Drilling fluid products for rotary drilling

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Drilling fluid in well construction

With the introduction of mobile, hydraulically driven flush drilling equipment at the end of the 1950s, circulation fluids have become increasingly important in well construction. Through the controlled use of agents in water-based drilling fluids, it has been possible to satisfy the continuously increasing demands of clients for deeper, larger and more efficient wells.

Modern drilling fluids becoming state-of-the-art technique enables for the fast drilling of uncased boreholes for water supply, monitoring purposes, geothermal applications and mineral exploration.. The technical and economic benefits in comparison to the dry hole method are indisputable.

As a leading manufacturer and supplier of well construction materials, SBF-Hagusta GmbH provides a complete range of bentonites, protective colloid polymers, weighting materials and chemicals for the creation of up-to-date circulation systems.

1.0 Definitions

The development of drilling fluid technology began with the invention of the rotary drilling process which was patented by Robert Beart in 1845. Water was originally used as the drilling fluid which, as drilling progressed, became gradually infused with cuttings, forming a sludge known as drilling mud. Experience showed that drilling mud, particularly after sinking through swelling clay particles, demonstrated better properties than pure circulation successfully water. Subsequently, clay-water suspensions were used instead of pure water. In 1921, drilling fluids with baryte were introduced for the first time in high-pressure beds. Chemicals and water-soluble polymers were added to optimise the drilling fluid characteristics from 1929 onwards.

Nowadays, semi-complex circulation systems are available for nearly all drilling tasks, where the term 'drilling fluid' describes all circulating liquids and gases in the borehole that are controlled during the drilling process.

2.0 Functionally of Drilling fluids Drilling fluid products

The application of drilling fluids encompass the following areas:

- removal of cuttings from the bottom of the borehole and settling them at the surface
- supporing and stabilising of the uncased borehole wall
- balancing high rock as well as bedding pressures
- protecting target formations
- cooling and lubricating the drill bit

According to experience, these requirements cannot be sufficiently fulfilled if only pure water is used as a circulating fluid. The use of water is therefore limited to a few isolated cases, for example drilling in stable, low-permeable bedrock.

2.1 Removal of cuttings

The removal of cuttings from the bottom of the hole to the surface is significantly influenced by 3 factors:

- the uphole-flowrate of the fluid
- the relative densities of the fluid and the cuttings
- the viscosity of the drilling fluid

Particularly in cases where the circulation fluid is pumped down the drill pipe (pressure drilling), the drilling equipment (bit, rod diameter, circulation pump) must be appropriately designed that the ascending fluid reaches flow rates between 0.5 m/s – 1.0 m/s in the annulus of the borehole.

To achieve these desired uphole velocities, the following pump rates are recommended:

Minimum pump rate 110 l/min per inch bit diameter

Drilling progress < 4.5 m/h: approx. 130 l/m per inch bit diameter

Drilling progress > 4.5 m/h: approx. 160 l/m per inch bit diameter

To be avoided: pump rates > 200 l/min per inch bit diameter. These rates cause turbulent flows which lead to borehole enlargements and wear of drilling tool.

The smaller the difference in density between the drilled solids (approx. 2.6 kg/l) and the drilling fluid, the lower their settling rate. However, it is not recommendable to increase the density of the drilling fluid with the aim of improving its carrying capacity as heavy fluids laden with solids impede drilling progress and raise the risk of the target borehole zones becoming permanently blocked.

It is much more suitable to use drilling fluids having alow solid content and to enhance their viscosity by adding special additives (Table 1).

2.2 Borehole stabilisation

Essentially, for the uncased borehole to be supported, the pressure of the fluid column must be greater than the exerted by the groundwater and the formation.

Table 1:
Overview of agents for raising carrying capacity/viscosity

Chemical characterisation	Recommended use
active bentonite	fresh water fluids
polyanionic CMC*	fresh/salt water fluids
industrial CMC*	fresh/salt water fluids
polyacrylamide	fresh water fluids with low solids content
hydroxyethylcellulose (HEC)	fresh/salt water fluids Ca2+Mg2+ content > 1500 ppm
guar gum	bentonite-free fresh water fluids

* ??????????????????

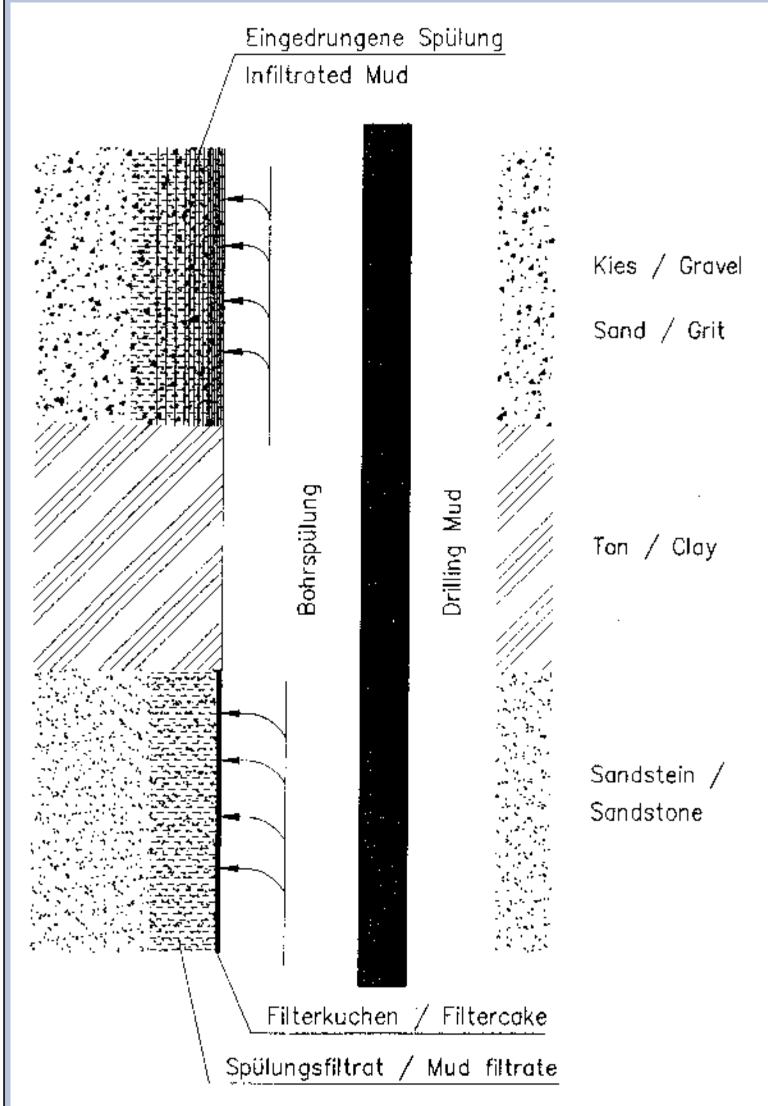
A difference in hydrostatic pressure of 2 m H2O has proven to be sufficient. In addition, an impervious zone must form in the forward drilling area so that the fluid column pressure can act on the earth and groundwater pressure, thus preventing circulation losses.

The filtration processes that build up the filter cake on the borehole wall (or an impervious zone in the forward drilling area) differ depending on the pore size of the lithology encountered:

- **The voids (pores) are larger than the solid particles in the fluid.**

This situation usually occurs when drilling in unconsolidated sediments such as beds of gravel and sand (see Fig. 1, upper section of borehole with grit/gravel). Particles in the drilling fluid (clay particles/bentonite platelets/long-chained polymer molecules) form a mesh in the open spaces of the permeable formation which balances the pressures. The water slowly penetrates through this mesh and a successively impermeable thin layer is build up at the borehole wall. This lowpermeability layer is called „Filter Cake“.

Fig. 1: **Mud infiltration in an aquifer**



- **The pores are smaller than the solid particles in the fluid.**

The water is squeezed at the borehole wall and slowly build up a tight barrier through the pores, the solid particles are deposited (see Fig. 1, lower section of borehole with sandstone/filter cake).

Pore sizes exceeding a certain limit result in losses of circulation. In such cases, special materials (lost circulation materials) are applied having a certain size and shape enabling them to block the open spaces in the formation and thereby minimise or stop the circulation losses. (see Table 2).

In addition to protecting unconsolidated sediments from caving in, drilling fluid has another important role: to prevent hole instability caused by the hydration of cutting constituents composed of clay minerals. Depending on the content of swelling components in the cuttings, the following may occur:

High concentration of high swelling constituents.

- constriction of the hole whereby the cuttings often develop plastic properties
- no caving
  pulling overload possible due to
  clayey sticking and keyholing of drill string
- rapid thickening of the drilling fluid due to loading with cuttings

Table 2:
Overview of agents for stabilising the uncased hole

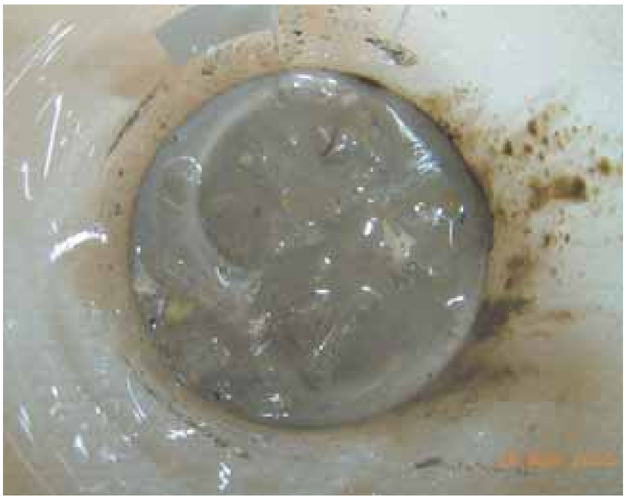
Characterisation	Recommended use
active bentonite	stabilisation of sand/gravel beds in fresh water fluids
polyanionic CMC*	clay inhibition in fresh/salt water fluids
industrial CMC*	clay inhibition in fresh/salt water fluids
polyacrylamide	clay inhibition in fresh/salt water fluids
hydroxyethylcellulose (HEC)	clay inhibition in fresh/salt water fluids where Ca^{2+}/Mg^{2+} content > 1500 ppm
guar gum	clay inhibition in fresh water fluids
For lost circulation materials in all systems, see appended datasheets	

* ??????????????????

Overview of agent properties							
	Bentonite	Pure CMC HV	Industr. CMC HV	Industr. CMC LV	HEC polymer	PAA	Polysac charide
Viscosity forming effect	++	++	++	–	++	++	++
Stabilising effect on unconsolidated sediments	++	0	0	–	0	–	+
Clay inhibition	–	++	++	0	++	++	++
Salt stability NaCl/KCl	–	+	+	+	+	0	0
Salt stability Ca^{2+}/Mg^{2+}	–	–	–	–	++	–	–
Temperature stability	+	+	+	+	+	++	–
Biological stability	++	0	0	0	0	+	–
Key: ++ = very good / + = good / 0 = moderate / - = poor							

Fig. 2 **Clay cuttings in different drilling fluids**

Dry cuttings before insertion



Cuttings after 24 hours in water

Cuttings after 24 hours in Viscopol fluid

Cuttings after 24 hours in salinised Viscopol fluid

Low concentration of swelling constituents

- enlargement of the hole diameter, caused by the loosening of the structure of compact cuttings and their resulting disintegration
- caving which increases with the hydration of the forward drilling zone
- continuous removal of debris from the instable cuttings

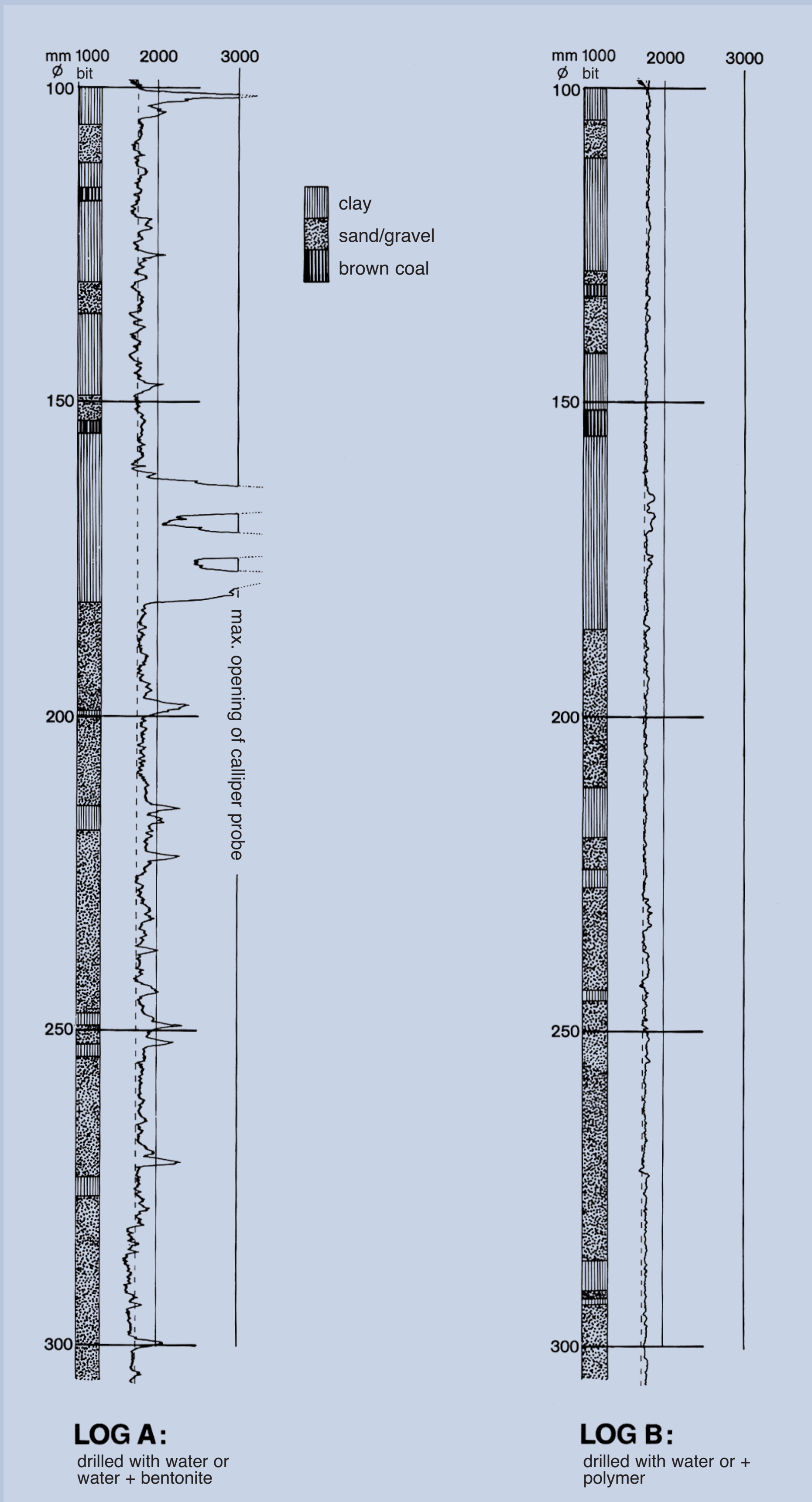
Clay-inhibiting polymers, if necessary in mixed with with sodium chloride or potassium chloride, prevent or at least slow down the progress of the instabilities described, enabling for the drilling of geometrically perfect boreholes even in difficult geological environments (Fig. 3).

2.3 Offsetting high rock and bed pressures

If high rock and bed pressures are encountered while drilling, a fluid column pressure must be created by raising the specific weight of the drilling fluid so that artesian groundwater is prevented from entering the hole. The weighting must be such to create a pressure of at least 2 mH_2O.

Materials used for weighting are namely ground chalk (density 2.6 kg/l) for fluid densities < 1.25 kg/l, and baryte (density 4.2 kg/l) for higher fluid densities (see appended datasheets).

Fig. 3 **Calliper logs of two well holes**



Example of determining the fluid density required in the case of artesian overpressure:

Depth of the artesian inflow: 50 m
Water pressure at 50 m: 5,0 bar

Artesian overpressure, ground level: 0,5 bar / 5 mH_2O

Required fluid density to offset the inflow and create a drop in pressure of 2 mH_2O (0.2 bar) at depth.

$$\text{Fluid density (kg/l)} = \frac{\text{Artesian overpressure + required drop in pressure}}{\text{water pressure at inflow depth}} + 1.0$$

$$\text{Fluid density (kg/l)} = \frac{0,5 + 0,2}{5,0} + 1,0$$

Fluid density (kg/l) = 1,14 kg/l

Fluid weighting:

$$t/m^3 = \frac{W3 \times (W2 - W1)}{W3 - W2}$$

W1 = density of outflow fluid kg/l
W2 = required fluid density kg/l
W3 = density of weighting material kg/l

It is essential to ensure that weighted fluids have an increased carrying capacity so that weighting material does not settle and instead remains evenly distributed in the suspension. Active bentonite usually forms the basis of this type of system.

2.4 Protection of the target aquifer – fluid control

As previously described, the higher hydrostatic pressure of the fluid column compared to the groundwater pressure in the aquifer causes the fluid to penetrate the forward drilling area and enables the formation of an impervious zone a filter cake. After finalising the borehole, this filter cake must be removed in order to enable the groundwater to flow into the well. This is done by developing the well. To prevent the building-up of a filter cake which is to thick or which is penetrating to deep into the formation, low solids polymer fluids are applied.

In practice, it is essential that the effectiveness of the polymers is controlled and thereby safeguarded, particularly when drilling in target formation. One method, among others, is to measure the **filtration time** (see appendix on fluid measuring devices).

Guideline for protective fluid according to DVGW (German Technical and Scientific Association for Gas and Water) information sheet W 116:

Filtration time: > 1000 s

For holes > 500 m, it is also advisable to check the filtration process directly using the API filtration test.

Guidelines:	**API filtrate**	**< 10 ml**
	Filter cake thickness	**< 1 mm**

In order to obtain a protective drilling fluid, it must also be ensured that the fluid does not become excessively loaded with fine solids. Experience has shown that due to their high intrinsic weight, fluids high in solids penetrate deep into the aquifer and form thick filter cakes that are difficult to remove.

If borehole conditions allow, the fluid should not exceed the following threshold value in the screened borehole zones (DVGW recommendation W 116):

Recommended value for fluid density: < 1,10 kg/l

If the fluid density exceeds this value, suitable corrective measures must be taken, including new fluid applications. Here, it should also be whether the capacity of the settling tanks/pools has been exhausted and they need to be emptied. Also, if meeting the upper limit causes further problems, for example rapid ascent while drilling, it may be the case that the carrying capacity of the fluid is too great.

Settling tank system for effective control of solids

This can easlily be tested with by measuring the Marsh time (see appendix on fluid measuring devices):

Recommended values:

Funnel viscosity:	**AZ**	**38 - 45 s**
Funnel emptying time	**RAZ**	**28 - 35 s**

Adhering to the recommendations given above will result in drilling fluids having a sufficient carrying capacity so that the solids are transported to the surface and are in the settling areas of the fluid tanks. Without additional equipment to control solids (jigging screen/desander/desilter/mud cleaner), higher viscosities cause rapid loading with the negative results described.

Fluid parameters and details of the quantity and type of agents/water quantities used should be regularly measured during drilling and recorded on appropriate forms (see appended data checking sheet), not least as a proof of the quality of services rendered.

3.0 Fluid formulations

The selection of the agent is normally determined by the following factors:

- stability of the rock
- permeability of the rock
- pressure ratios in the rock
- drilling method

The use of additive-free water as a circulating fluid is limited to a few isolated cases, for example drilling in stable, low-permeable bedrock. If it would be applied in the case of unconsolidated sands/gravels, the borehole would not be adequately stable. Equally, water or pure bentonite fluids only have limited use in clayey, cohesive sediments. Due to their inadequate inhibiting properties and high filtration times, solids normally accumulate quickly and the clay minerals present start to swell which causes constriction of the hole or erosion through caving. Furthermore, the pores in the aquifer are clogged by cutting substances, such as sand, clay and silt, in a way that is greater and more permanent than had the correctly dosed additives been applied.

When drilling in primarily clay sediments it is recommended that PAA or CMC polymer are used as the sole additives. In this case, the use of bentonite is not required as the small quantities of clay cuttings in the fluid will disperse and, in conjunction with the polymer, form a tight, thin filter cake.

3.1 Fluid formulation when drilling in primarily clay sediments

	1 m³	**water**
	+ 2 kg	**pure CMC**
or	**+ 6 kg**	**industrial CMC**
or	**+ 2 kg**	**high-viscosity PAA**

A bentonite/polymer fluid should be used in interbeds of sand/gravel/clay, particularly if grits and gravels are present towards the surface. Bentonite is usually used for the initial application of the fluid and later the volume is increased with solid-free polymer solution, as clay cuttings also remain in the fluid even when cohesive sediments are encountered.

Foam circulation for down-hole hammer drilling in bedrock.

3.2 Fluid formulation – initial application if drilling in interbeds of sand/gravel/clay

	1 m³	water
	+ 20 kg	bentonite
		(left to pre-soak for min. 1 h)
	+ 1,5 kg	pure CMC HV
or	+ 4,0 kg	industrial CMC HV

If artesian water is encountered, bentonite-polymer fluids are used which are weighted with ground chalk until the required weighting is achieved (see table in appendix 3). If the fluid density required to balance the groundwater pressure rises over 1.25 kg/l, baryte should be applied to achieve further weighting.

Injector for mixing polymer fluids

With regard to the sequence in which products are mixed, it is essential that bentonite is always dispersed first in polymer-free water. There must be a minimum swelling time of 1 h before the polymers can be added.

Injectors are used to mix the products to produce a free of lumps fluid. These injectors can be driven by the fluid pump which is present at the drilling site (see above). Alternatively, smaller polymer quantities can be interspersed at a turbulent location in the fluid circuit above ground.

3.3 Formulation for weighted fluids

	1 m³	water
	+ 20 kg	bentonite
		(left to pre-soak for min. 1 h)
	+ 1,5 kg	pure CMC HV
or	+ 4,0 kg	industrial CMC HV
	+ x kg	ground chalk
or	+ x kg	baryte with density upwards from 1.25 kg/l

In this special case, this mixture is also used to increase volume.

Volume increases

In order to regulate the viscosity of the fluid or to reduce the content of solids in the fluid (= density) the total fluid volume needs to be increased. This should be done by adding pure polymer fluids to the original mixture. In cases of drilling in sand/gravel formations, small proportions of bentonite should be added. An exception of this procedure are weighted fluids.

3.4 Formulation for volume increase

	1 m³	water
	+ 0-20 kg	bentonite
		(left to pre-soak for min. 1 h)
	+ 1-2 kg	pure CMC HV
or	+ 3-6 kg	industrial CMC HV
		depending on viscosity

Prakla universal drilling equipment with settling tank system

4.0 Testing drilling fluids

Marsh funnel for determining the carrying capacity of drilling fluids

- Seal the bottom end of the funnel and fill with fluid through the screen until the level touches the bottom side of the screen (1500 ml).
- Release the lower opening and use a stop watch to determine the time required for the outflow of 1000 ml of fluid. This time period is called „Funnel Viscosity“.
- Then measure the time the remaining 500 ml of fluid needs to flow out of the funnel. This time period is called „Funnel Emptying Time“.

Guidelines:	funnel viscosity	38 – 45 s
	funnel emptying time	28 – 35 s

Ring device for measuring filtration time

- Place a filter pape on the base.
- Position the metal ring centrally on the filter paper.
- Fill the conical ring opening with the drilling fluid to be tested.
- Start your stop watch when the first drop touches the filter paper.
- Measure the time required for the whole of the filter paper completely soaked. This is called „Filtration Time“.

  Recommended value: > 1000 s

Hydrometer/aerometer for determining the relative density of the drilling fluid

- Fill the cup at the bottom end of the hydrometer with the fluid to be tested, and connect it to the hydrometer without trapping any air.
- Immerse the hydrometer in a tube filled with water.
- Read off the density of the fluid from the point at which the surface of the liquid touches the stem of the hydrometer. This number gives you the density of the fluid in kg/l.

  Recommended value for unweighted fluid: < 1,10 kg/l.

[1] 50 mm diameter filter paper, type Schleicher & Schüll 2040a

Marsh funnel and measuring jug

Ring device with filter paper, stop watch

Mud balance and hydrometer

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