2.
Drilling with fluids

Fluid – plain water or water with additives – is forced by a pump down the centre of the drill pipe through the drill bit and back in the annular space formed between drill bit and the drill pipe to the surface into a 'mud'-settling pit. The fluid does a number of key jobs, which each need to be properly understood to keep the hole under construction under the control of the drillers.

2.1 Adequate pump flow for diameter of well being drilled

As the fluid flows through the drill bit it picks up loose debris cut by the drill bit and carries it to the surface. It is only able to do this effectively if the water flow is sufficiently rapid to carry the particles

Up-hole velocity should range from 15–30 metres/minute and the required circulating pump capacity can be calculated using the following formula:

$(D^2 - d^2) \times 7.5 =$ litres/minute

where:

D = drill bit diameter in inches
d = drill pipe diameter in inches

This gives the minimum flow requirement; double the figure for the maximum flow requirement

Example:

A 6" (150mm) diameter hole drilled with 3" (75mm) diameter drill pipe.

$(6^2 – 3^2) = (36 – 9) = 27 \times 7.5 =$ 202.5 litres/minute minimum pump flow.

Table 2.1 Formula to calculate required fluid circulation pump flow

Drill Bit Diameter		***Drill pipe diameter***					
mm's	Inches	58mm (2.1/4")		75mm (3")		88mm (3.1/2")	
		Min	Max	Min	Max	Min	Max
75	3"	30	60				
90	3.1/2"	54	108	25	50		
100	4"	82	164	55	110	25	50
125	5"	150	300	120	240	100	200
140	5.1/2"	190	380	160	320	135	270
150	6"	230	460	200	400	175	350
200	8"	450	900	415	830	390	780
250	10"	700	1,400	685	1,370	650	1,300
Useful conversion figures:							
Litres per minute		x.06	= Cubic metres per hour				
Litres per minute		x.22	= imperial gallons per minute				
Litres per minute		x 13.2	= Imperial gallons per hour				

Table 2.2 Fluid Flow in litres per minute required to drill holes of various diameters

from the bottom of the hole to the top. This speed depends on the flow capacity of the pump and the diameter of the hole and needs to be within a specific range. If it is too slow, debris will clog the hole above the drill bit and if it is too fast it will erode the wall of the hole and create problems with steady material removal as the drilling is deepened. Table 2.1& 2.2 gives examples of fluid flow speeds required for various hole diameters.

2.2 Fluid circulating pumps: 'mud pumps'

Large, deep-hole drilling equipment invariably uses big and powerful piston pumps of the 'fixed displacement' type. This means that they are capable of delivering a steady flow rate at a given piston speed no matter what pressure restrictions are placed in drill-pipe and borehole. Lighter equipment invariably uses 'centrifugal' impeller pumps. These are capable of delivering large volumes (flows) of water with minimal power but they have very limited capacity to develop pressure (head). Any obstructions to the free flow of water through small, diameter hoses or fittings, or friction loss in long lengths of drill pipes increases the pressure head and this means that the flow drops off.

Progressive cavity pumps are also used successfully as mud pumps (Figure 2.1). By rotating a thread -shaped steel stator in a thread shaped rubber sleeve, the 'progressing cavity' formed induces flow and a pressure head. Like the piston pump this type of pump has a fixed displacement capacity – giving the same flow despite the pressure head put on it. With this type of pump, it is important to select a model that produces the required flow by keeping the rotating speeds quite low. This will prevent high internal velocities of what becomes a very abrasive fluid, which could quickly wear pump internal components.

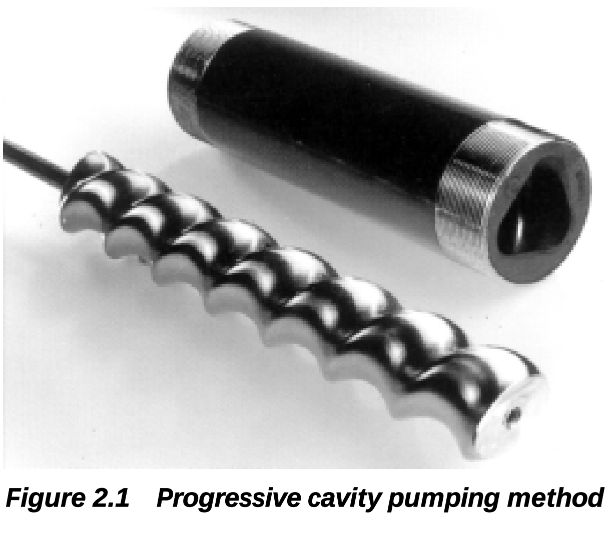
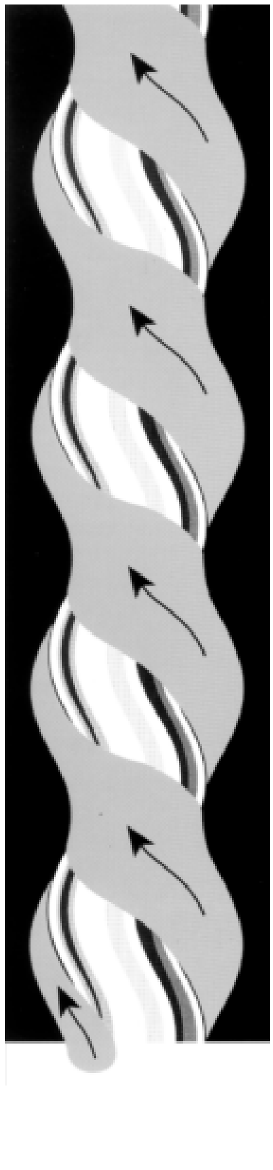


Figure 2.1 Progressive cavity pumping method

All pumps wear from pumping abrasive, soil-laden drill fluid, however effective the settlement, and will need replacement of wearing parts to keep them delivering required volume and pressure.

2.3 Flow and friction

When using centrifugal impeller pumps, care must be taken that the design of the equipment caters for easy flow (internal diameters as large as feasible) through swivels and drill pipes, and that pump speeds are carefully controlled to ensure that the flow is kept low at the top of a hole. This will prevent erosion (Figure 2.2) of the hole diameter and the engine speed should be increased to maintain the pump flow at the bottom of a hole where flow losses occur due to the friction build-up between the



pumped fluid and the confining drill pipe. The capacity of the pump to remove material steadily from the bottom of the hole dictates the penetration speed of the drill bit.

2.4 Preventing hole collapse – 'hydrostatic head'

By keeping a drilled hole full of water/fluid at least 3 metres above the natural water table exerts a water pressure (a hydrostatic head) on the sides of the hole. This will prevent even the softest, finest sand from collapsing into a drilled well (Figure 2.3). It is important to maintain this level throughout the drilling, removal of the drill-pipe, and insertion of casing. Drilling on sites with unconsolidated geology that require support from collapse, and with high water tables (water resting less than 3 metres below surface) need special solutions. By using fluid additives of higher density than water, it is possible to build up the equivalent of 3 metres head: the density required is dependent on the exact column

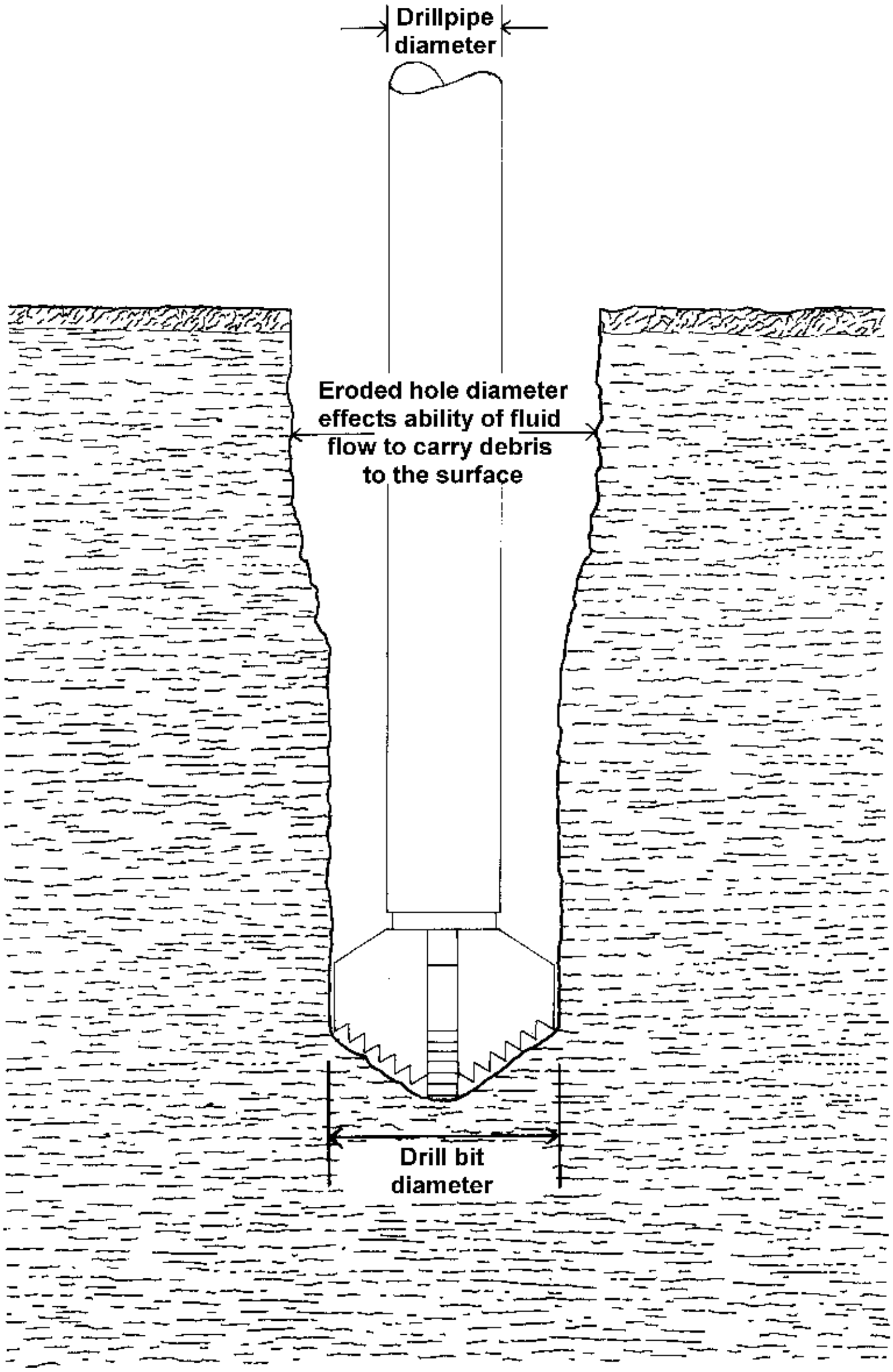


Figure 2.2 Fluid drilling – Effect of eroding diameter

of water required. Salt is one of the simplest and most available chemical additives that could be added to increase density of the drill fluid.

2.5 Hole Cleaning

The up hole velocity of 15 to 30 metres/minute means that it takes several minutes to achieve full circulation of the fluid and carriage of debris from the hole base to the surface. The time debris takes being lifted is not just a calculation of the up hole velocity against hole depth as the debris is not fixed into the fluid but is dropping through the rising column of liquid. Quite simply the deeper the hole the longer the full cycle of cleaning will take.

Having drilled each successive drill pipe to depth the drill pipe should be left at the hole base with the fluid circulating and an amount of time, think minutes not seconds, to be given to allow the hole to clean – to circulate clear the debris.

A clean hole can be easily seen when changing, adding, a drill pipe. Having stopped the mud pump and 'broken' that is unthreading the drill pipe connection between the rig rotary head and lifted the head clear the column of fluid in the drill pipe should

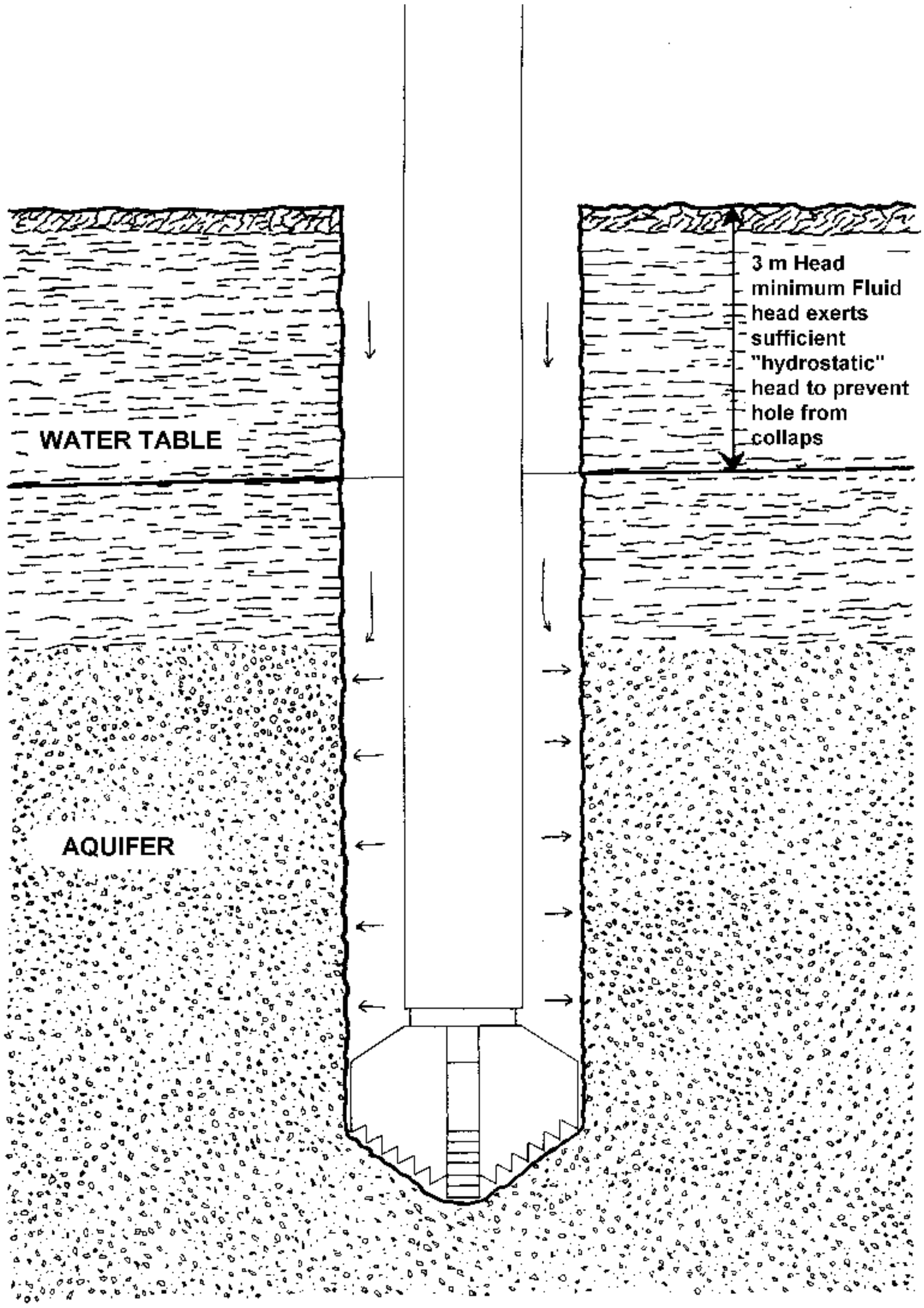


Figure 2.3 Hydrostatic head

quickly drop the short distance to the level of the fluid resting in the borehole. A hole still full of debris or with a blockage will result in fluid flowing out of the drill pipe. Why? It is the manifestation of different density that is being seen – if the fluid in the annulus of the borehole has a load of debris in suspension it is heavier or denser than the clean 'settled' fluid in the centre of the drill pipe so when left open to atmosphere – when the drill pipe connection is broken and lifted clear - the heavier fluid in the annulus will displace the lighter fluid in the centre of the drill pipe.

The more 'out of balance', the bigger the flow out of the drill pipe the more debris is being left in the hole. Seen early a little more time can be given to hole cleaning and the problem solved – left unresolved will mean debris could flow back into the restricted drill pipe bore and this will result in a physical blockage that simply cannot be cleared by the pressure head of the fluid.

2.6 Adequate settling pits

For the circulating fluid to do its job the settling pits must be of an adequate size to enable the debris to settle from the fluid before it is pumped back down the drill-pipe. The practical convention is to have the surface pits volume three times the total volume of the hole to be drilled (see Table 2.3) and to arrange the pits so as to encourage maximum settlement of material from the fluid. The pit dimensions should encourage flow, of the fluid, to slowly flow through the mud pit system to induce as much settling out as possible of 'fines' from the fluid (Figure 2.4). Ideally, the width should equal the depth but local topsoil conditions might influence pit construction considerably. It is always difficult to balance the available transportable water with which to drill and the energy and vigour of the drill crew to dig out the optimum size mud pit. The quality and efficiency of construction of the final drilled hole will benefit from an adequate volume of water.

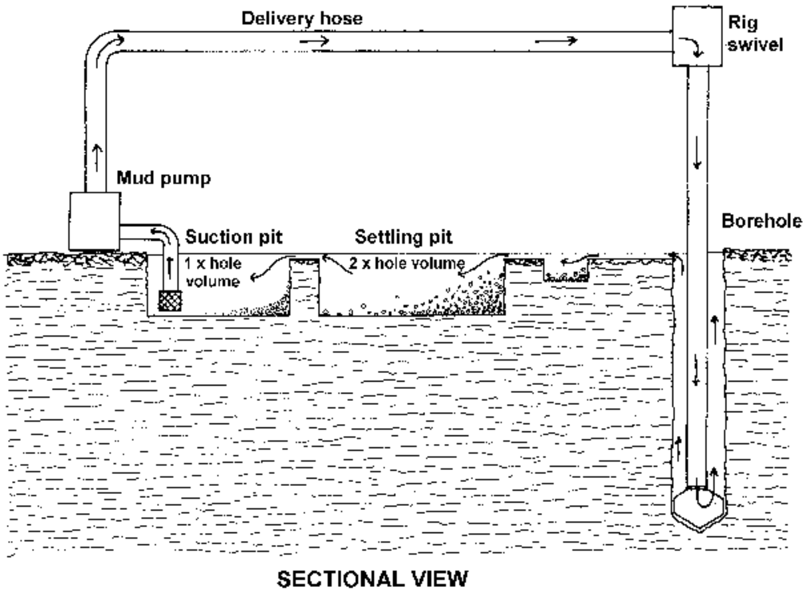
Borehole Diameter & Depth	***Volume of hole***	***Approx Volume of hole****	***Required Volume of Settling Pits***	***Settling Pit - Recommended dimensions in metres***			***Suction Pit - Recommended dimensions in metres***		
mm (inches) x m	***M^3***	***Litres***	***Litres***	***Length***	***Width***	***Depth***	***Length***	***Width***	***Depth***
100 (4") x 25m	0.20	200	600	0.8	0.6	0.8	0.6	0.6	0.6
100 (4") x 50m	0.39	400	1,200	1.2	0.8	0.8	0.8	0.8	0.6
100 (4") x 75m	0.59	600	1,800	1.6	0.9	0.9	0.9	0.9	0.7
100 (4") x 100m	0.79	800	2,400	1.6	1.0	1.0	1.0	1.0	0.8
150 (6") x 25m	0.44	450	1,350	1.2	0.9	0.8	0.9	0.9	0.6
150 (6") x 50m	0.88	900	2,700	1.6	1.1	0.9	1.1	1.1	0.7
150 (6") x 75m	1.33	1,300	3,900	2.0	1.3	1.0	1.3	1.3	0.8
150 (6") x 100m	1.77	1,800	5,400	2.2	1.4	1.1	1.4	1.4	0.9
200 (8") x 25m	0.79	800	2,400	1.6	1.0	1.0	1.0	1.0	0.8
200 (8") x 50m	1.57	1,500	4,500	2.1	1.3	1.1	1.3	1.3	0.9
200 (8") x 75m	2.36	2,350	7,050	2.4	1.5	1.3	1.5	1.5	1.1
200 (8") x 100m	3.14	3,150	9,450	2.8	1.6	1.4	1.6	1.6	1.2
250 (10") x 25m	1.23	1,200	3,600	1.9	1.1	1.2	1.1	1.1	1.0
250 (10") x 50m	2.45	2,500	7,500	2.6	1.4	1.4	1.4	1.4	1.2
250 (10") x 75m	3.68	3,700	11,100	2.8	1.7	1.5	1.7	1.7	1.3
250 (10") x 100m	4.91	4,900	14,700	3.2	1.8	1.7	1.8	1.8	1.5

All Mud settling pits will require topping up during the drilling operation The amount of water required to 'top up' would depend on the porosity of the formation being drilled and the viscosity of the polymer. It is recommended a minimum of the ***Final Hole Volume** should be available as stored water on the drill site to make up losses.

Table 2.3 Recommended settling pit dimensions & borehole volumes

In most cases, surface topsoil will be stable enough to construct settling pits – clay being absolutely ideal material. If the pits are in soft permeable soil they can often be satisfactorily plastered with neat cement & water or possibly sand & cement to seal and strengthen the sides (Figure 2.5). Alternatively local clay could be used to line the pits or plastic sheets used – take care to ensure water cannot flow behind any sheet.

Other key attributes of good settling pits are slow flowing level and flat channels running away from the borehole (Figure 2.6). These provide fast settling as well as, good places to collect borehole samples



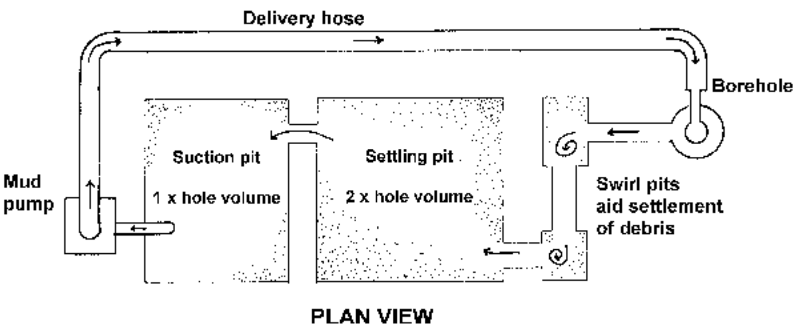


Figure 2.4 Recommended arrangements for surface settling pits

Figure 2.5 Well proportioned mud pits ready for filling

Figure 2.6 Functioning mud pits – slow moving flow for good settlement

and shovel clear a great deal of the bulk of debris being drilled. The pump suction line needs to be hung on a support, lifting it from the settling pit bottom but ensuring that it is sufficiently below the pit level so the pump is fed with as clean and settled fluid as possible.

By planning the design of mud settling pit in advance, the major construction can be accomplished before the main drilling equipment is taken to the site. Mud pit construction can often use labour provided by the local community.

2.7 Drill fluid additives

Drilling performance is much improved by using additives mixed with water. Broadly two main types of additives are used: bentonite and polymers.

2.7.1 Bentonite

Bentonite is a natural clay, which, when mixed in sufficient volume, will increase viscosity. Bentonite produces a 'solids-based fluid' that works extremely well but will line the borehole with a 'wall cake' of bentonite clay. This is impervious to water and will need dispersal on completion of the hole with specific chemical or mechanical methods. Bentonite also needs to be left for 12 hours after initial mixing to build sufficient viscosity. For these two reasons, bentonite is not normally recommended for construction of water wells.

2.7.2 Polymers

The best water-well additives are natural polymers, which, when mixed with water, thicken into a viscous fluid. This fluid can carry debris at much slower pumping flow rates and will also line the borehole walls to prevent heavy seepage of fluid into the formation. It thus helps to maintain the 'hydrostatic head' of fluid above the natural water table, keeping the borehole from collapse. It also prevents permeable water-bearing layers from contamination by the invasion of fine 'silty' particles. Most polymers are natural products used as stabilisers and thickeners in the processed food industry and are biodegradable, so the viscous properties will disappear naturally in a few days. Alternatively, introducing chlorine solutions can accelerate their dispersal.

2.8 Viscosity measurement

Drill-fluid viscosities are measured with a Marsh Funnel (Figure 2.7). This is a simple device used to measure the rate at which a given volume of fluid (1 litre) drains through a funnel with a 5-mm spout.The more viscous the fluid, the longer the funnel takes to drain.

Alternative devices

Although the Marsh Funnel is used throughout the drilling industry it is a relatively simple device for comparing viscosities. Any funnel or similar device could be adapted to give comparative measurements of the viscosity of clean water and drill fluid. For example, a nail hole in the bottom of a soft-drink can allow a timed reading of clean water measured against a mixed fluid and allow repetitive comparison between various drill fluid mixes.

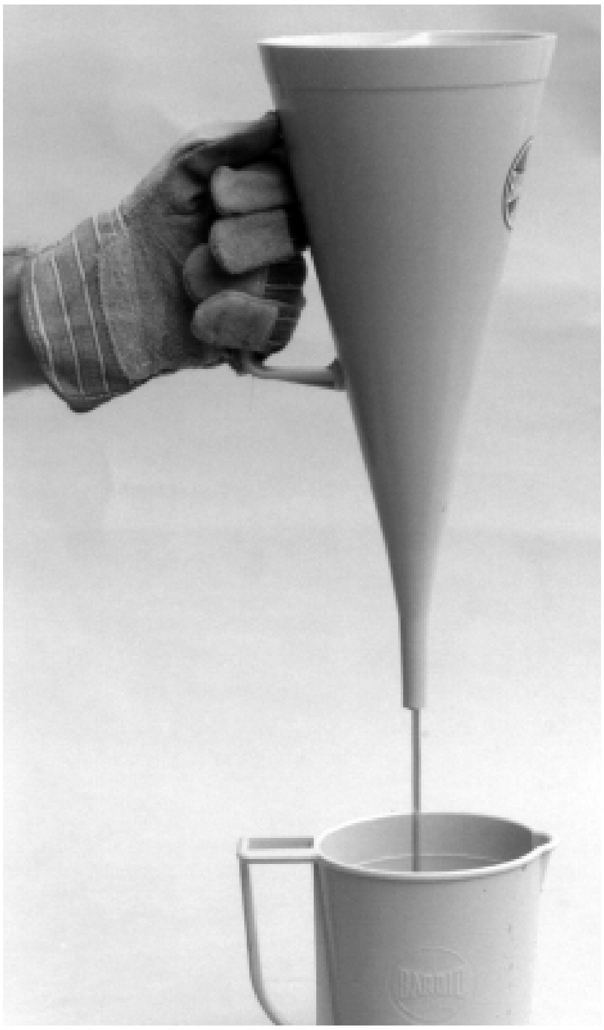


Figure 2.7 Marsh funnel & jug

2.8.1 Mixing volumes

At the start of drilling a hole, it is relatively easy to match the mud pit volume with the fluid additive being used. However, as drilling continues and pits need topping up it is easy to lose control of the viscosity of the drill fluid. This can lead directly to some very specific difficulties discussed below.

2.8.2 Correct viscosity

It is important to get the viscosity just right for the job in hand. If a fluid is too viscous (‘thick and heavy’) for the formation being drilled, it becomes laden with borehole debris. This gets re-circulated through the pump, rig swivel, drill-pipe and drill bit and will cause considerable wear to components as well as stop the ability of the fluid to pick up more debris.

If a fluid is too light (‘runny’) it can soak into the formation being drilled, resulting in a loss of fluid in the pits. This could lead to borehole collapse and will also potentially damage water-bearing layers by blocking the pores with fine borehole debris carried into the formation by the fluid (Table 2.4).

2.9 Tips on the use of polymers

Polymers are quite expensive and to use more than is required is a waste of money.

Mixing

Generally, polymers are supplied as very fine white or off-white powders. They are best mixed into a jet of water at a rate that prevents lumps of powder forming on the surface (Figure 2.8) . All polymers take a period of time to ‘yield’ -to build viscosity: generally 30 minutes is the minimum time needed for any significant yield to take place. It is always best to allow the maximum time possible and to mix the polymer early during the setting up of the rig, so that it has yielded sufficiently by the time drilling starts. Water quality can effect how polymers mix and yield, and mixes may require adjustment. In rare situations, the mix water might require chemical correction to enable a polymer to mix and yield.

2.10 Ability to biodegrade

As discussed earlier, polymers based on natural ingredients are biodegradable. With time and bacterial action they will breakdown and smell rotten! Warmth and presence of bacteria will speed the breakdown. Generally a natural polymer can be expected to last 4 days, but perhaps just 2 or 3 in tropical conditions, and certainly it would be best to avoid mixing polymer just before a long-weekend work break.

Drilling Condition	*Marsh Funnel seconds*
Normal drilling	35-40
Coarse permeable sands/gravels	50-60
Areas of high permeability	60-80
"Pill" 100+	
Note: It takes 27 seconds for clean water to drain through the spots of a Marsh funnel and fill 1 litre jug	

Table 2.4 Typical viscosities used for drilling

Figure 2.8 Mixing polymer

2.11 Dispersing

On completion of the hole, the job of the polymer is complete and it is important to get rid of it as thoroughly as possible. If this is not done, the resultant rotting and smelly fluid will affect water quality, at least during initial operation of the well. Removal of the polymer is best achieved by displacing the mixed drilling fluid from a completed hole with clean water – pumping clean water down the casing out through the well screen, thus displacing the drilling fluid to surface. It is also advisable to pump out the settling pit – spreading the fluid over a flat area quickly breaks down the polymer and prevents a unpleasant smell that would result from leaving a bulk of fluid in the settling pits.

2.11.1 Chlorine

In addition, most polymers are broken down by the addition of chlorine. Chlorine is available in many forms, from simple domestic disinfectants through sodium hypo-chlorite solutions to stabilized powders and granules. A well that has been largely flushed clear of residual drill fluid might require an addition of 10 ppm (parts per million) of free chlorine, whereas a hole full of viscous fluid will need 1000 ppm. The added chlorine will destroy the viscosity properties of the polymer, aid well development, kill the bacteria feeding on the polymer and sterilise the well. Any added chlorine must be pumped out or the well rested until all traces, both smell and taste, disappear (Table 2.5).

2.12 Lost circulation / fluid losses

As drilling proceeds, a little loss of fluid volume can be expected because the liquid will be absorbed into the borehole walls to depth of a few centimetres.

SAFETY NOTE
Chlorine needs careful handling. It is hazardous both to exposed skin, eyes and as a gas given off during use. Follow the manufacturer's recommendations for safe use.

Table 2.5 Safety

A suitable volume of water/ready-mixed drill fluid should be available to steadily make up these losses. Larger or complete losses need to be controlled in order to maintain the process of debris removal and to keep a 'hydrostatic head' on the formation being drilled.

2.13 Remedies

There are several remedies: three are listed below.

2.13.1 'Pills'

For partial loss into water-bearing zones, increase the viscosity of the fluid until loss slows. If necessary prepare a 'pill' – a 200-litre drum or similar volume of very thick polymer, which is just about pumpable. Alternatively, very thick polymer can be poured by buckets into the annulus of a borehole. Pump or bucket this into the hole and allow it to sit for a while (30/60 minutes).

This is where drilling relies on human skill, the ability to anticipate the problem and to remedy it rapidly and efficiently. A 'pill' left to stand to yield viscosity and be ready to be used before severe loss of circulation occurs, requires that someone in the drill crew has spotted the formation changing, seen signs of fluid loss and acted immediately.

2.13.2 Fibre

For partial or complete loss into areas of a hole not likely to produce water, introduce fine fibre into the fluid – sawdust, grain husks, cow dung (dried and crushed). This will block the pores into which fluid is being lost. Mix the fibre with drill fluid in a 200-litre drum so that it is just pumpable and pump into the hole, ensuring that the volume pumped is sufficient to displace clean drill fluid from the portion of the borehole absorbing fluid. As this fluid seeps or flows into the porous formation the fibre will block the pores, slowing seepage flow until normal fluid circulation can resume.

It is not advisable to use this method in the area of the hole that bears ground water because it is difficult or even impossible to develop out the fibre after screen is placed in position.

2.13.3 Liquid Cement

For losses uncontrollable by the first two methods liquid cement can be used as a last resort to seal off a specific zone permanently, particularly a fissure or similar formation that fibre alone is unlikely to block.

2.14 Drilling Clay

Thick, solid bands of clay are frequently encountered during drilling. The key to the efficient drilling of clay is:

To drill with a sharp-toothed drag blade drill bit, which penetrates slowly and steadily to encourage small curls of clay to be steadily washed to the surface (Figure 2.9). If the bit is pushed too fast or too hard, clay will begin to clog the hole above the drill bit. Constantly monitor the returning flow to see that flow is maintained correctly and cuttings are being removed in proportion to the drilling penetration.

2.15 Collaring

Clay is very prone to 'collaring', in which complete rings of sticky clay form above the drill bit (Figure 2.10). Once formed they have to be removed or the problem gets worse very quickly. Maintaining the flow and reaming the drill bit up and down the hole repeatedly can push the collar to the surface where it will be pushed out of the hole as a solid mass (Figure 2.11). It can then be removed smartly by an alert drilling crew armed with shovels or spades. Sometimes it might be necessary to ream back the drill bit to the surface to remove very obstinate sticky collars. It is important to ensure such collars are completely removed because they can hold up the insertion of screen and affect the placement of formation stabiliser or gravel pack.

2.16 Polymer

Polymer drill fluids coat individual clay cuttings and can largely prevent collars forming. If the collaring is especially bad, salt added to the drill fluid will help keep clay drill cuttings separate.

2.17 Summary

Fluid drilling as a drilling method can look quite daunting and complicated. However, this need not be the case if each required attribute described above is addressed in order.

The mud -pump specification, its flow (volume) and pressure (head) with the internal restrictions of drill

Figure 2.9 Individual clay cuttings washed to the surface

Figure 2.10 Clay collar

pipe will define the possible diameter a well can be drilled. A target depth leads to determining the size of the settling pits and the amount of water required to fill them by transport or nearby source. Knowing the water volume allows for a suitable mud to be mixed and drilling to commence.

Good site management is key: ensuring make-up water is continually available as required; ensuring that labour is organised with routine tasks of collecting samples, shovelling clear the bulk of debris and mixing up additives through to the well-lining materials being available for insertion immediately the hole is complete.

Invariably, an analysis of the drilling set-up for mud/fluid drilling will reveal what item is incorrect or unsatisfactory and why things start to go wrong.

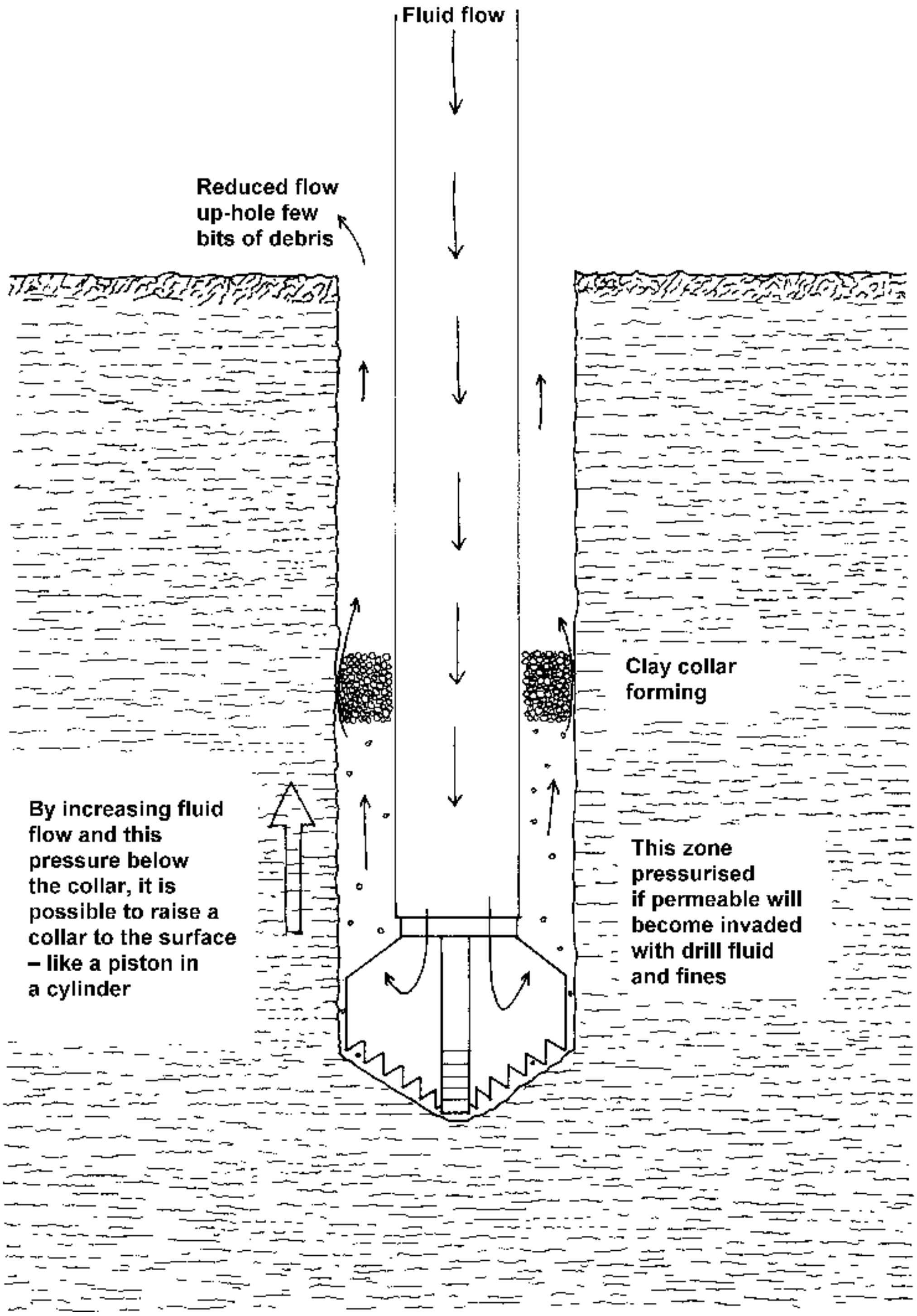


Figure 2.11 Effects of a clay collar in a hole