Mud cleaning for pipejacking and slurry shield tunnelling applications.

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Abstract

The paper describes the main tasks that muds have to accomplish when used for Microtunnelling, Pipejacking and Slurry Shield Tunnelling applications together with the ways in which cleaner and better quality mud can help achieve these. The techniques of mud cleaning are outlined with some examples of the different types of equipment that are appropriate for various ground conditions and applications. Plant selection charts and illustrations of the mud cleaning plants that might be used on microtunnelling, pipejacking and large diameter segmental tunnel projects are provided. A chart is included which could help planners, having selected the equipment they wish to use and the quality of mud cleaning that they require for their project, to evaluate the space and the power needed for the mud cleaning plant. A section of the paper describes methods of cleaning surplus or waste muds with the object of reducing or eliminating off-site disposal of contaminated fluids by tanker.

MUD

Muds have to perform different tasks for Microtunnelling, Pipejacking and Slurry Shield Tunnelling applications. For microtunnelling the size of particle to be transported from the face is relatively small and the amount of support that the mud needs to provide to the face is small because rates of advance are quite fast and hence the soil does not remain unsupported for a long period of time and even if a collapse of soil occurred at the face when the tunnelling machine was not advancing, the volume of material involved would be small with probably negligible effects on surface movement. In addition no man access to the face is ever required. Effective transport of the cuttings may be accomplished by a light mud or even water if the pipework is sized so as to provide adequate flow velocities. The type and quality of the mud to be used for microtunnelling will therefore be determined mainly by the need to limit loss of circulation fluid to the formation. If there are open granular soils then a bentonite mud with the ability to build a good filtercake might be used so that a layer of semi-permeable filtercake is deposited which would allow an overpressure to be applied to the face and annulus thereby helping to keep the bore stable and prevent collapse of soils on to the pipe. For cohesive soils the use of a strong bentonite mud is probably unnecessary and a mud made from water and native soils or a very light bentonite mud could be selected.

For Pipejacking the particles may be up to gravel sized and the mud should be capable of transporting the solids from the face to the surface. The excavated face is larger than for microtunnelling and so in granular soils it is more likely to collapse. Support can be provided to the face by the circulation fluid and especially so if an over-pressure is applied. In granular soils it is desirable to use a mud with the ability to build a good filtercake and a bentonite mud, perhaps with a fluid loss additive, is usually a good choice. For cohesive soils the loss of fluid to the formation is much less likely to be a concern and the use of water as a circulation fluid may suffice but for reactive clays the wetting and subsequent swelling of the clay may present problems. Such wetting can often be reduced by the use of a low fluid loss mud which may be a treated bentonite mud or a polymer mud could be selected.

For Slurry Shield Tunnelling the size of cuttings to be transported from the face may be quite large and a quality mud with good suspension properties may be necessary to achieve this. The rate of removal of cuttings may also be large, especially in granular soils where excavation rates might be rapid. The mud would therefore have to transport large volumes of suspended solids and sometimes these might contain gravels or cobbles. When excavating in soft or broken rock some of the cuttings may also be large and so the requirement to be able to move large cuttings may arise even though the rate of advance in these harder formations might be much slower. The need to provide support to the face with the circulation fluid and to limit fluid losses to the formation are similar to the requirements for pipejacking and for granular soils or broken rock it would be usual to choose a bentonite based mud. For clay or cohesive strata the tunnelling might be undertaken with water but then there is a risk of the wetted soils swelling and causing balling of the bit and cutters. The risk of this happening is reduced with a fluid that limits the wetting of the soils. A low fluid loss bentonite mud or an encapsulating polymer mud may be selected.

Fig. 1: 750 cubic metre per hour

MUD CLEANING

In all the above applications a good quality clean mud provides better transport of the cuttings and a thinner and less permeable filtercake. It should therefore be self evident that efficient mud cleaning is an important part of the tunnelling process and the quality of the mud can have a significant effect upon the rate of tunnelling and the stability and integrity of the hole.

The size and amount of mud cleaning equipment will depend upon the flowrate from the machine, the rate of excavation, the strata being excavated, the type of mud being used and the costs and logistics of off-site disposal for used or waste mud.

For microtunnelling the flowrates and the amount of mud in the system are relatively small so the costs of making mud and of disposing of mud may not be high. Nevertheless there is still the need for the excavated solids to be separated from the circulation fluid. In applications where the circulation fluid is water or a light mud the separation of solids may be achieved by gravity settlement where the mud gently flows through tanks or lagoons thereby allowing the solids to settle. The tanks or lagoons must be of sufficient size to allow the slow and even flow of the fluid through them and of course they will need to be emptied from time to time. This arrangement of settlement lagoons may take up more space than is readily available and in any case this system is not really suitable for a mud that has a good gel strength or viscosity for such a mud will keep the cuttings in suspension and so the small particles will not settle out. For bentonite based muds mechanical separators, such as desanders and desilters, may be used. The machines used for microtunnelling works are normally quite small, mount on top of the mud storage tanks and clean the mud using screening and hydrocyclones.

For pipejacking the amount of cuttings being excavated is higher and the need to efficiently separate these from the circulation fluid becomes more important. Gravity settlement is not usually appropriate and mechanical mud cleaning is used in most instances. This mechanical separation may use primary screens, desanding hydrocyclones, desilting hydrocyclones and screens for the dewatering of the hydrocyclone underflows. Ultra-fine desilters or centrifuges can be used downstream of the desanders and desilters for the removal of finer solids than can be separated by these other machines. Sometimes chemical flocculation is employed to separate the finest solids and the resultant sludge can be partially dewatered by centrifuges or belt presses. This latter technique may be used for the cleaning of the active mud and also for the clean up of any waste mud during the work or at the end of the drive or project.

For slurry shield tunnelling the volume of material being excavated is very much higher and efficient solids separation is essential. The cuttings are likely to have a wide range of sizes and most slurry shield tunnelling machines operate with relatively large diameter mud circulation pipes to handle these large cuttings. Because of the large pipes the volume of mud being circulated is high and the energy required to carry out this pumping is relatively large. The velocity of flow within the pipes can be minimised if the mud has good solids carrying characteristics but this in turn makes it more difficult to clean the mud on surface. The minimisation of flowrate does however have the advantage that a smaller flowrate generally requires a smaller mud cleaning plant but this can be offset if the mud is so difficult to clean that extra equipment or processes have to be employed to separate the excavated solids from the circulation mud. There are therefore many factors which must be considered when selecting the type of cutters to be used, the desired rate of penetration, the size of the circulation pipework, the circulation rate, the type of mud to be used and the size and complexity of the mud cleaning plant.

MUD CLEANING EQUIPMENT

PRIMARY SCREENS

Screening is the cheapest and most energy efficient method of removing solids from the circulation fluid. Unfortunately primary screening is only applicable to the separation of sand sized or larger particles. Factors that affect the throughput capacity and the size of particle that can be separated include the screening area, the type and aperture of the screens, the angle and the type of motion of the screens, be this elliptical or linear.

In order to handle clays or sticky solids a steeply declined screen is usually chosen for the solids will transport or roll down the deck more easily than would be the case for a flatter deck. Primary screens are available as single or multiple deck machines. The advantage of a multi-deck screen is that the lower deck can be dressed with finer screens than the upper deck thereby allowing the upper deck to remove large solids while the lower deck separates smaller solids. The disadvantage is that access to the lower deck is restricted and sometimes clogging of the lower deck screen will occur and this is difficult to remedy. Single deck screens are easy to maintain but any damage to the screen deck will allow oversize solids to pass through the screen and these may cause problems with downstream equipment.

For small flowrates the primary screening deck may be dressed with relatively small aperture screens which allow the screened solids to be processed by desilting hydrocyclones, thereby omitting the desanding stage. This is very space and energy efficient but high quality equipment and screens are required, which adds to the cost of these high efficiency compact mud cleaners.

For medium flowrates up to about $300 m^3 hr^{-1}$ the primary shaker deck may be incorporated in to the same shaker that is used to dewater the underflow from the desanding hydrocyclones. The primary separation is usually relatively coarse for the solids that pass through the primary screen can be handled by the desanding hydrocyclone.

For large flows, such as used for slurry shield tunnelling works, the primary shaker is usually a stand alone item which can handle the full flow on a single machine. This primary shaker is used to separate large solids and is often equipped with heavy duty, robust, wedge wire or polyurethane screens that will tolerate the large solids loadings that can arise during tunnelling operations.

CLAYBALL SEPARATORS

Sticky clays tend to adhere to the screens of shakers and the vibration of the screens increases the tendency for the clays to attach more firmly to the screen wires. This problem can be partially overcome by the use of steeply declined decks and special anti-clogging screen materials but another approach is to use Clayball Separators. These machines use a slotted conveyor belt on to which the mud and solids are discharged. The belt, which is usually slightly inclined, is driven towards the discharge end and during its transit the mud falls through the slots while the oversized solids remain on the belt. These solids do not move relative to the belt and so there is little tendency for the solids to become strongly attached to the belt. Some Clayball Separators have overhead fans which blow large volumes of air over the belt to help to further dewater the solids on the belt. The separated solids fall off the end of the belt for later removal.

DESANDERS

Desanders are available with a wide range of capacities from just tens of cubic metres per hour to individual machines that can handle flowrates of more than 1000 m^3hr^{-1} Most machines operate with one or more hydrocyclones, in the size range of 150mm (6") to 660mm (26"), and these discharge their underflows to a dewatering shaker deck. Small and mid capacity desanders may incorporate the primary shaker screen within the same piece of equipment. Desanders are available which can separate up to 150 tonnes per hour of solids. Some desanders are equipped with discharge pumps used for the onward transfer of the processed mud, usually to desilters or centrifuges.

The method of operation of a desander is that the mud is pumped to the hydrocyclone(s) at a near constant pressure. The hydrocyclone has no moving parts but the swirl caused by the tangential entry angle of the mud to the hydrocyclone causes the heavier materials to be flung outwards more strongly than the lighter materials. For most tunnelling applications where a water based mud is used the heavier materials are the soils and the lighter materials are the fluids or mud. The heavier materials make their way down the body of the hydrocyclone towards the discharge or underflow end and exit, with some fluids, through the discharge spigot. Meanwhile the lighter materials, mud, form in the core of the hydrocyclone and exit by way of the vortex finder to the overflow. Some light solids, such as vegetable matter, paper etc. are likely to be carried to the overflow so hydrocyclones cannot always separate a particular size of solids for they are basically density separators and will allow the passage of light solids to their overflows.

The underflow from the hydrocyclone(s) is usually dewatered by a screen shaker. This both reduces the moisture content of the solids that are discharged and recovers mud that would otherwise be sent for disposal. The dewatering shaker deck is subject to a heavy loading of cuttings and is normally fitted with either stainless steel wedge wire screens or polyurethane screens which are stronger and better able to resist wear than woven wire screens. The material and the aperture of these screens together with the 'G" force of the loaded shaker greatly influence the dewatering and solids transport which determines the overall efficiency of the desander unit.

Fig. 2: SM300DP desander

DESILTERS

Desilters are used to separate particles that are smaller than can be separated by a desander. The method of operation of a desander and a desilter is very similar except that a desilter uses smaller diameter hydrocyclones than desanders and the dewatering shaker can work with much finer screens. The geometrical shape of a hydrocyclone influences the size of particle that it can separate to its underflow. Generally the smaller the diameter of the hydrocyclone the finer is its cut point and the less is its throughput capacity. There are however other parameters that affect the performance of a hydrocyclone and these include taper angle and body length. It is therefore possible to make 125mm (5") hydrocyclones that have finer cut points than 100mm (4") hydrocyclones while offering the advantage that they handle more flow and will accept larger solid particles. The hydrocyclone underflows discharge on to a shaker for dewatering. The performance of this dewatering shaker has a great influence upon the efficiency of the desilter. Some dewatering shakers are high speed units that run with pre-tensioned, very fine stainless steel woven wire mesh screens that can separate particles down to about 30micron metres. Other units use less efficient woven wire screens, perhaps running on a slower speed shaker while yet others use slotted polyurethane screens running on relatively slow 'G' shakers, similar in concept and performance to the shakers used on desanders.

For low volume mud cleaning it is possible when using high efficiency mud cleaners to progress directly from the primary screening to desilting without the need to use a desander in between. For medium flowrates, such as used for pipejacking, it is usual to employ a desilter as it allows fine sands and some silts to be separated from the mud, thereby extending the life of the mud before disposal becomes necessary. For large circulation rates the use of desilters is very likely for even in sandy soils or in rocks there will probably be a significant portion of the cuttings that the desanders do not separate and which can be extracted by the use of efficient desilters. If desilters were not employed these fine solids would either remain as contaminants in the mud or would have to be removed by other devices such as centrifuges. As the volume of cuttings is so great in a large diameter tunnel, the failure to separate even a few percent of solids at the appropriate stage can soon result in severe contamination of the mud and this leads to either more expensive downstream treatment or the need for the early disposal of the waste mud.

MUD CLEANERS

Mud cleaners combine primary screening, hydrocyclone desilting and dewatering of the hydrocyclone underflow in one machine. They are particularly useful for projects where the flowrates are small to medium and where the user wishes the mud cleaning to be accomplished to a good standard by one small piece of plant. Mud cleaners are however quite limited in the amount of solids that they can separate per hour and so it is necessary for the user to evaluate the solids handling capacity of the machines in addition to their fluid process capacity. The performance of a mud cleaner is influenced not only by the number, diameter and shape of the hydrocyclones but also by the efficiency of the dewatering screen. The best performing mud cleaners use high frequency dewatering shakers dressed with pre-tensioned stainless steel woven wire mesh screens. These screens are available with very small apertures and can separate solids down to about 30 microns. High performance mud cleaners can therefore be used to remove virtually all of the sands and much of the silt fraction from a mud, provided the volume of solids being handled is not too large to allow adequate drainage through the pre-tensioned screens. A solids handling rate of 10 m^3hr^{-1} is a practical upper limit for such a dewatering shaker.

For larger flowrates or where larger amounts of solids have to be separated it is considered better to divide the functions of the mud cleaner between different types of machine, such as primary screens, desanders and desilters, rather than use multiple mud cleaners working in parallel.

CENTRIFUGES

Centrifuges are another form of gravity settlement device except that they create their own, very high, gravitational force within the bowl of the machine and this causes the rapid separation of sand and most silt sized particles from the carrier fluid or mud. Even so light solids such as vegetable matter, leaves and peat may not be separated by a centrifuge. These machines have relatively small throughput capacities for their size and cost, these range from $6m^3hr^{-1}$ to a little over $100m^3hr^{-1}$ for the largest machines. Centrifuges are therefore most commonly used to process just part of the circulation flowrate to a high standard. They can typically separate particles down to about 6 micron metres and so they can often remove significant amounts of silts from a mud and are effective tools even though perhaps only a small portion of the mud is being processed by the centrifuge. Most centrifuges that are used for mud cleaning applications operate with medium to large flowrate systems where the steady, but near continuous, separation of fine solids permits the extended use of the mud over a longer period than would otherwise be the case. Their use may significantly reduce the need for mud disposal thereby helping to minimise the off-site tanker traffic, vehicular disturbance to neighbours and of course the environmental problems of liquid disposal to landfill.

WASTE MUD CLEAN-UP

A final stage of mud cleaning that may be appropriate is that of waste mud clean-up. Even with the use of primary shakers, desanders, desilters and sometimes centrifuges there usually comes a time when the mud becomes so contaminated that its further use is counter-productive and it needs to be replaced. This situation can often be avoided by the use of a flocculation plant working in conjunction with a centrifuge or belt press to treat a portion of the active mud on a regular and on-going basis. The method of work is for a portion of the mud from the desilter to be treated in a separate system where it is chemically flocculated so that the fine solids join together and form lumps which are easier to separate from the liquid phase of the mud. This flocculated fluid is then partially dewatered by belt press or centrifuge to produce a near solids free liquid and a solids rich sludge. The fluids can either be reused on site or very often they are suitable for disposal to the public sewer system. The concentrated sludge is normally thick enough that it may be handled by backhoe and transported from site by tipper truck. The steady removal of contaminated mud from the active system allows space within the system for new, clean mud and so the active mud may be kept in use for long periods of time, sometimes for months.

A variation on this method of work is for heavily contaminated mud to be removed from the active system and placed in to store. This waste mud is then processed by flocculation and partial dewatering instead of being disposed of off site by tanker. Such treatment limits the amount of tanker journeys and often the centrifuge can be used for day to day active system mud cleaning and then used with the flocculation plant on an intermittent basis, as and when required, to clean up waste mud.

The partial dewatering of the flocculated waste mud may be carried out by a belt press instead of a centrifuge. Belt presses require much more space than centrifuges to process the same flowrate and belt presses also usually require a stronger flocculated sludge, which costs more in flocculant, but the solids cake produced by a filter press is generally a little drier than the solids discharge from a centrifuge.

For large projects multiple centrifuges can be used and this provides the opportunity to carry out active mud cleaning and waste mud clean up with any combination of the available centrifuges working to carry out either operation, at the same time. The biggest types of centrifuge can carry out waste mud clean up at rates of up to $120m^3hr^{-1}$ and the use of two or three of these machines working in parallel downstream of an efficient solids separation plant should enable the on site treatment of waste mud to be achieved in support of the largest of slurry shield tunnelling machines.

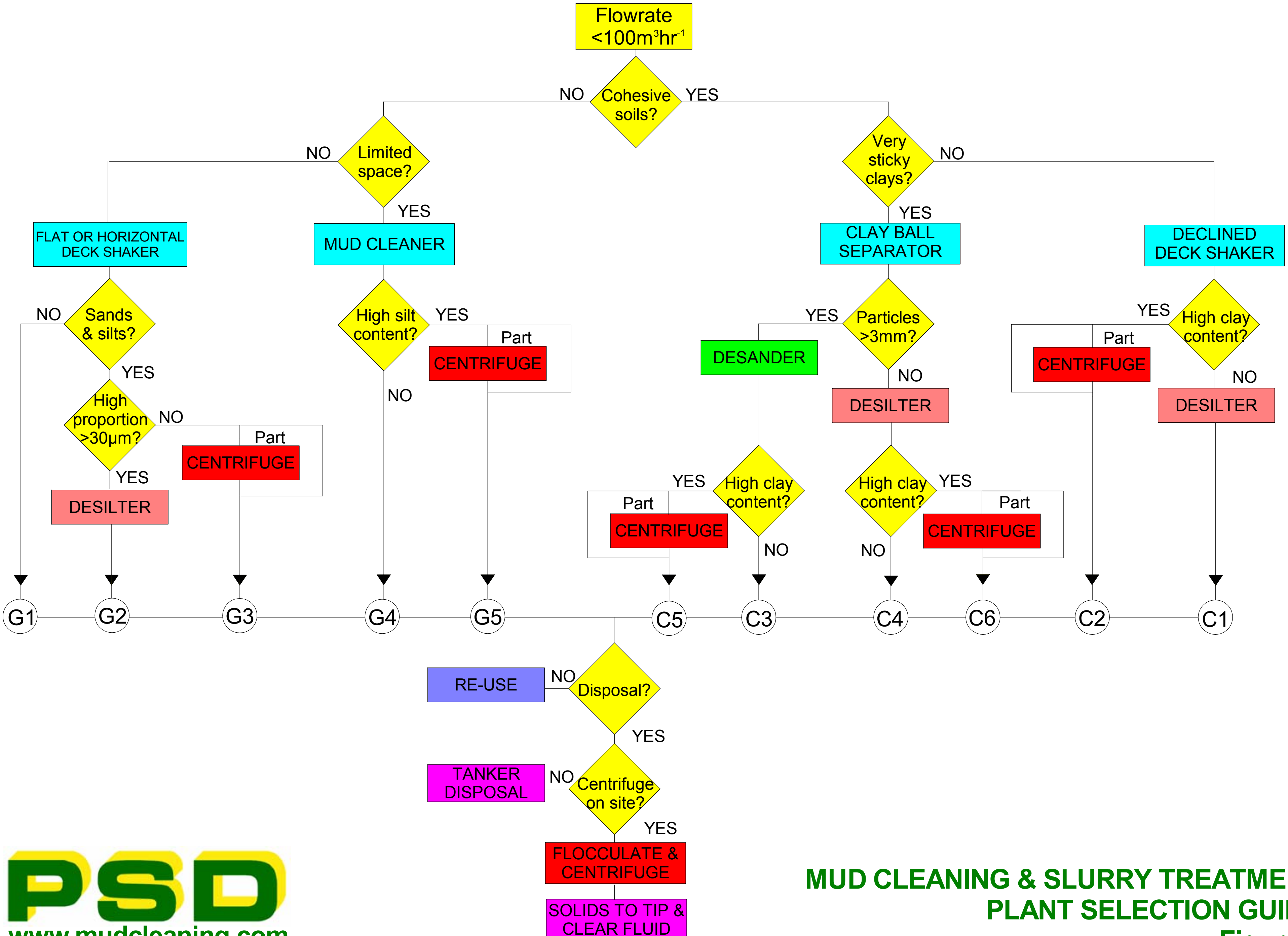

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Figure 3

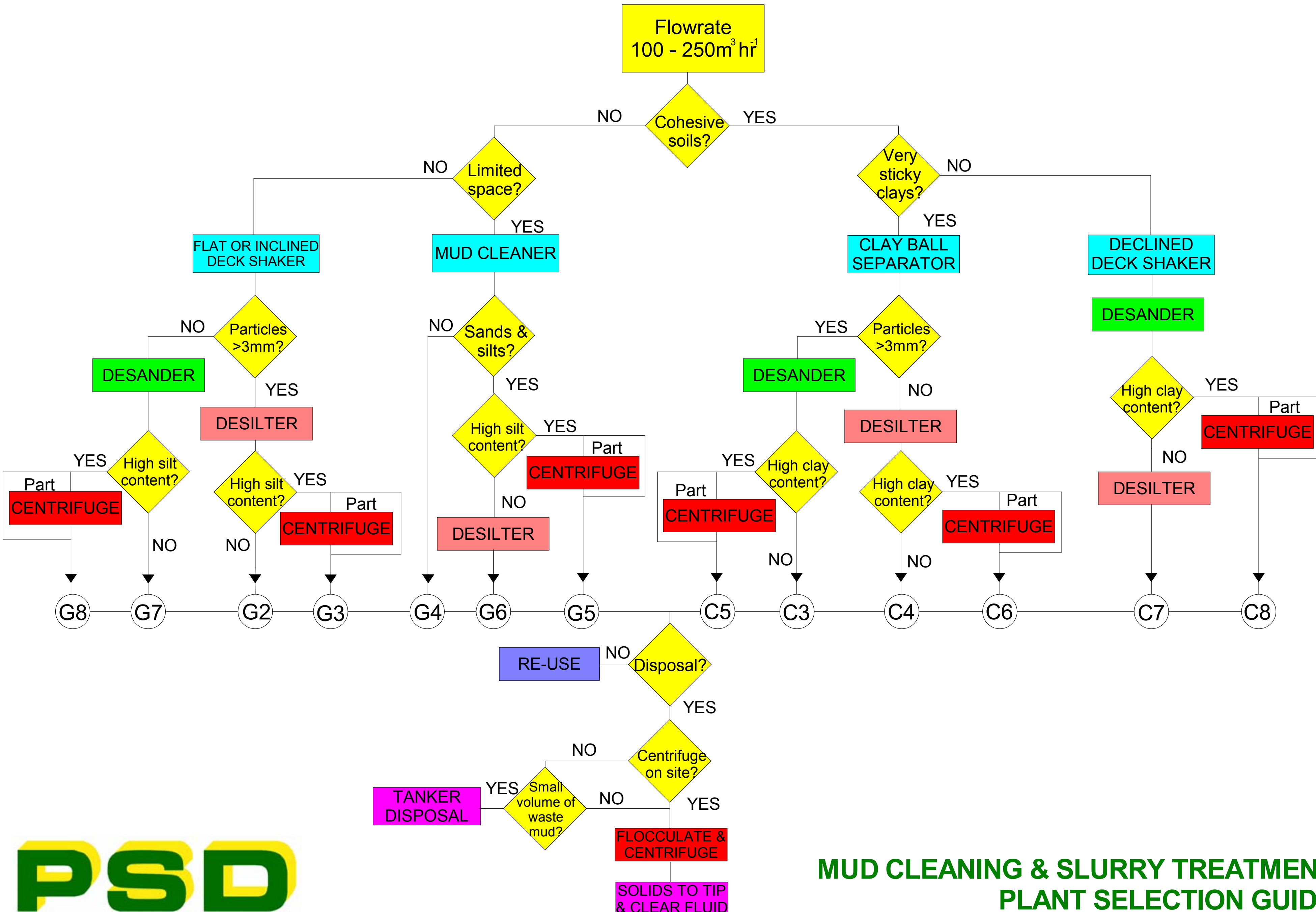

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Figure 4

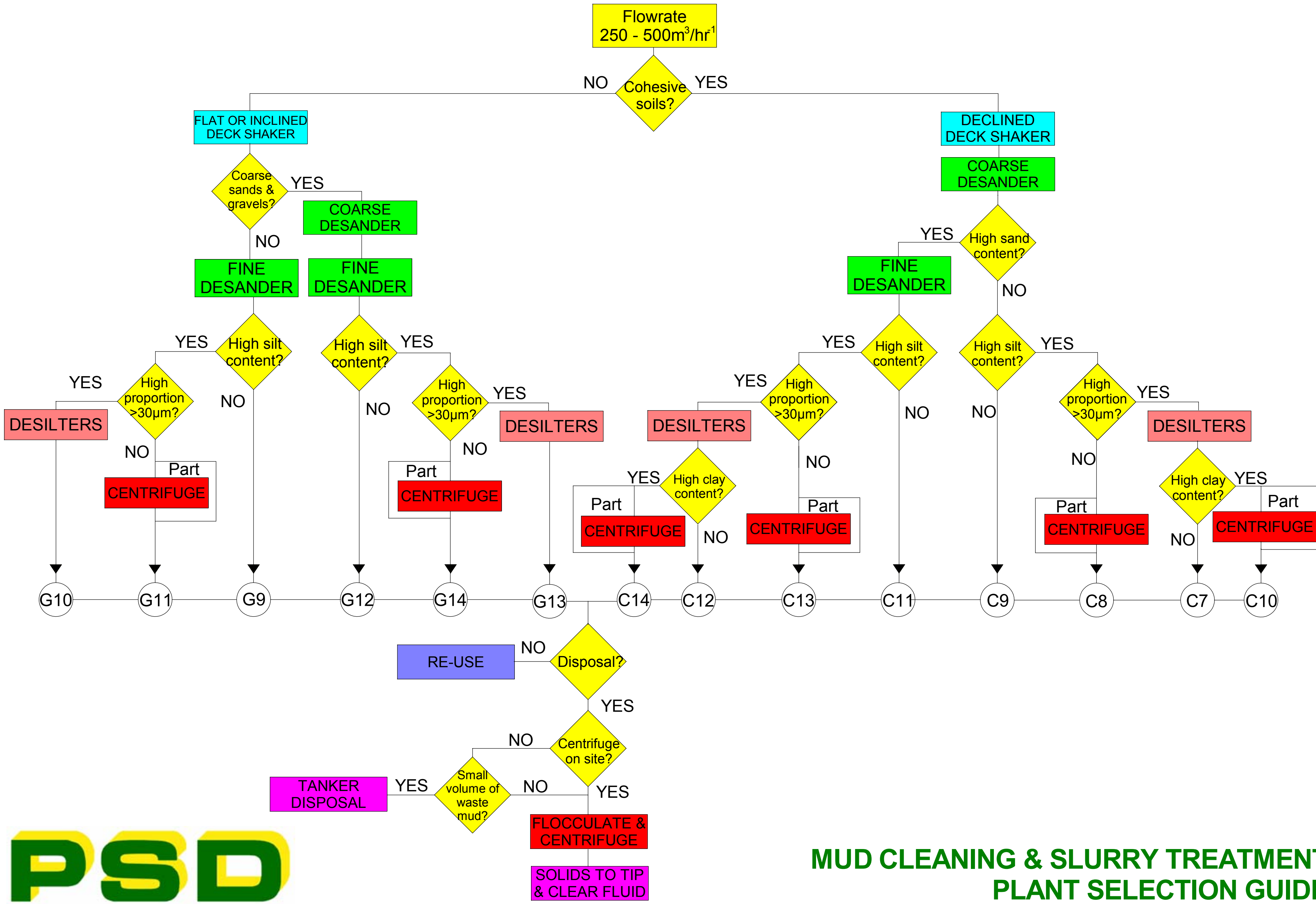

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Figure 5

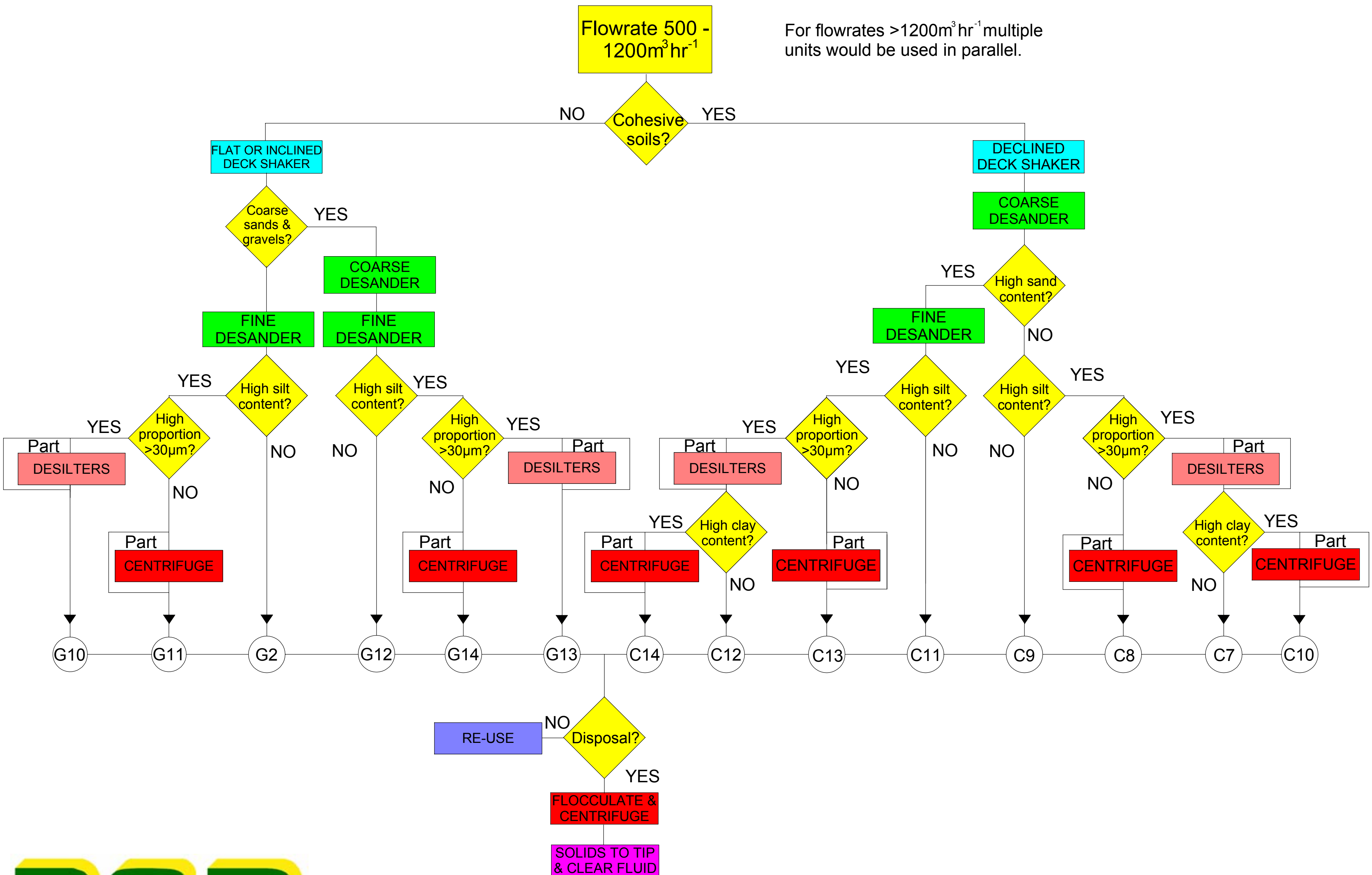

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Figure 6

GRANULAR SOILS

EQUIPMENT SELECTION & FLOWRATE	FLOWRATE <100m³hr⁻¹	FLOWRATE 100-250m³hr⁻¹	FLOWRATE 250-500m³hr⁻¹	FLOWRATE 500-1200m³hr⁻¹
G1	Footprint: 4 x 3m Power:25kW			
G2	Footprint: 7 x 3m Power:55kW	Footprint: 7 x 3m Power:110kW		
G3	Footprint: 10 x 3m Power:85kW	Footprint: 10 x 6m Power:130kW		
G4	Footprint: 3 x 3m Power:30kW	Footprint: 6 x 3m Power:40kW		
G5	Footprint: 7 x 3m Power:60kW	Footprint: 12 x 3m Power:95kW		
G6	Footprint: 7 x 3m Power:60kW	Footprint: 10 x 3m Power:115kW		
G7		Footprint: 7 x 3m Power:95kW		
G8		Footprint: 14 x 3m Power:160kW		
G9			Footprint: 7 x 6m Power:170kW	Footprint: 10 x 7m Power:320kW
G10			Footprint: 10 x 7m Power:330kW	Footprint: 10 x 7m Power:575kW
G11			Footprint: 10 x 7m Power:330kW	Footprint: 16 x 7m Power:480kW
G12			Footprint: 10 x 7m Power:320kW	Footprint: 13 x 7m Power:425kW
WASTE MUD CLEAN UP	Footprint: 7 x 3m Power:40kW Throughput: up to 8m³hr⁻¹	Footprint: 7 x 6m Power:80kW Throughput: up to 20m³hr⁻¹	Footprint: 7 x 6m Power:180kW Throughput: up to 40m³hr⁻¹	Footprint: 10 x 7m Power:360kW Throughput: up to 80m³hr⁻¹

KEY:
- PRIMARY SCREENING / MUD CLEANING
- DESANDING
- DESILTING
- CENTRIFUGING

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Figure 7

COHESIVE SOILS

EQUIPMENT SELECTION & FLOWRATE	FLOWRATE <100m^{3}hr^{-1}	FLOWRATE 100-250m^{3}hr^{-1}	FLOWRATE 250-500m^{3}hr^{-1}	FLOWRATE 500-1200m^{3}hr^{-1}
C1	Footprint: 7 x 3m Power:55kW			
C2	Footprint: 7 x 3m Power:50kW			
C3	Footprint: 7 x 3m Power:50kW	Footprint: 7 x 3m Power:95kW		
C4	Footprint: 7 x 3m Power:50kW	Footprint: 7 x 3m Power:100kW		
C5	Footprint: 11 x 3m Power:80kW	Footprint: 14 x 3m Power:160kW		
C6	Footprint: 11 x 3m Power:80kW	Footprint: 14 x 3m Power:165kW		
C7		Footprint: 11 x 3m Power:190kW	Footprint: 13 x 6m Power:340kW	Footprint: 20 x 7m Power:375kW
C8		Footprint: 14 x 3m Power:175kW	Footprint: 7 x 7m Power:345kW	Footprint: 10 x 7m Power:535kW
C9			Footprint: 10 x 6m Power:185kW	Footprint: 6 x 7m Power:215kW
C10			Footprint: 15 x 7m Power:500kW	Footprint: 13 x 7m Power:695kW
C11			Footprint: 10 x 7m Power:320kW	Footprint: 10 x 7m Power:350kW
C12			Footprint: 17 x 7m Power:480kW	Footprint: 16 x 7m Power:585kW
C13			Footprint: 11 x 7m Power:480kW	Footprint: 11 x 7m Power:745kW
C14			Footprint: 17 x 7m Power:640kW	Footprint: 16 x 7m Power:980kW
WASTE MUD CLEAN UP	Footprint: 7 x 3m Power:40kW Throughput: up to 8m^{3}hr^{-1}	Footprint: 7 x 6m Power:80kW Throughput: up to 20m^{3}hr^{-1}	Footprint: 7 x 6m Power:180kW Throughput: up to 40m^{3}hr^{-1}	Footprint: 10 x 7m Power:360kW Throughput: up to 80m^{3}hr^{-1}

KEY:
- PRIMARY SCREENING
- DESANDING
- DESILTING
- CENTRIFUGING

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Figure 8