Drilling muds ; management, treatment and recycling for trenchless technology

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Abstract

Trenchless Technology, mainly Horizontal Directional Drilling (HDD) & Micro tunnelling using drilling fluids has been expanding for several years. These new construction methods have undoubtedly gained wide acceptance, particularly in highly congested urban areas and in environmental engineering like soils remediation of industrial sites.

In the framework of the National Project "Microtunnels" a working group of FSTT (French Society for Trenchless Technology) has proposed "a drilling fluids research program" to manage the drilling fluids used during soil's excavation. It's worth looking for various criteria: technical performances, economic and environmental considerations to reduce dumping and wastage during the underground works.

HDD requires the use of large volume of drilling fluids that provides the following functions: hydraulic cutting with a jet, provide energy to the drill motor, lubricate and cool the cutting head and reduce torque and drag, transport drill cuttings to the surface, stabilise the hole against collapse, guard against loss of drilling fluid into surrounding formations.

The drilling mud is pumped downhole and circulates back to the surface and collected in return pit then passed through machinery that separate the cuttings from the slurry.

Drilling muds are bentonite based. They are very sensible to either physical, chemical contamination. During drilling operation, their physico-chemical properties are constantly modified because of the excavated soil/water interaction inducing different flow and filtration properties, which have implications for the drilling performances.

Significant amount of drilling mud is normally disposed of at the end of a project. Economics for disposal is extremely site specific. This drilling mud can be disposed of by:

- ♣ Use at another drilling location.
- ♣ Spread onto raw land for water retention improvement
- ♣ Evacuate to dump site after treatment with cement, lime, water retention polymer…
- ♣ Treated to separate the solid phase (bentonite and cuttings) and the liquid fraction (water)

This paper describes:

1. Consequences on waste treatment and disposal at the working end; management criteria, key parameters and limit values
2. Different cases obtained from standard bentonite fluids to more complex bentonite/polymers systems.

Keywords: drilling, fluid, waste, management, bentonite

1. Introduction

Originally used in the 1970s, HDD is a marriage of conventional road boring and rotary directional drillings of oil wells. The method is now the preferred method of construction. Crossings have been installed for pipelines carrying oil, natural gas, petrochemicals, water, sewerage and others products. Ducts have been installed to carry electric and fibre optic cables. Besides crossing under rivers and waterways, installation have been made crossing under highways, railroads, airport runways, shore approaches, islands, area congested with buildings, pipeline corridors and future water channels. Tentative of uses can now include recovery of coal gas seams, soil decontamination and geotechnical investigation in the tunnelling industry.

HDD has been widely executed in environmentally sensitive or protected sites.

Technology limits are: the longest crossing to date has been about 1800 m. Pipe diameters up to 1.60m have been installed. Although HDD was originally used in alluvial soils, more and more crossings have being undertaken through gravel, cobble glacial till and hard rock.

HDD have limited environmental impact of any alternate method. The technology offers maximum depth of cover under the obstacle thereby, affording maximum protection and minimising maintenance costs. River traffic is not interrupted, as most of the work is confined to either bank. HDD have often a predictable and short construction schedule.

2. Drilling techniques and waste management

2.1 drilling techniques

Drilling procedures consist of three phases: pilot hole, reaming, and pullback of the conduit (figure 1).

- ♣ **Pilot Hole:** A pilot hole is drilled beginning at a prescribed angle from horizontal and continues under and across the obstacle along a design profile made up of straight tangents and long radius arcs. The drill path is monitored by an electronic package housed in the pilot drill string near the cutting head, the data is transmitted back to the surface where calculations are made. Adequate quantities of drilling fluid are pumped into the hole to maintain the integrity of the hole and to flush out the drilled cuttings.
- ♣ **Reaming:** Once the pilot hole is complete the hole must be enlarged to a suitable diameter for the product pipeline. Generally, the reamer is attached to the drill string on the bank opposite the drilling rig and pulled back into the pilot hole. Adequate quantities of drilling fluid is pumped into the hole to maintain the integrity of the hole and to flush out the drilled cuttings
- ♣ **Pullback:** Once the drilled hole is enlarged, the product pipeline can be pulled through it. A reamer is attached to the drill string and then connected to the pipeline via a swivel.

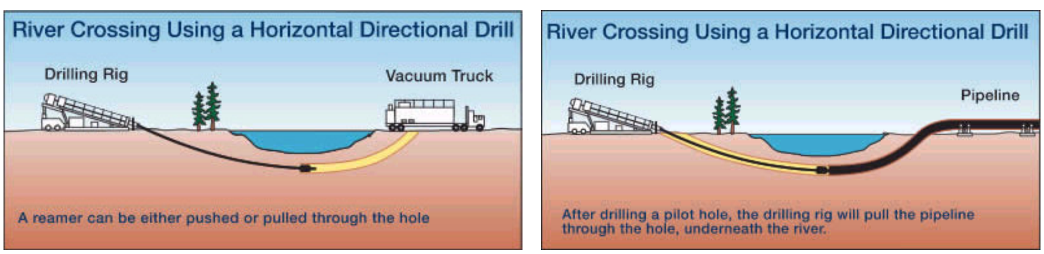


Figure 1. Usual representation of the steps 2 and 3

On every project, it is necessary to consider:

- ♣ Drilling mud containment
- ♣ Optimum recycling of the drilling mud with solid control equipments and other adequate treatment.
- ♣ Use mud treatment to cope with environmental regulations before disposal.

Awareness of environment concerns among the public, regulatory agencies, project owners has made environmental respects a key issue . Environmental issues are broad-based and complex, influencing all aspects of drilling mud technology from product selection to use mud treatment (Pantet and Monnet, 2003).

2.2 waste management

A general analysis was recently discussed in recommendations of the French Society Trenchless Technology, 2003 and by Pantet et al. 2000.

The waste management depends on 3 main criteria:

- ♣ **Site:** Geological and geotechnical conditions, and also the environmental state of the site as known or unknown, polluted or non-polluted site.
- ♣ **Project:** Geometry and consequently volume of spoil to treat, implementation of the site (urban, industrial area, countryside, shore approach…)
- ♣ **Type of drilling fluid used:** Bentonite mud, Bentonite/Polymer mud, or pure Polymer mud.

Each project is unique and waste management must be analysed according to predefined criteria. Methodology or guidelines can be established.
In order to limit the consumption of mud additives and waste volume, it is necessary to recycle the drilling mud. The recycled drilling mud is pumped through vibrating screens, desanding and desilting hydrocyclones before return to the mixing/succion tank.
But in all cases, at the end of the project, a remaining volume of drilling mud has to be eliminated from the site. As drilling muds are essentially constituted of water (70 to 90% as an average) the remaining parts being bentonite and drilled cuttings, the most important is to separate the liquid and the solid phase. After an adequate physico-chemical process (coagulation, flocculation and dewatering) the liquid phase can be dumped in the local sewer network, river… and the solid phase to landfill site…
An another way is possible by solidifying the slurry with fibbers or cement to built embankment or diaphragm walls, but this solution is economically interesting only if the two building sites are next to each other. The cost of slurry transport is high.

2.3 European legislation

In the European waste classification, the drilling waste are usually banal waste and can be usually dumped in a classical landfill site (named in France, class III) after simple separation treatment between the liquid and solid phases. Recommended tests to render acceptable the storage of the solid phases in landfill site as inert waste are essentially siccity (dried matters percentage in mud) and percolation analysis through column of waste (AFNOR/X30YN56, 2000). For the liquid phase recommended tests are: pH, Chemical Oxygen Demand (COD $mg.L^{-1}$ – AFNOR/NFT90-101,2001), Biochemical Oxygen Demand (BOD $mgO_2.L^{-1}$- AFNOR/NFT90-103, 1998), Total Suspended Matters and chemical analysis as: sulphates, hydrocarbons, heavy metals (Pb, Cu, Cr, Nl, Zn, Mn, Sn, Hg, Fe, Al. The acceptable values are given in the table 1. If values are exceeding, a treatment is required.

Table 1. Bound values defined by the legislation to authorise the inert waste in a landfill site (for solids) and in natural medium (for liquid)

State of the waste	Acceptable values of the minima parameters
Solids	Siccity >30% Percolation tests and elutes or lixiviats analyses
Liquid	pH : 5.5-9 temperature <30°c suspended matters < 35 $mg.L^{-1}$ COD <125 $mg.L^{-1}$ [a] [BOD < 30 $mg.L^{-1}$, COT <70 $mg.L^{-1}$, sulphates <250 $mg.L^{-1}$, heavy metal sum <15 $mg.L^{-1}$ and hydrocarbons <10 $mg.L^{-1}$]

[a] Remarks, the tests defined in [-] are not practised in this study

3. Constituents of drilling muds and efficient properties

Drilling mud is mixed on the surface and pumped down the drill string, out the bit and circulated back to surface. This mixture is best described, as a mixture of clean water, premium bentonite, and if required, a small amount of hydrosoluble polymer and lubricant. The drilling fluid used is generally bentonite, naturally occurring clay with thixotropic properties (Besq et al. 2003). As the excavation continues bentonite slurry is poured into the trench to support the sides of the excavation. The bentonite slurry forms a filter cake at the sides of the hole by clogging the voids and bridging across them. The fluid pressure exerted by the slurry is sufficient to support the sides of the hole and keep it from collapsing (Harispure and al, 2004). The sides of the excavation are ' supported' until pipes are placed finally. In some specific cases bentonite can be replaced by polymer or more often a mixture of polymer and bentonite. It must be verify that the used materials will not harm the environment, we examine here the most constituents of the muds, inside the water.

3.1 Constituents

3.1.1 Bentonites (natural and commercial)

Bentonite is clay generated frequently from the alteration of volcanic ash, consisting predominantly of smectite minerals, usually montmorillonite. Other smectite group minerals include hectorite, saponite, beidelite and nontronite. Smectites are clay minerals, i.e. they consist of individual crystallites the majority of which are <2µm

in largest dimension. Smectite crystallites themselves are three-layer clay minerals. They consist of two tetrahedral layers and one octahedral layer. In montmorillonite tetrahedral layers consisting of [SiO_4] - tetrahedrons enclose the [$M(O_5,OH)$]-octahedron layer (M = and mainly Al, Mg, but Fe is also often found). The silicate layers have a slight negative charge that is compensated by exchangeable ions in the intercrystalline region. The charge is so weak that the cations (in natural form, predominantly Ca^{2+}, Mg^{2+} or Na^{+} ions) can be adsorbed in this region with their hydrate shell. The extent of hydration produces intercrystalline swelling. Depending on the nature of their genesis, bentonites contain a variety of accessory minerals in addition to montmorillonite. Main rockforming minerals of bentonitic clay: calcium montmorillonite, quartz, feldspar, calcite and gypsum, insignificant quantity of palygorskite are marked rarely. The presence of these minerals can impact the industrial value of a deposit, reducing or increasing its value depending on the application. Bentonite presents strong colloidal properties and its volume increases several times when coming into contact with water, creating a gelatinous and viscous fluid. The special properties of bentonite (hydration, swelling, water absorption, viscosity, and thixotropy) make it a valuable material for a wide range of uses and applications. As the electrostatic attraction is low, exposure to polar fluids will cause the formation of a monomolecular lattice of water between the silicate layers. The basis behind bentonite swelling is that several layers of water dipoles can form into weak "stacked" tetrahedral structures, causing the silicate layers to separate - this is termed intercrystalline swelling.
The nature and volcanic origins of bentonite deposits give rise to varieties of the mineral that are often extremely heterogeneous, as the depositional environment and subsequent weathering processes also differ by region and deposit. The most common bentonites can be described as calcium or calci-sodium bentonites.

Bentonite deposits are normally exploited by quarrying. Extracted bentonite is distinctly solid, even with moisture content of approximately 30%. The material is initially crushed and, if necessary, in the case of natural calcium bentonites activated with the addition of soda ash (Na_2CO_3). Bentonite is subsequently dried (air and/or forced drying) to reach a moisture content of approximately 15%. According to the final application, bentonite is either sieved (granular form) or milled (into powder and super fine powder form).

3.1.2 Polymers

Three classes of hydrosoluble polymers are commonly considered:

- Organic (Guar, Zanthan, considered as biodegradable)
- Semi-synthetic (modified organic polymer, as CMC, PAC)
- Synthetic (polyamides and derivatives phpa)

Generally they have be used as an additive in a bentonitic fluid, each brings different properties to the fluid. Polymers are used to enhance the properties of the drilling mud as for example to protect the bentonite from salt flocculation or to limit difficult drilled clay hydration… Whereas they can be used alone in the case of remediation project where bentonite fluid does not break down easily and is not suitable, because the fluid must preserve the permeability of wall formations, but maintains the integrity of the hole. Many manufactories have introduced powder, which forms biodegradable, clay-free drilling fluids when mixed with water.

3.2 Methods to control muds properties during the works

Using of wrong formulation is the cause of many problems, but the most appropriate fluid suitable for all particular projects must be defined after a mud program defined by expertise. Procedures are developed in "recommendations", we can referee to the articles of Besq et al. (2000) and Malfoy et al. (2001). A set of site testing equipment is widely use to ensure the drilling mud properties are within the required range. The routine tests include: density, Marsh viscosity, gel strength, filtration control, pH.
During the drill, the original mud becomes working mud, whose properties change following the geological conditions. Nevertheless, particles analysis of the principal components of drill mud shows that they consist mainly of fine silts and clays. If we consider only that the particles are very small, settling velocities are also very smell. But following the conditions the drilling wastes can readily flocculate to from fragile aggregates with settling velocities more high; during the drill this phenomena must be avoid but during the treatment it must be used (adding acid or coagulant).

This mud balance is used to measure the density or the unit weight of the slurry (the "mud") periodically, to ensure that it is within the required limits. The mix can be adjusted to increase or decrease the weight of the slurry (D= 1.02 to 1.30).
The Marsh funnel is used to measure the viscosity of the slurry periodically by measuring the length of time required for a given volume of slurry to flow out of the funnel. The mix can be adjusted to increase or decrease the viscosity of the slurry.
To measure the filter parameters, the used filtration apparatus is the API cylindrical cell (diameter 90 mm and height 90 mm). Fig . 2 shows a filtration cell containing mud volume. The 700 kPa pressure is applied at the top of the column of fluid by purified compressed air, remained constant during 30 minutes. This pressure forces filtrate trough the filter paper placed at the base of the cell (Whatman 5 - average filtration - 2.5 µm retention), leaving a cake of clay particles which are too large to pass trough the filter pores. Clay material forms a deposit or a cake, which siccity is defined as the ratio mass after drying/mass before drying on paper filter. The filtrate mass M (g) is measured at time 30 minutes. All measurements were performed at room temperature.

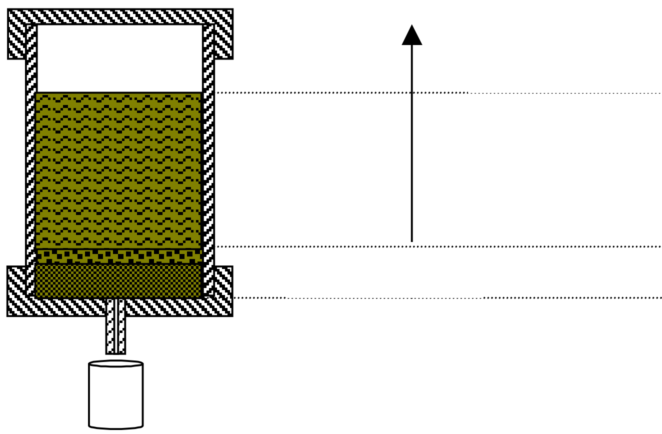


Figure 2. API filtration apparatus

Apparent viscosity, plastic viscosity and gel strengths of the drilling are measured with an API Rheometer. Understanding the rheological behaviour of drilling mud is important to control hole cleaning and borehole stability (especially in high permeability soils). Gel strength is of the utmost importance especially in coarse-grained soils.

The pH of the slurry is measured periodically to ensure that it is within the required limits (the range of 7 to 10). If not, the bentonite may flocculate, and the slurry will not be able to support the sides of the hole as it should. The mix can be adjusted to increase or decrease the pH of the slurry if necessary.

4. Laboratory study

Our study presents the first results obtained to begin to establish the methodology for the experimental design (Goupil, 1999). The analytical program is to compare different powdered bentonite and different polymer-bentonite mixtures, distinguishing initial mud (without cuttings named M) and usual mud (with cuttings named Mc).
The recommended tests to allow the storage in landfill site are pH, COD (Chemical Oxygen Demand), siccity, and NTU measured commonly following the usual norms.
We consider this case, the most simple because it is the most current observed in the HDD industry. When there are toxic elements, the source is generally the polluted soil (known or most dangerous unknown).

4.1 Materials

In engineering applications clays will seldom in contact with demineralised water, so we chose to study with municipal water of the town Poitiers.
Three standard Bentonites (named I, V and W) were used. After mineralogical characterisation, they were predominantly comprised of natural Na-montmorillonite, for V and W and Na-activated montmorillonite for I.

Three polymers (named P1, P2, P3) are used with only W bentonite. Two kinds of muds are compared at different pH: the initial mud (M) and the charged mud with cuttings (Mc).
The suspension preparation follows a procedure to obtain uniform dispersion and to complete hydration. The mass of dry bentonite powder is added and rapidly dispersed into the water at the concentration of 40 gL^{-1}. To simulate the spoil, a mass (100 g) of fine sand is added inside the mud. The level of dispersion is important, to obtain a stable suspension, the bentonite particles must be reduced to their finest constituent parts to expose the maximum surface area to the surrounding liquid and activate the gelling effect. But to reduce the water content, it is necessary to separate liquid and solid phases and to agglomerate the particles, the problem is that bentonite is a good suspending and stabilising agent and is used as an adsorbent or a clarifying agent in many industries. To chemically destabilise the mud, acidification was used, but other process with salts, organic coagulant and flocculant can also be considered. To physically concentrate the solid phase filtration was used. Filtration is one method to separate the solid phase from the liquid phase but other dewatering systems are used as centrifugation. The API filtration test was used in our laboratory study.

4.2 Results

Table 1. gives the basic rheological properties used to control the mud during the drill and the results of the characteristics tests to accept the waste as an inert waste in landfill. The viscosity and filtration properties are ordinary for commercial bentonites. In these conditions, it is impossible to discharge the drilling waste in this state. So the separation phase is necessary and this solution is better than a large dilution, which uses large water volumes and distributes very small particles (clay).
Our results show that even after filtration (API – 700 kPa), the solid phase is not acceptable because the water content is always to high, but the liquid phase can be discharged in natural environment (if no toxic ions). It appears that bentonite powder generate an own COD depending the kind of powder.

Table 1. Comparison of most properties between three bentonite muds and environmental tests

Concentration 40 gL^{-1}	Bentonite V	Bentonite I	Bentonite W
pH	8.7	9.3	9.3
Marsh viscosity (s)	30	31	32
Filtrate API (mL)	32.5	23.9	20
Sicity cake (%)	16.4	15.1	17.7
COD susp ($mgO2.L^{-1}$)	300	360	140
COD filtrate ($mgO2.L^{-1}$)	40	50	<30

As shows the table 2, acidification of the mixtures modifies the Ca and Na concentrations inside the filtrate. Indeed the acidification dissolves many other minerals (primarily carbonates as calcite), destabilises the electrical environment of the particles (modifying the double diffuse layer around the particles) and breaks the links between polymers and clay-particles, so this increasing is normal.

Table 2. Ca and Na moistures inside the filtrate with and without acid

Concentration 40 gL^{-1}	Bentonite V	Bentonite I	Bentonite W
in natural conditions			
Ca (mg. L^{-1})	10.4	15	14
Na (mg. L^{-1})	300	400	300
With acid (pH= 6)			
Ca (mg. L^{-1})	16.8	345	112
Na (mg. L^{-1})	400	700	600

The tables 3 (a, b, c) give the data of the tests for each kind of polymer at different concentrations and pH of the mixture obtained after acidification step at the same time for original mud and charged mud with sand.
The acidification step has an important effect on the COD value, which is smaller at pH 3 than at pH 6. The COD decreasing ranges between (20 and 70 %). This large variation of the COD values shows that the acidification effect is amplified by the cuttings contained inside the mud and by the concentration of polymer as shown figure 2.(b). All values are lower than to the limit value (<125 $mg.L^{-1}$). Differences appear following the nature of polymers. The number of tests is insufficient to generalise following the class of polymers defined above (natural, semi synthetic or synthetic).

Table 3(a,b,c). Results of environmental tests.

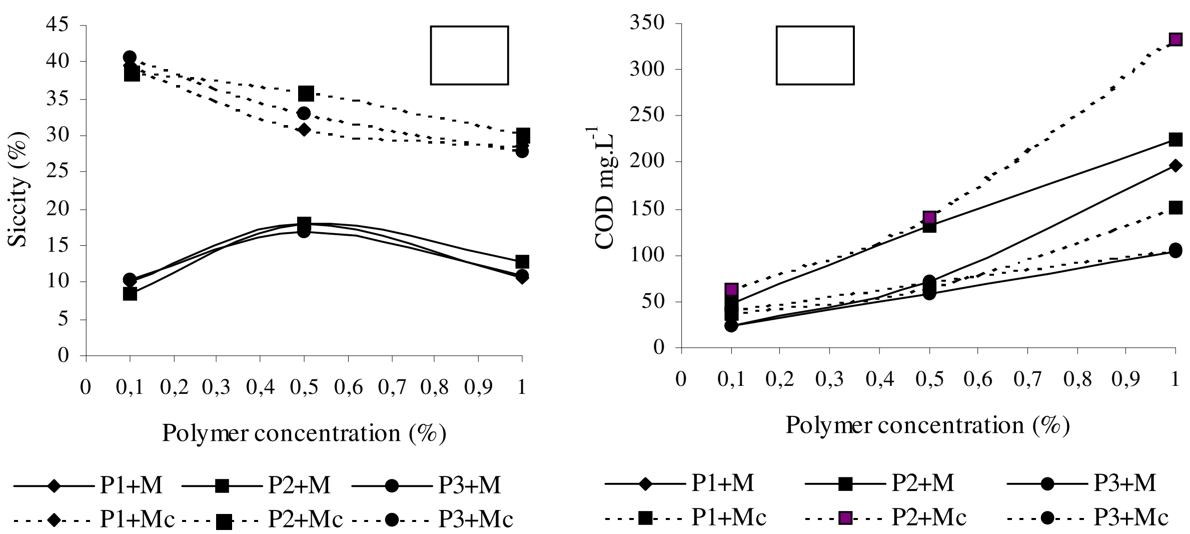
Polymer P1 and bentonite 40 gL^{-1}	Polymer concentration 0.1 %						P.c. 0.5 %				P.c. 1 %	
	Without acid		pH=6		pH=3		pH=6		pH=3		pH=3	
	M	Mc	M	Mc	M	Mc	M	Mc	M	Mc	M	Mc
pH	9.1		7.2	6.4	6.2	4.3	7.1		4.9	3	3.1	3
Turbidity (NTU)	1		0.9	9.1	1.3	0.7	1.2		3.2	1.5	3.4	7.7
Sicity cake (%)	11.3		5.7		10.2	39.5	18.1		18.1	30.8	10.7	28.6
OCD filtrate ($mgO2.L^{-1}$)	86		48	97	24	37	108		72	65	196	152

Polymer P2 and bentonite 40 gL^{-1}	Polymer concentration 0.1 %						P.c. 0.5 %				P.c. 1 %	
	Without acid		pH=6		pH=3		pH=6		pH=3		pH=3	
	M	Mc	M	Mc	M	Mc	M	Mc	M	Mc	M	Mc
pH	8.8		7.7	6.6	4	4.1	7.7		3	3.2	3.3	3.9
Turbidity (NTU)	0.6		0.8	2.8	0.4	1.1	1.6		12	1.03	0.2	1.9
Sicity cake (%)	9.9		6.4		8.5	38.6			18	36	12.9	30.4
OCD filtrate ($mgO2.L^{-1}$)	86		76	76	48	63	153		132	140	225	333

Polymer P3 and bentonite 40 gL^{-1}	Polymer concentration 0.1 %						P.c. 0.5 %				P.c. 1 %	
	Without acid		pH=6		pH=3		pH=6		pH=3		pH=3	
	M	Mc	M	Mc	M	Mc	M	Mc	M	Mc	M	Mc
pH			7	7	4.8	4.7			5.2	4.1	2.5	3.9
Turbidity (NTU)			2.1	3.1	1.5	0.5			2.1	1.45	2.5	3.1
Sicity cake (%)			6.1	25.2	10.5	40.5				33.1	10.9	27.7
OCD filtrate ($mgO2.L^{-1}$)			86	51	24	42			58	71	103	106

The siccity of the mud with cuttings (Mc) is increased significantly compared with the original mud (M), but the dependence with pH is not much important. The nature of polymer has also no real effect. The values are upper than the limit value (mini 30%) with the filtration procedure API.

The figure 2.(a) shows the important effect of the cuttings (coarse part), for the three polymers. We must remenber that the cuttings are here sand, in the case of clays or chalk, the results must be reconsidered.The NTU values are always small and inferior to the limit value.



Figures 2. Data of siccity (a) – COD (b) for 6 mixtures with (Px+Mc) and without (Px+M) cuttings at pH=3 and at 3 concentrations

5. Conclusions

As all activities, HDD produces risks and impacts. This work develops two aspects relating to the waste drilling fluid management: a fist part with analysis of the problem position and the law context with the definition of the limit values and a second part with few experimental results following the nature of the muds. It appears that each project is unique with its own specifications. A large number of factors, reduced in three criteria can be listed and have effects on drilling wastes. The disposal of used drilling mud has a potential impact on the environment. The used mud treatment (related to water treatment technology) is well known and effective to comply with legal obligations. However depending on project size, it's not always viable, as for most of the projects the volume to be dispose of is in the range of 10 to $100m^3$ and very exceptionally above $1000m^3$

Contractors should consider first all other viable alternatives as landfarming, some disposal option may be valid for one location, but not for another one. Drilling fluid disposal must be considered as a whole part of the project, it must be efficient and not impose unnecessary constraints on this rapidly developing industry. From now, users must much better prepared to manage; instrumentation and methodology are available to conduct more efficient and meaningful environmental effects scientific program. It requires objective, credible and timely scientific information.

References

AFNOR/NFT90-101, février 2001, Chemical Oxygen Demand

AFNOR/X3O YN56, 2000 - Protocole de percolation ascendante : application prénormative européenne. ADEME-BRGM9974079.

AFNOR/NFT90-103, mai 1998, Biochemical Oxygen Demand

Besq A., C. Malfoy, A. Pantet, Ph. Monnet, D. Righi, 2003 Physico-chemical characterisation and flow properties of some bentonite muds. Applied Clay Science 10 p

Brindley, G.W. Brown G., 1980, *Crystal structures of clay minerals and their X-ray identification*. Mineralogical society, London, 1980, 495 p

Chamayou, Legros, 1989, *Les bases physiques, chimiques et minéralogiques de la science du sol* , Presses universitaires de France.

French Society Trenchless Technology, 2003, Recommandations *"forages dirigé"* Projet national Microtunnels Paragraphe 6.5 p.104-116 et annexe 5 p 191-196 - Editions : Hermès- Lavoisier – ISBN 2.7462-0792-3

Goupil J., 1999, Plans d'expérience pour surfaces de réponse, Editions Dunod, 400 p.

Harispure N., A. Pantet, Ph Monnet, 2004, *Fonction stabilisatrice des fluides de forage à base de bentonite dans le cas de forages dirigés,* Comité International de Mécanique des Sols – Beyrouth – 8 p.

Kim H. T., 1982, Principles of soil chemistry second edition 362 p

Malfoy C. A. Besq, A. Pantet, Ph Monnet, 2001, *A better knowledge of bentonite fluids for directional drilling : physical, chemical and rheological properties to control flow conditions.* DCA, 6 th annual congress Strasbourg, Development, Construction, Approval, 9 p.

Pantet A., Ph Monnet, 2003, *Bentonite Muds ; a tool for Horizontal Drilling* in Proceedings of the NASTT/ISTT International No-Dig 2003 Show. Las Vegas, Nevada: ISTT, Session D1-031-10 p

Pantet A. , N. Merlet, J.F. Ouvry, G. Didier, 2000, *Traitement et recyclage des boues : document technique et législatif* - FSTT, Projet national « Microtunnels », 26 p

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