxide	<p>Manganese tetraoxide is of low acute toxicity. Mn_3O_4 is not a skin irritant, nor a sensitizer. Mn_3O_4 dust may cause some mechanical irritation to the eye. Results from a repeated dose study in monkeys and rats exposed to 11.6, 112.5 and 1,152 μMn_3 as Mn_3O_4 aerosol 24 h/day for 9 months, show no exposure related effects on pulmonary function, limb tremor or electromyographic activity.</p> <p>There are several reports about manganese toxicity as a result of exposure to fume/vapour from elemental manganese and by inhalation of pyrolusite (MnO_2). Long-term inhalation (years) of manganese oxides may cause chronic manganese intoxication affecting the central nervous system, potentially leading to extensive disablement. Health risk of MnO_2 (widely described in literature) may be different from that of MnO, Mn_2O_3, and Mn_3O_4. The differences in oxidation states of the element Mn in these compounds may affect their bioavailability and distribution and thus their potential effects.</p>
Viscosity	
Bentonite (or other clays)	<p>An important determinant of the toxicity of bentonite and other clays is the content of quartz (SiO_2). Exposure to quartz is causally related to silicosis and lung cancer. Statistically significant increases in the incidence of or mortality from chronic bronchitis and pulmonary emphysema have been reported after exposure to quartz.</p> <p>Single intratracheal injection into rodents of bentonite and montmorillonite with low content of quartz produced dose- and particle size-dependent cytotoxic effects, as well as transient local inflammation, the signs of which included oedema and, consequently, increased lung weight. Single intratracheal exposures of rats to bentonite produced storage foci in the lungs 3–12 months later. After intratracheal exposure of rats to bentonite with a high quartz content, fibrosis was also observed. Bentonite increased the susceptibility of mice to pulmonary infection. No adequate studies are available on the carcinogenicity of bentonite. Long-term occupational exposures to bentonite dust may cause structural and functional damage to the lungs. However, available data are inadequate to conclusively establish a dose-response relationship or even a cause-and-effect relationship due to limited information on period and intensity of exposure and to confounding factors, such as exposure to silica and tobacco smoke. (<i>Environmental Health Criteria</i>, Vol. 231 (2005) 159 p.)</p>
Organophilic clay (montmorillonite, attapulgite, hectorite)	<p>In general, the acute toxicity of organophilic clays is low. Some organophilic clays are used in cosmetics. Data on a hectorite clay show that the clay is of low acute and repeated dose toxicity. The clay is not a skin or eye irritant, nor a skin sensitizer. In dust form the hectorite clay may cause mechanical eye irritation. Data indicate that the hectorite clay is not genotoxic. Data on reprotoxicity and carcinogenicity are not available. Check the MSDS for the compound-specific information.</p>
Biopolymers	<p>The biopolymers used are generally low toxicity compounds. Some of these biopolymers are also used as food additive. Check the MSDS for the compound-specific information.</p>
Carboxymethyl cellulose	<p>Carboxymethyl cellulose is of low toxicity. Carboxymethyl cellulose is approved for and used as food additive. (<i>WHO Food Additives Series</i>, Vol. 42 (1999) pp 175–9)</p>
Polyanionic cellulose	<p>Cellulose compounds are generally low toxicity compounds. Some of these cellulose compounds are also used as food additive. Check the MSDS for the compound-specific information. (<i>WHO Food Additives Series</i>, Vol. 40 (1998) pp 55–78; and <i>WHO Food Additives Series</i> Vol. 42 (1999) pp 175–9)</p>
Guar gum (polysaccharide)	<p>Guar gum is a low toxicity compound, commonly used as food additive. Allergic rhinitis following repeated inhalation exposure to guar gum dust has been reported. (Lagier <i>et al.</i>, 1990, <i>J. Allergy Clin Immunol</i>, 85(4) p. 785–790; Kanerva <i>et al.</i>, 1988, <i>Clin Allergy</i>, 18(3) p245–252)</p>
Emulsifiers	
Soaps	<p>See Table 2. Several emulsifiers may irritate skin and/or eye and may be harmful by inhalation or if swallowed. Check the MSDS for the compound-specific information.</p>
Amines	<p>See Table 2. Several emulsifiers may irritate skin and/or eye and may be harmful by inhalation or if swallowed. Check the MSDS for the compound-specific information.</p>
Imidazolines	<p>See Table 2. Several emulsifiers may irritate skin and/or eye and may be harmful by inhalation or if swallowed. Check the MSDS for the compound-specific information.</p>
Polyamides	<p>See Table 2. Several emulsifiers may irritate skin and/or eye and may be harmful by inhalation or if swallowed. Check the MSDS for the compound-specific information.</p>

continued ...

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Appendix 8: Detailed health hazard information on drilling fluid components

Table 1: Health hazards of drilling fluid components (continued)

Component	Human health hazard
Dispersants	
Modified polyacrylates	Modified polyacrylates is a general term for several specific polyacrylates each having compound-specific toxicological properties. Check the MSDS for the compound-specific information.
Lignosulphonates	Lignosulphonates are complex polymers with a broad range of molecular mass and are derived from trees. The wood from trees is composed mainly of three components—cellulose, hemicellulose and lignin. In the sulphite pulping process, the lignins are sulphonated so they become water soluble and thus can be separated from the insoluble cellulose. A review of available toxicity data on several lignosulphonates by the US EPA indicated that lignosulphonates are of very low toxicity (www.epa.gov [Federal Register: February 16, 2005 (Volume 70, Number 31)]). The oral acute LD50 values are all greater than 2 g/kg. Repeated dose studies indicate NOAELs and LOAELs in the order of magnitude of g/kg/day. There is some (unsubstantiated) information that lignosulphonates given to rats before, during, and after mating at doses as high as 1,500 mg/kg/day did not cause adverse effects on reproduction or offspring. But at a dose level of 500 mg/kg/day there were histopathological changes in the lymph nodes of the mothers. There were no concerns identified for the mutagenicity or carcinogenicity of lignosulphonates. Based on the physical/chemical properties, and particularly on the large molecular weights of the lignosulphonates, lignosulphonates are not likely to be absorbed via any route of exposure. The only health effects of concern upon exposure to lignosulphonates are irritation of skin, eyes and respiratory system. For some lignosulphonates contact allergy has been reported (Andersson <i>et al.</i> , 1980; Contact Dermatitis 6(5): 354–355). The toxicity depends on the type and size of the lignosulphonate. Check the MSDS for the compound-specific information.
Tannins	Tannins are polyphenols derived from plants. Due to their ubiquitous presence in food they have been subject of many toxicity studies. In general, tannins are of low acute toxicity. Tannins in food have been associated with several beneficial and adverse health effects (Chung <i>et al.</i> , 1998 <i>Crit Rev Food Sci Nutr</i> 38(6): 421–64). IARC has evaluated tannic acid and tannins and concluded that although tannins were carcinogenic in animals upon subcutaneous injection, no epidemiological evidence in humans was available to evaluate their toxicity in humans. (IARC <i>Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Man: Some Naturally Occurring Substances</i> , Vol. 10, pages 253–262). Check the MSDS for the compound-specific information.
Fluid loss	
Synthetic polymers	Check the MSDS for the compound-specific information.
Carboxymethyl cellulose	See above (viscosity)
Polyanionic cellulose	See above (viscosity)
Starch	Starch is a low toxicity compound, commonly used as food additive.
Bentonite	See above (viscosity)
Modified lignites	Modified lignites are derived from brown coal. The toxicity mainly depends on the modification. Check the MSDS for the compound-specific information.
Asphalt	Asphalt, more commonly referred to as bitumen in Europe, is a dark brown to black, cement-like semisolid or solid or viscous liquid produced by the non-destructive distillation of crude oil during petroleum refining. When asphalts are heated, vapours are released; as these vapours cool, they condense. As such, these vapours are enriched in the more volatile components present in the asphalt and would be expected to be chemically and potentially toxicologically distinct from the parent material. Asphalt itself is considered to be of low toxicity. Asphalt fumes are the cloud of small particles created by condensation from the gaseous state after volatilization of asphalt. Symptoms associated with asphalt fume exposure are eye, nose, and throat irritation and coughing. These health effects appear to be mild in severity and transient in nature. Additional symptoms include skin irritation, pruritus, rashes, nausea, stomach pain, decreased appetite, headaches, and fatigue, as reported by workers involved in paving operations, insulation of cables, and the manufacture of fluorescent light fixtures. Asphalt fumes and vapours may be absorbed following inhalation and dermal exposure. Results of several <i>in vitro</i> mutagenicity studies on asphalt fumes are ambiguous. Results of carcinogenicity studies indicate that some asphalt fume condensates can cause tumours when applied dermally to mice. A meta-analysis of 20 epidemiological studies failed to find overall evidence for a lung cancer risk among pavers and highway maintenance workers exposed to asphalt. Under various performance specifications, it is likely that asphalt fumes contain carcinogenic substances. (<i>Concise International Chemical Assessment Document (CICAD)</i> Vol. 59 (2004))

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Appendix 8: Detailed health hazard information on drilling fluid components

Table 1: Health hazards of drilling fluid components (continued)

Component	Human health hazard
Resins	There are several types of resins, both naturally derived and synthetic. The toxicological properties vary. Some resins have been associated with skin irritation and allergic contact dermatitis. Check the MSDS for the compound-specific information.
Gilsonite	<p>Gilsonite is a form of natural asphalt found in large amounts in the Uintah Basin of Utah. Workers can be exposed to the dust of gilsonite and to the fumes of gilsonite when heating or boiling the material. Gilsonite dust may cause mechanical eye irritation, while the fumes may be irritating to the eyes and respiratory system (Fairhall (1950) <i>Industrial Hygiene Newsletter</i>, 10(5): 9-10).</p> <p>Industrial hygiene characterizations were performed by NIOSH at three gilsonite mills and nine gilsonite mining operations to measure occupational exposure to gilsonite and its constituents and to evaluate potential health effects (Kullman <i>et al.</i>, <i>Am Ind Hyg Assoc J</i> (1989) 50(8): 413–418). Six out of seven bulk gilsonite samples had crystalline silica contents below 0.75% wt., no asbestos or other fibrous mineral compounds were detected in bulk samples from five different veins of gilsonite, and polynuclear aromatic hydrocarbons were not detected in any bulk samples. The authors conclude that the gilsonite dust exposure data are consistent with results of an earlier respiratory health survey of gilsonite workers in which the most definitive finding was an excess prevalence of bronchitic symptoms.</p> <p>The respiratory health survey (Keimig <i>et al.</i>, <i>Am J Ind Med.</i> (1987); 11(3): 287–296) showed that increased prevalences of cough and phlegm were found in workers with high-exposure jobs, but no evidence for dust-related pulmonary function impairment was noted.</p>
Inhibition	
Salts	See above (osmotic—salts)
Glycols (polyglycols)	Glycols, glycol ethers and polyglycols have different toxicities. Polyglycols are generally of low toxicity. Check the MSDS for the compound-specific information.
Silicate	<p>The most commonly used silicates in drilling fluids are potassium silicate and sodium silicate. These ingredients combine metal cations (potassium or sodium) with silica to form inorganic salts. Sodium silicate administered orally acts as a mild alkali and is readily absorbed from the alimentary canal and excreted in the urine. The toxicity of silicates has been related to the molar ratio of $\text{SiO}_2/\text{Na}_2\text{O}$ and the concentration. Potassium and sodium silicates have a low to moderate acute toxicity. Rats orally administered 464 mg/kg of a 20% solution containing either 2.0 or 2.4 ratio to 1.0 ratio of sodium oxide showed no signs of toxicity, whereas doses of 1,000 and 2,150 mg/kg produced gasping, dyspnea, and acute depression. A case report describes that neutralized sodium silicate produced vomiting, diarrhea, and gastrointestinal bleeding in human.</p> <p>Dermal irritation of potassium silicate and sodium silicate ranged from negligible to severe, depending on the species tested and the molar ratio and concentration tested. Potassium silicate was non-irritating in two acute eye irritation studies in rabbits. Sodium silicate was a severe eye irritant in acute eye irritation studies. A skin freshener (10% of a 40% aqueous solution) containing sodium silicate was non-irritating. Sodium silicate in another three eye irritation studies was highly irritating, irritating, and nonirritating, respectively. Detergents containing 7%, 13%, and 6% sodium silicate mixed 50/50 with water were negligible skin irritants to intact and abraded human skin. A 10% of a 40% aqueous solution of sodium silicate was negative in a repeat-insult predictive patch test in humans. The same aqueous solution of sodium silicate was considered mild under normal use conditions in a study of cumulative irritant properties. Sodium silicate tested in elbow crease studies and semiocluded patch tests, produced low grade and transient irritation.</p> <p>Repeated dose studies in Beagles and rats showed no overt signs of toxicity.</p> <p>Sodium silicate was non-mutagenic in a standard bacterial assay. Reprotoxicity studies with sodium silicate in rats showed some effects on the number of offspring at high doses but no effects on male rat fertility. (<i>Int J Toxicol</i> Vol. 24 Suppl. 1 (2005) pp 103–7)</p>
Polyacrylamides (partially hydrolysed)	There are various different types of polyacrylamides. Check the MSDS for the compound-specific information.
pH control	
Sodium hydroxide (NaOH)	Sodium hydroxide is a skin and eye corrosive. In a human 4-hour patch test, sodium hydroxide (0.5%) was a very clear skin irritant. Irritation of the nose, throat, or eyes was observed in workers engaged in cleaning operations and in a small number of users of an oven spray. Ingestion might be fatal, as a result of, e.g., shock, infection of the corroded tissues, pulmonary necrosis, or asphyxia. No increase in mortality in relation to duration or intensity of exposure to caustic dust was found in a group of 265 workers for periods ranging from less than 1 year to up to 30 years. (Health Council of The Netherlands, 2000, sodium hydroxide)

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Appendix 8: Detailed health hazard information on drilling fluid components

Table 1: Health hazards of drilling fluid components (continued)

Component	Human health hazard
Potassium hydroxide (KOH)	Potassium hydroxide is a skin and eye corrosive. Following ingestion of (a solution of) potassium hydroxide, rapid corrosion and perforation of the oesophagus and stomach, stricture of the oesophagus, violent pain in throat and epigastrium, haematemesis, and collapse may occur. When inhaled in any form, potassium hydroxide is strongly irritating to the upper respiratory tract. Acute exposures may cause symptoms in the respiratory tract including severe coughing and pain. Additionally, lesions may develop along with burning of the mucous membranes. Inhalation may be fatal as a result of spasm, inflammation, and oedema of the larynx and bronchi, chemical pneumonitis, and pulmonary oedema (which can develop with a latency period of 5–72 hours). Chronic exposures may cause inflammatory and ulcerative changes in the mouth and possibly bronchial and gastrointestinal disorders. It has been reported that 10% of workers exposed to KOH during the production of ascorbic acid developed allergic dermatitis. At least one case of oesophageal carcinoma at the site of hydroxide-induced strictures has been reported. In mice, repeated applications of aqueous solutions (3–6%) of KOH to the skin for 46 weeks resulted in an increased incidence of skin tumours. Since tumourigenesis was associated with severe skin damage inducing marked epidermal hyperplasia, a non-genotoxic mechanism is assumed. (Health Council of The Netherlands, 2004, potassium hydroxide)
Calcium hydroxide (Ca(OH) ₂) Lime	<p>Acute exposures to calcium hydroxide may cause irritation, along with coughing, pain, and possibly burns of the mucous membranes with, in severe acute exposures, pulmonary oedema and hypotension with weak and rapid pulse. Solid calcium hydroxide is corrosive to the eyes and may cause severe injury to the skin. There are numerous case reports on accidental exposures to calcium hydroxide resulting in corneal and skin alkali burns and caustic ulcers. Generally, these effects are caused by the solid material and less commonly or rarely by solutions. Ingestion of alkali is reported to be followed by severe pain, vomiting (containing blood and desquamated mucosal lining), diarrhoea, and collapse.</p> <p>Two epidemiological studies that addressed the association between cement-dust exposure and stomach cancer were considered insufficient to reach any conclusions on the association between cement dust exposure and stomach cancer. However, no adverse effects have been experienced by long-term exposed workers. Oral LD50 values of approximately 7,300 mg/kg bw were reported for rats and mice. No adequate repeated-dose toxicity (including carcinogenicity and reproduction toxicity) or genotoxicity/mutagenicity studies are available. (Health Council of The Netherlands, 2004, calcium hydroxide)</p>
Citric acid	Based on many experimental data in animals and on human experience, citric acid is of low acute toxicity. The NOAEL for repeated dose toxicity for rats is 1200 mg/kg/d. The major, reversible (sub)chronic toxic effects seem to be limited to changes in blood chemistry and metal absorption/excretion kinetics. Citric acid is not suspected of being a carcinogen nor a reprotoxic or teratogenic agent. The NOAEL for reproductive toxicity for rats is 2500 mg/kg/d. Further, it is not mutagenic <i>in vitro</i> and <i>in vivo</i> . Also, the sensitizing potential is seen as low. In contrast, irritation, in particular of the eyes but also of the respiratory pathways and the skin, is the major toxicological hazard presented by citric acid. (SIDS. Screening Information Data Set for High Production Volume Chemicals, 2004)
Sodium bicarbonate (NaHCO ₃)	Sodium bicarbonate is of low acute toxicity. Oral LD50 values are higher than 4,000 mg/kg bw, and an inhalation study in rats using a concentration of 4.74 mg/l inhalable dust produced no deaths. Sodium bicarbonate is slightly irritating to the skin and eye of rabbits. There is no indication of any adverse effects of long-term use or exposure via any route. <i>In vitro</i> bacterial and mammalian cell tests showed no evidence of genotoxic activity. Sodium bicarbonate is not a reprotoxicant. Based on the available information there are no indications that sodium bicarbonate has carcinogenic effects. Sodium bicarbonate has a long history of use in food and normal handling and use will not have any adverse effects. Acute oral ingestion of high doses may result in a ruptured stomach due to excessive gas development. Acute or chronic excessive oral ingestion may cause metabolic alkalosis, cyanosis and hypernatraemia. These conditions are usually reversible, and will not cause adverse effects. (SIDS. Screening Information Data Set for High Production Volume Chemicals, 2003)
Calcium oxide (CaO; Quick lime)	Occupational and accidental exposures have shown calcium oxide to be very irritating and corrosive to mucous membranes, eyes, and moist skin because of local liberation of heat and dehydration of tissues upon slaking of the small size particles and the resulting alkalinity of the slaked product (calcium hydroxide). Fatal burns have been reported after massive exposure. Calcium oxide was stated not to be sensitizing in an open epicutaneous test. Calcium oxide can cause severe irritation and burns to the eyes, oedema, hyperaemia, lachrymation, blurred vision, corneal opacities, ulceration, and perforation and loss of vision. Inflammation of the respiratory passages, ulceration, perforation of the nasal septum, and pneumonia have been attributed to inhalation of calcium oxide dust. Workers in lime factories for up to 40 years have experienced no ill effects from exposure to lime. (Health Council of The Netherlands, 2006, calcium oxide)

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Appendix 8: Detailed health hazard information on drilling fluid components

Table 1: Health hazards of drilling fluid components (continued)

Component	Human health hazard
Wetting agent	
Sulphonic acid	Sulphonic acids are a class of organic acids which have the tendency to bind to proteins and carbohydrates. The salts of sulphonic acids are the sulphonates. The toxicity of sulphonic acids depends on the specific type. Sulphonic acids may be irritating to skin and/or eye. Check the MSDS for the compound-specific information.
Amides	Amides are formed from the reaction of a carboxylic acid with an amine and are, compared to amines, very weak bases. The toxicity of amides depends on the specific type. Amides may be irritating to skin and/or eye. Check the MSDS for the compound-specific information.
Polyamides	There are different types of polyamides with a different toxicity. Check the MSDS for the compound-specific information.
Rheological modifier	
Fatty acids	Fatty acids are aliphatic monocarboxylic acids and can be naturally derived (from animal or vegetable fat) or synthetic (from oil or wax). Fatty acids are generally low toxicity compounds. Check the MSDS for the compound-specific information.
Polyacrylates	See above (dispersants)
Filtration control	
Asphalt	See above (fluid loss)
Lignite	See above (fluid loss)
Gilsonite	See above (fluid loss)
Lubricating agents	
Ester oils	Check the MSDS for the compound-specific information.
Asphalts	See above (fluid loss)
Graphite	In humans, the pathological and physiological response to inhaled graphite flake is similar to that induced by nuisance dusts and cause only transient pulmonary changes. Repeated exposure to very high concentrations may overwhelm the clearance mechanisms of the lung and result in pulmonary damage from the retained particles in unprotected individuals. However, these lesions either resolve with time or are of limited severity. Driver <i>et al.</i> (1993), <i>Govt Reports Announcements & Index</i> (GRA&I), Issue 06, 2094.
Other	
Bactericides	Check the MSDS for the compound-specific information.
Lost Circulation Material (CaCO ₃ , graphite, walnut shells, mica)	Lost circulation material may form a generic dust hazard. Mechanical irritation to the eyes and respiratory system may occur.
Ammonium bisulphate (max 63% aq. solution)	Ammonium bisulphate in solution is irritant to eyes and skin, and is irritating to the respiratory system. Inhalation of dust can produce irritation to gastro-intestinal or respiratory tract, characterized by burning, sneezing and coughing.
Sodium sulphite (approx 50% aq. solution)	Sulphites that enter mammals via ingestion, inhalation, or injection are metabolized by sulphite oxidase to sulphate. Sodium sulphite is of low to moderate acute toxicity. The oral mouse LD50 is 820 mg/kg. Exposure to the aerosol may irritate the upper respiratory tract. A three-day exposure of rats to a sodium sulphite aerosol produced mild pulmonary edema following exposure to 5 mg/m ³ , and irritation of the tracheal epithelium with 15 mg/m ³ . Between 2% and 5% of asthmatics are sulphite sensitive. Sodium sulphite may be irritating to skin and eyes. Positive reaction in human patch tests have been reported. Sodium sulphite is not considered to be reprotoxic; in rats, sodium sulphite heptahydrate at large doses (up to 3.3 g/kg) produced fetal toxicity but not teratogenicity. Sodium sulphite was negative in genotoxicity studies. IARC concluded that sodium sulphite is not classifiable (group 3) as to their carcinogenicity for humans. (<i>Int J Toxicol</i> Vol. 22, Suppl. 2 (2003) p. 63–88)

Appendix 9: Monitoring methods (Supplementary)

Air monitoring

The methods used to collect samples will vary with the target substance of interest and the duration of the sample.

The most commonly used industrial standards for air sampling of vapour and oil mist are NIOSH 1550 and NIOSH 5026 respectively and although it should be noted that as written the flow rates of the two methods are not compatible, it is possible to modify the test to collect both vapour and oil mist simultaneously in a single sample using glass-fibre filters with a charcoal tube backup in series^{3,7}. Oil mist collected on the filter is analysed by Fourier Transform Infrared Spectrometry (FTIR), while the oil vapour is the fraction in the charcoal tube and is analysed by gas chromatography (GC) with flame-ionizing detector. Although FTIR analysis was recommended for both vapour and mist quantification⁷, the industry has historically preferred GC-FID analysis for determination of oil vapour. The analytical methods are in accordance with NIOSH methods 1500* (vapour) and 5026** (mist).

* www.cdc.gov/niosh/nmam/pdfs/1550.pdf

** www.cdc.gov/niosh/nmam/pdfs/5026.pdf⁸

Other methods include:

Colorimetric detector tubes

These are easy to use, direct reading indicator tubes. The tubes are designed for specific gases or vapours; each tube is filled with a different chemical. A sample of air containing a gaseous air contaminant is drawn through the tube with a hand pump. The air contaminant reacts with the chemical in the tube to produce a colour change. The length of the colour stain indicates the concentration of the contaminant in the air.

Advantages of detector tubes include instantaneous reading, ease of use and relatively low cost. The short sampling time low accuracy and interfering gases and vapours are among the disadvantages of detector tubes.

Detector tubes are primarily used to obtain a quick assessment of relative exposure levels. Some tubes are made to be used with low flow air pumps to provide long duration exposure measurements.

Passive and active adsorption sampler

Passive and active adsorption samplers are longer term devices which trap gaseous air contaminants for laboratory analysis. Commonly, tubes and passive samplers (badges) are filled with activated charcoal and analysed by gas chromatography. Other adsorbents, such as silica gel, are used for some materials.

Advantages of these samplers include the relatively low cost of tubes and the capability to determine a wide range of materials in the air, often simultaneously. Disadvantage include analytical expense and, for active samplers, the need for an air sampling pump.

Filters

Filters are used to collect particulate materials in the air. A sampling pump is used to draw air through a filter, which collects the material to be analysed. Analysis may involve weighing the filter before and after sampling to determine the mass of material collected, or laboratory analysis by one of a number of analytical methods.

The advantage of sampling with filters is the capability to determine the concentration of a wide variety of particulate materials in the air. Disadvantages of filter sampling include analytical costs and the need for an air sampling pump.

Other methods

Other sampling methods may be used for specific air contaminants. These include direct reading instruments and absorption methods.

Skin monitoring

Most gases and vapours are not absorbed through the skin. However, the following conditions may apply:

- Solids generally need to dissolve to allow dermal uptake.
- High molecular weight liquids (>500 Daltons) and an octanol-water partition coefficient of less than about -1 or greater than 4 is unlikely to permeate through the skin.
- Contact dermatitis may be contracted from exposure to water, drilling fluids, organic solvents.
- Occlusion may increase skin uptake, e.g. when using contaminated gloves.

A worker's skin may be exposed to hazardous chemicals through direct contact with contaminated surfaces, deposition of aerosols, immersion, or splashes. When substantial amounts of chemicals are absorbed, systemic toxicity can result.

Passive dermal monitoring

Passive dermal monitoring can be used both to evaluate exposure and/or glove performance under actual use conditions⁹. Dermal dosimetry is not a simple or routine procedure and so has not been widely accepted as common practice¹⁰. A patch dosimeter is like a sandwich holding a passive chemical adsorbent matrix flat, protecting it from skin perspiration. Dermal dosimetry can be used to quantify the magnitude of the dose, and also describe the deposition density and pattern of exposure across body locations. One of the most important limitations (not restricted to dermal dosimeters) is the difficulty in accurately collecting depositions of volatile chemicals.

Visual examination

Traditionally, skin condition has been assessed by visual examination (usually of the hands). This has a significant limitation in that it is very subjective (reliant on the competence of the assessor) and will only identify damage already visible on the skin surface. The effect of contact between the skin and irritant substances is thought to be cumulative. There may be no visual signs of damage until what described as a 'threshold' is reached, by which time the skin will have become significantly weakened with a real probability of irritant contact dermatitis¹¹. This cumulative effect is usually the result of contact between the skin and many different irritant substances and can occur over a lengthy period (possibly many years) with no visible signs of damage.

There are two measurements that have been accepted as relevant for skin condition monitoring: the measurement of trans-epidermal water loss and of the moisture content of the stratum corneum.

Trans-epidermal water loss

Trans-epidermal water loss (TEWL) is the amount of moisture that is lost through the skin's permeability and is considered an indicator of the skin's barrier properties. An adequate level of hydration of the stratum corneum is known to be an essential condition for a healthy skin. Many studies indicate that repeated exposure to irritant substances will elevate TEWL and reduce skin moisture

content. Measuring these two parameters can provide information about the skin's general condition; repeated measurements can establish deterioration or improvement trends¹².

Skin moisture level measurement

Skin moisture level measurement is carried out simply and quickly by placing a probe on the surface of the skin which creates an electrical field that enables the capacitance of the skin to be measured and compared with that of pure water and expressed as a number. Since the band within which normal skin values should lie has been established by dermatological studies, this shows whether the skin as measured is normal, excessively dry or excessively moist.

A visual inspection of the skin should be carried out at the same time and the observations of the assessor recorded alongside the measurements. Information such as general appearance, cleanliness, condition of nails, cuts or grazes etc. can be very significant in assessing the overall condition and in determining future action.

Appendix 10: Health surveillance for exposure to drilling fluid

As several drilling fluid components have the potential to cause skin dryness and irritation, and have the potential for respiratory exposure, both dermal and respiratory health surveillance techniques are relevant. Some forms of health surveillance are required by law in specific regions.

Dermal health surveillance

A simple strategy for skin surveillance may include a baseline assessment of workers' skin condition as soon as possible after they start a relevant job (e.g. within six weeks):

- Introduce regular testing—every few months or annually—as advised by the health professional. This could involve a questionnaire and skin inspection (hands, forearms and, if these can be contaminated, lower legs).
- A competent person should be able to interpret the results and identify any need to revise the risk assessment.
- The reporting of symptoms that occur between routine tests should be encouraged and provided information analysed for trends in exposure patterns.

Traditionally, skin condition has been assessed by visual examination (usually of the hands). This has a significant limitation as it is very subjective (reliant on the competence of the assessor) and will only identify damage already visible on the skin surface. The effect of contact between the skin and irritant substances is thought to be cumulative. There may be no visual signs of damage until what is described as a 'threshold' level is reached by which time the skin will have become significantly weakened with a real probability of irritant contact dermatitis¹¹. This cumulative effect is usually the result of contact between the skin and many different irritant substances and can occur over a lengthy period, possibly many years, with no visible signs of damage.

There are two measurements that have been accepted as relevant for skin condition monitoring: the measurement of trans-epidermal water loss and the moisture content of the stratum corneum.

Trans-epidermal water loss (TEWL) is the amount of moisture that is lost owing to the skin's permeability and is considered an indicator of the skin's barrier properties. An adequate hydration level of the stratum corneum is known

as an essential condition for healthy skin. Many studies indicate that repeated exposure to irritant substances will elevate TEWL and reduce skin moisture content. Measuring these two parameters can provide information about the skin's general condition; repeated measurements can establish deterioration or improvement trends¹².

Skin moisture level measurement is carried out simply and quickly by placing a probe on the skin surface which creates an electrical field that enables the capacitance of the skin to be measured and compared with that of pure water, and then expressed as a number. Since the band within which normal skin values should lie has been established by dermatological studies, this shows whether the skin as measured is normal, excessively dry or excessively moist.

A visual inspection of the skin should be carried out at the same time and the assessor's observations recorded alongside the measurements. Information such as general appearance, cleanliness, condition of nails, cuts or grazes etc. can be very significant in assessing the overall condition and in determining future action.

Respiratory health surveillance

Simple respiratory health surveillance may involve asking the employee to complete a respiratory health questionnaire to try to determine whether breathing problems may have developed as a result of workplace substance exposure.

More technical methods can also be used, such as spirometry, a lung function test to assess the capability of the lungs in gaseous exchange. This will detect any underlying lung impairment. The test, which should be conducted by medical practitioners, involves having the participant blow into a tube and totally empty the lungs as a measure of lung function. Occupational asthma or other respiratory diseases may be identified by this procedure, although further diagnostic testing may be required.

Appendix 11: Potential health effects that may result from exposure to certain components of drilling fluids

Potential health effects of exposure to components of drilling fluids				
Target organ	Potential health effects	Signs and symptoms	Examples of first aid	Examples of medical treatment
Skin	Dermatitis—acute, chronic	Drying, redness, cracking, chafing, chapping	<ul style="list-style-type: none"> Wash affected areas immediately with mild soap and water. Remove contaminated clothing from the skin. 	<ul style="list-style-type: none"> Topical application of emollient cream to affected areas (may be applied twice a day) Avoid perfumed products which may contain a sensitizing reaction. Consider the use of corticosteroid creams, following physician assessment. (maybe applied 2–4 times per day).
	Folliculitis		<ul style="list-style-type: none"> Wash affected areas with mild soap and water. Apply warm compresses. 	<ul style="list-style-type: none"> Warm compresses Following physician assessment, topical antibiotics 2–3 times per day.
	Oil acne		<ul style="list-style-type: none"> Wash affected areas with mild soap and water. 	<ul style="list-style-type: none"> Wash affected areas with mild soap and water 1–2 times per day. Avoid greasy products; use water based cosmetics. Acne treatment depends on severity of condition. Topical antibacterials for milder cases; oral antibiotics for severe acne.
	Urticaria		<ul style="list-style-type: none"> Wash affected areas immediately with mild soap and water. 	<ul style="list-style-type: none"> Following physician assessment, use of antihistamines as an added treatment to prevent urticaria and further skin infection.
	Corrosion/irritation/inflammation		<ul style="list-style-type: none"> Wash affected areas immediately with mild soap and water. Remove contaminated clothing from the skin. 	<ul style="list-style-type: none"> Lubricant creams a few hours after the application of topical steroids—continue for days or weeks until after inflammation has cleared.
	Skin sensitization		<ul style="list-style-type: none"> Immediately wash off splashes by irritant or sensitizing substances with soap and water. Minimize exposure to sunlight, as workable. Avoid further contact with the causative substance. Antihistamines (topical or oral) as per prescribed instructions. 	<ul style="list-style-type: none"> Avoid further contact with the causative substance, to relieve & eliminate redness. If there is a risk of ongoing exposure, gloves and protective clothing are to be used. Antihistamines (topical or oral) as prescribed following physician assessment, to relieve itchiness. Barrier creams as required.

continued ...

Drilling fluids and health risk management

A guide for drilling personnel managers and health professionals in the oil and gas industry

Appendix 11: Potential health effects that may result from exposure to certain components of drilling fluids

Potential health effects of exposure to components of drilling fluids (<i>continued</i>)				
Target organ	Potential health effects	Signs and symptoms	Examples of first aid	Examples of medical treatment
Respiratory system	Silicosis	Cough, phlegm, shortness of breath, inflammation of large airways, impaired lung function, can lead to heart failure.	<ul style="list-style-type: none"> • Inhalers—bronchodilators to open airways. • Fluids to prevent thick secretions 	<ul style="list-style-type: none"> • For those with breathing difficulties, drug therapy to keep airways open and free of mucus. • Control of dust in the workplace, use of proper PPE, and regular chest X-ray monitoring for exposed workers as preventative measures.
	Respiratory tract irritation	Cough, phlegm, sore throat	<ul style="list-style-type: none"> • Oxygen therapy • Fluids • Bronchodilator inhaler if required 	<ul style="list-style-type: none"> • Oxygen therapy • Fluids • Use of appropriate face mask/chemical cartridge as preventative measure.
	Respiratory tract sensitization	Cough, sore throat, sputum	<ul style="list-style-type: none"> • Oxygen therapy • Fluids • Inhaler—bronchodilator 	<ul style="list-style-type: none"> • Oxygen therapy • Fluids • Corticosteroids to reduce inflammation can be helpful.
	Occupational asthma	Shortness of breath, wheezing, cough, chest tightness, sneezing, congested nose, teary eyes	<ul style="list-style-type: none"> • Oxygen therapy • Inhalers—bronchodilators to open airways 	<ul style="list-style-type: none"> • Oxygen therapy • Bronchodilators to open airways (inhalers, oral form) • If severe, to reduce inflammation, oral corticosteroids for short term therapy; inhalers for long term therapy). • Vapour and dust control as preventative measures.
	Chronic obstructive pulmonary disease	Cough, sputum production, shortness of breath on exertion and with activities, respiratory rate irregularity, wheezing, leg swelling, cyanosis, weight loss	<ul style="list-style-type: none"> • Oxygen therapy—low flow rate • Metered-dose inhaler for bronchodilation • Fluids to loosen thick secretions 	<ul style="list-style-type: none"> • Oxygen therapy—low flow rate • Following physician assessment, metered-dose inhalers to relieve airflow obstruction. • For severe disease, nebuliser mode of therapy (inhalation of drug via mist). • Drug dose control and monitoring required by physician. • Corticosteroids for symptoms not controlled by other drugs (inhaled has less side effects than with oral form). • Spirometry/pulse oximetry to monitor symptoms. • Plenty of fluids to avoid dehydration & prevent thick secretions. • Antibiotics for bacterial infection.

continued ...

Drilling fluids and health risk management

A guide for drilling personnel managers and health professionals in the oil and gas industry

Appendix 11: Potential health effects that may result from exposure to certain components of drilling fluids

Potential health effects of exposure to components of drilling fluids (continued)				
Target organ	Potential health effects	Signs and symptoms	Examples of first aid	Examples of medical treatment
Respiratory system (continued)	Chemical pneumonia	Sudden shortness of breath, cough within minutes or hours; sore throat; possible fever & pink frothy sputum; possible chest pain	<ul style="list-style-type: none"> • Oxygen therapy • Intravenous fluid therapy for hydration if have a decreased intake of oral fluids. 	<ul style="list-style-type: none"> • Oxygen therapy • Mechanical ventilation if required—suctioning of trachea to clear secretions. • Prescribed antibiotics, corticosteroids. • Monitoring of oxygen saturation and chest X-ray assessments.
	Nose bleeds	Trickling or steady bleeding from nose	<ul style="list-style-type: none"> • Control bleeding by firmly pinching the sides of the nose together for 5 to 10 minutes. • Ice packs to nose. 	<ul style="list-style-type: none"> • Physician assessment required if pinch technique does not stop the bleeding. • Nasal packing may be required for minor bleeding. • For more severe or recurring bleeding, cauterization of the bleeding source may be required. • Humidify air during the winter.