

## Safe, Efficient Cuttings Handling Decreases Environmental Risk

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### Abstract

Due to improved environmental awareness and legislation stringency, there has been a substantial increase in the need for better containment and transportation of drilling waste. In the offshore markets, many areas virtually prohibit the dumping of drilling waste overboard. On land rigs, the practice of constructing large earthen reserve pits is declining in favor of “zero discharge, closed-loop systems.”

### Drivers: HSE

Many advantages are associated with the use of positive pressure pneumatic conveying systems to store and transfer drill cuttings. These advantages include: reduced handling, reduced rig/boat space, decreased manpower, total containment and reduced safety risks. However, with these advantages come many associated inherent challenges.

### The Challenge

Drill cuttings are not homogeneous. The heterogeneous nature of drill cuttings is influenced by mud type, formation lithology, drilling conditions, solids control methodology and treatment/storage techniques. This leads to a large variance in expected transport and storage requirements. Any reliable system must be able to compensate for these wide material differences and must continue to operate effectively in moving wet, dry, oil-based (OBM), water-based (WBM), or synthetic-based (SBM) cuttings. In addition, the transport mechanism must be easily configurable to different rig layouts and should be easily maintained.

“Dense phase” positive pressure pneumatic transport designed specifically for the transfer of drill cuttings meets all the challenges brought about by the offshore drilling industry. The system has proven to be a cost effective means of “total containment,” while providing a safer means to handle cuttings with less personnel intervention.

This paper will show the design criteria and the testing performed that has brought this substantially improved new cuttings transport mechanism to market. In addition, we will share some of the field data collected to substantiate the improved safety, environmental compliance and improved economics.

### Introduction

Developing technology to transfer drill cuttings is very challenging. The main reason is that drill cuttings are not

homogeneous. In fact, the characteristics of drill cuttings vary substantially. The actual composition is dependent upon a number of factors, thus leading to a variety in properties as illustrated below, all of which influence the “flowability” of the drill cuttings.

Mud type	WBM, OBM, or SBM
Particle Size (super fine to coarse)	-5 microns to > 20 millimeters
Particle and Bulk density	1.3 to 4.2 g/cm <sup>3</sup>
Particle Shape	Flaky, prismatic, spherical, cuboid
Particle hardness	1 to 8 Mohs hardness
Liquid content, water and oil	15% to 70%
Shear Strength	1.2 to 40kN/m <sup>2</sup>

This inherent inconsistency in drill cuttings can lead to cuttings handling problems. Some technologies work better with near-dry powders, while others need near-slurry conditions to function at an optimum level. Until very recently, few transport systems have proven to work well with both extremes.

### Conveyors

The most common method for transferring drill cuttings on an offshore rig is with a mechanical conveyor. Although belt conveyors have been used, they have many disadvantages, including risks for accidents. However, the main reason that belt conveyors are not used often is that they do not contain liquids well. Therefore, when incidents with high liquid contents happen, as they always do, there is a high potential for spills.

Screw conveyors are much more common than belt conveyors and are probably the most economical method for handling drill cuttings. They are well suited for transporting drill cuttings with wide consistencies, ranging from dry powders to liquid slurries. Although screw conveyors are efficient at transferring cuttings in a wide variety of physical conditions, they do present a potential safety hazard. The slow speed of rotation presented by most screw conveyors generally means a high-torque condition that can crush or sever whatever may fall into the conveyor, including human limbs. In addition, screw conveyors present significant installation problems when cuttings must be conveyed over

longer distances. There are even more obstacles present when cuttings must be conveyed around corners and/or transferred vertically. In general, screw conveyors are the best choice when cuttings must be moved a short distance, but long runs with significant direction change and elevation change make screw conveyors problematic.

### Positive Displacement Pump

Another way to move cuttings is with positive displacement pumps. Several different types of positive displacement pumps have been used to transport cuttings. In general, these piston-type pumps are able to move cuttings, but require them to be, at least, somewhat wet. With modern solids control equipment, the cuttings in many cases are too dry for the pumps to move effectively. Halliburton conducted tests using a 332 ft horizontal pipe run and drill cuttings at 15.5 lbs/gal. The results indicated that even at this relative low density, the cuttings needed to be diluted with an additional 8.4% of drilling fluid. Although the tests showed that cuttings could be pumped, it was required that the cuttings be diluted with drilling mud.<sup>3</sup>

Nearly all environmental management systems and processes require that the volume be minimized. Dilution with drilling fluid is a costly operation since the fluid is expensive and the disposal is typically related to volume. An additional 8.4% volume increase is very significant and is not desirable in many cases. If the mode of cuttings disposal is cuttings injection, then it may be acceptable to dilute the cuttings with water before transporting the solids via a cuttings pump. However, in most cases, dilution followed by pumping is not the optimal way to transport cuttings offshore.

### Pneumatic Transfer

Pneumatic conveyance has been used for years to load solid free-flowing materials. The segment known as dilute phase or lean phase flow suspends the conveyed particles in a stream of rapidly moving air. Dilute phase transport, in its most recognizable form, is characterized by high gas velocities (greater than 20m/s) and low solids concentrations (usually less than 1% by volume). This results in low pressure drops per unit length of transport line (typically less than 5 mbar/m).

### Vacuum Systems

Vacuum systems are a form of pneumatic transport which generally rely on dilute phase flow for transport. Vacuum systems rely on air velocity to move the cuttings. The velocity is created by pulling a negative pressure on a collection tank, usually with some type rotary blower. The amount of vacuum pulled is important because it determines the force which can be applied should a clog occur. However, it is impossible to provide more than -1 bar (one atmosphere -14.7 psi) motive force. The real criteria for this type of pneumatic transfer is the volume of air moving through the conveying pipe.

In general, vacuum systems are considered to be safer than mechanical conveyors and offer the convenience of easy installation. A collection tank is set up under the shakers and a flexible hose is used to collect the cuttings. This allows the

system to be setup quickly and simply. This system does, however, possess some limitations. They have physical limitations on the amount of material they can transport and they can only move cuttings a short distance, usually less than 10 meters. Also, it must be pointed out that because the system relies on air velocity, great care must be taken to ensure that the system does not get plugged. Accordingly, the system generally requires that it be manned at all times.

### Positive Pressure Pneumatic Transfer

Dilute phase positive pressure transfer has been used for years, in many industries, to move “free flowing” material. In fact, the drilling industry has been using dilute phase pneumatic conveyance to move cement, bentonite, barite and frac sand for many years. As mentioned above, dilute phase flow is dependent on air velocity to move solids. When the gas velocity is no longer high enough to maintain the solids in suspension, the solids begin to settle on the bottom of the pipe. The gas velocity at this point is referred to as the saltation velocity. Further decreases in gas velocity result in the rapid “salting out” of solids and a rapid increase in pressure per unit length of pipe. This is the point where dilute phase flow becomes dense phase flow. Materials that have relatively uniform, homogeneous “free-flowing” particles can be transported using dilute phase pneumatic transfer. However, when the material to be transferred trends toward fine cohesive particles, like we see in drill cuttings, dilute phase transfer is practically impossible over a long distance. Extremely dry cuttings, such as those that report from a cuttings dryer, can be transported in dilute phase. Wet cuttings, on the other hand, must be transported in dense phase.

### Dense Phase Flow

Dense phase is defined as the condition in which solids are conveyed such that they are not entirely suspended in the gas. In the dense phase regime, a number of different flow patterns occur in both horizontal and vertical transport.

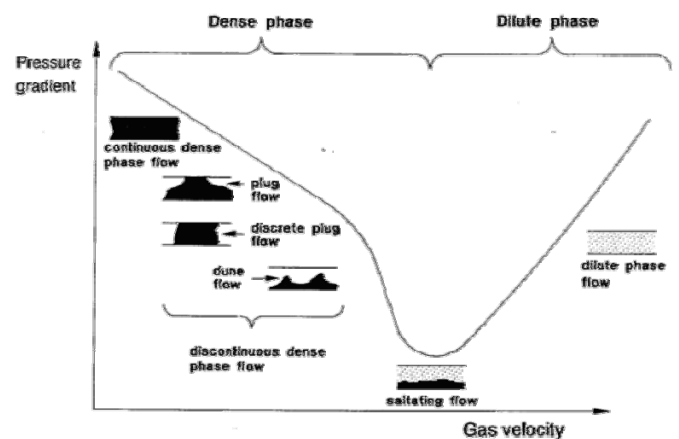


Fig. 1: Flow patterns in horizontal pneumatic conveying.

The continuous dense phase in which the solids occupy the entire pipe is virtually extrusion. Transport in this form requires very high gas pressures and is usually limited to short, straight pipe lengths and granular materials with high permeability.

Discontinuous dense phase flow can be divided into three fairly distinct flow pattern: (1) discrete plug, in which small distinct plugs of solids occupy the full pipe cross section, (2) “dune” flow, in which a layer of solids settled at the pipe bottom move along in the form of a rolling dune or wave and (3) a hybrid of discrete plug flow and dune flow, in which the rolling dune completely fills the pipe cross-section, otherwise known as a plug flow.

Saltating flow is encountered at a gas velocity just below the saltation velocity. Particles are conveyed in suspension above a layer of settled solids. Particles may be deposited and re-entrained from this layer. As the gas velocity is decreased, the thickness of the layer of settled solids increases and eventually “dune” flow is realized.

It should be noted that not all materials exhibit all these flow patterns. Additionally, within any transport line, it is possible to encounter more than one regime. In the case of drill cuttings, their heterogeneous nature makes it probable that all these flow regimes will be encountered.

The main advantage of dense phase transport arises from the low gas requirements and low solids velocity. Lower gas volumes requirements generally equate to low energy requirements per unit weight of product conveyed. It also means that smaller pipelines can be used without the usual erosion problems associated with dilute phase flow. The continuous dense phase flow pattern is most attractive from the point of view of low gas requirements and solids velocity, but has a serious drawbacks in that it requires high pressures and is very difficult to control, especially with material that is cohesive (i.e. drill cuttings). We are then left with the so-called discontinuous dense phase flow, along with its plugs and dunes. Performance in this area is unpredictable and can give rise to complete pipeline blockage, thus generating high pressures. The key to controlling this flow regime is to control the length of the slug, thereby reducing the chance for blockage.

### Conveyance, Drill Cuttings Behaviour

Positive pressure pneumatic conveying requires air to be fed into the start of the cuttings transfer line in order to convey the cuttings. The pressure drop seen over an empty line is minimal and results in a low pressure, high volume, high velocity air flow through the line. By feeding cuttings into the transfer line, the pressure drop “seen” by the conveying air within the line increases accordingly.

The key to successful and reliable drill cuttings conveyance is to ensure that the cuttings feed rate into the pipe is such that the restriction on air flow is controlled. This, in turn, ensures that the conveyance velocities are managed as seen in fig.2.0

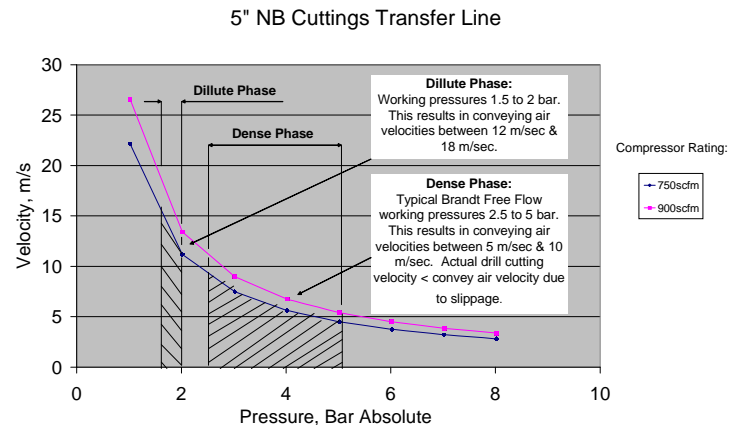


Figure 2.0: Variance in air velocity versus pressure for 900 and 750 scfm airflows through a 5" NB pipe (isothermal operation assumed; air temperature effect ignored for clarity).

Conveying air is compressible and, as such, variances in density are dependant upon pressure and temperature at a given point. Pressure is required to convey, hence the highest pressure is seen at the source. Ideally, a linear pressure drop occurs along the pipe length resulting in zero pressure at the discharge. This decreasing pressure causes the air to expand, hence the velocity of the air increases in the direction of flow.

Figure 2.0 illustrates the variance in air velocity dependant upon the pressure drop required to convey the cuttings. Continuity of airflow is critical to conveyance and, under controlled conditions, the cuttings slugs should remain permeable at all times such that airflow is maintained and “carries” or “drags” the cuttings slugs along with it.

This new technology utilizes a metering screw in order to “dose” the cuttings into the transfer line in a controlled manner. The speed of the screw is proportionally controlled, based upon transfer line pressure feedback. In order to achieve the optimal conveying conditions (as shown within Figure 2.0), a set-point of 4 bar is utilized for “wet” cuttings taken directly from the shale shaker, while a set-point of 1.5 bar is utilized for dried cuttings.

The relationship between the pressure required to convey a single slug and the slug size/length is exponential. A similar volume of cuttings transported as a series of smaller slugs will require a fraction of the pressure to convey (see Figure 2.1).

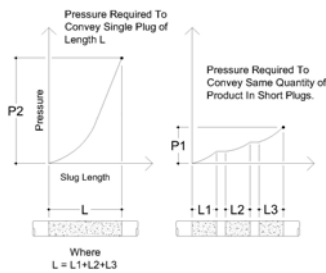


Figure 2.1: Lower pressure required for conveyance of smaller slugs (2).

Slug size is dependant upon the cuttings composition, pipe diameter and airflow. This new technology ensures that the slugs are spontaneously generated at their minimum size by offering cuttings into the airflow until such a time that the critical mass is attained, thus enabling conveyance.

The metering screw speed is automatically adjusted, utilizing the conveying air pressure for feedback. This ensures that the number and volume of slugs within the pipe are automatically controlled for optimal loading and that variances, such as cuttings consistency and pipe length, are automatically accounted for. Should the solids loading within the pipe exceed the established set point, the cuttings are prevented from entering the pipe until the conveying air clears the pipe and the pressure decreases to below the set point. Note that the compressor specified is capable of a 7 bar output, thus 7 bar pressure is available for conveyance and ensuring that plugs can be removed.

Should pipe overloading occur, the dense phase conveying within the pipe may approach an extreme, which is termed “plug flow.” In this case, the slugs are no longer permeable and reliance is placed upon air pressure alone for conveying the slug.

Due to the increase in wall friction, and the associated pressure drop the working pressure in the transfer line may rise to the maximum pressure setting (nominally 7 bar). The slug may restrict the airflow such that maximum pressure is continuous, but the actual airflow is limited to maintaining the maximum pressure behind the slug as it traverses through the line. The slug velocity in this case can be very low and the risk of plugging the line is high.

Air assists, or boosters, are sometimes employed at strategic points within the transfer line in order to try and split these slugs. Success, however, is by no means guaranteed. Should an air assist be incorrectly controlled, it can hinder flow by creating a higher pressure downstream than upstream.

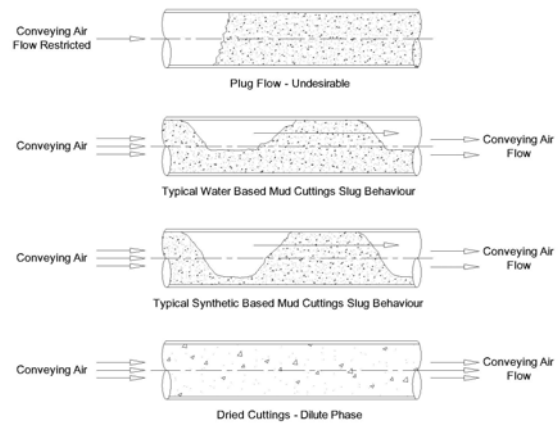


Figure 2.2: Drill cuttings flow regimes within the transfer pipe.

Under controlled conditions, Brandt NOV has found that synthetic-based cuttings tend to form a thin, 15 - 20mm thick bed on the 5” NB pipe bottom. This results in a bed approximately 90mm wide within the pipe, over which the slugs can slide. Water-based mud cuttings, due to their agglutinative nature, tend to form a deeper bed, around 40 – 50mm thick and 120mm wide, over which the slugs slide and/or shear.

It is critical that the stationary bed and the slugs are of the same material and, as such, it is imperative that the pipeline is cleaned when not used for an extended period. At the end of a section, or if drilling is stopped for 24 hours, a small volume of either drill mud or water should always be conveyed through the pipe in order to swirl and flush out the stationary bed before it starts to “cake” within the pipe.

### Positive Feed Rate Control

Figure 3.0 below shows the Brandt NOV FreeFlow Air Conveyor and illustrates the metering screw function of presenting the drill cuttings to the air flow. This ensures that the slugs are spontaneously generated at their minimum size. A 750 or 900scfm compressor is utilized for a 5” NB transfer line, capable of 7 bar pressure. This airflow is fed into the pipeline for conveying purposes only, with a tapping taken off to feed the top of the air conveyor body, equalizing the pressure across the metering screw.

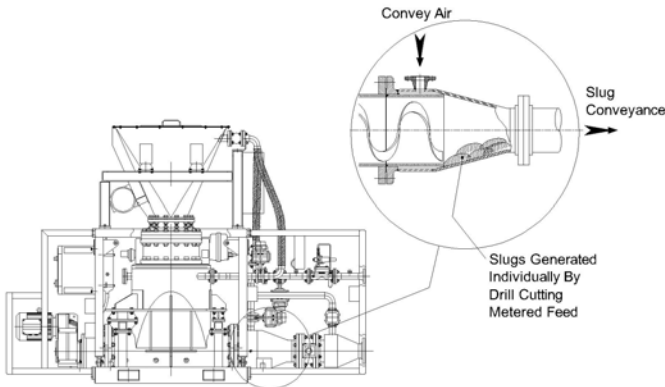


Figure 3.0: Air conveyor, detailing the metering screw and convey air interface (note: the slider tank discharge is identical to the above).

The speed of the metering screw is automatically adjusted in order to ensure optimal line loading. This is based on the pressure drop requirements for conveying the drill cuttings, as described above. As continuous airflow is achieved through the transfer line and the slug size/total volume number is controlled, the requirement for assist/boost air is negated in most cases.

In order to evaluate the improved control techniques employed by the Brandt NOV FreeFlow, it is necessary to compare it with traditional blow tank systems. Blow tanks utilize a similar conveying air specification for 5" NB conveying lines due to the above described velocity and mass flow requirements. They then rely upon apportioning a percentage of the airflow directly into the tank, such that a pressure is generated above the drill cuttings that "pushes" them from the tank and feeds them into the path of the conveying air. Pressure regulators and orifices are utilized in order to obtain the optimal percentage split of the airflow for a given product.

Any variance in product "flowability," which occurs frequently, may require a pressure adjustment, which is notoriously difficult to achieve accurately without observing the discharge behaviour.

Plug flow is usually observed via a high pressure, high volume, noisy discharge resulting from the energy release that occurs from the high pressure convey air behind the slug expanding into the atmosphere. This scenario is indicative of a poorly controlled conveyance system.

### Batch Control

The air conveyor, as shown within Figure 3.0, is comprised of the chisel bottom pressure vessel, metering screw, inlet hopper, control valves, inverter and control panel housing the PLC and interface screen. The inlet hopper is located above the chiselled pressure vessel to provide a buffer volume such that drill cuttings can be received on a continuous basis. Below this and on the discharge line, heavy duty spherical dome valves complete with pneumatic seals are utilized. This is the case with all drill cuttings "contact" lines.

As stated above, the metering screw speed is controlled by the PLC utilizing a P&I loop which is based on convey air pressure. The metering screw is operational only during the conveyance cycle, which in turn, is controlled to stop by either a timer (set via the control panel), or automatically, once the pressure drop returns to the value equating to an empty pipe. Should the timer expire while the pressure within the pipe exceeds that of an empty line, a blow-through is initiated via a convey air inlet valve downstream of the pressure vessel discharge valve. The convey air is fed into the transfer line until the pressure drop monitored approaches that of a clean line. Once the conveyance cycle is completed, the unit steps through to the fill cycle and stays within this mode until the timer expires (again, set via the control panel), or if the optional load cells are utilized, when a full load is registered. Either of these actions then initiate the convey cycle as described above. Use of the optional load cells ensure that conveyance occurs only when required and avoids unnecessary use of the air compressor.

### Storage Vessel Configuration – Designed to Flow

A feed rate controller can only function if the flow in and flow out are unhindered. The air conveyor utilizes a "chisel" type shaped pressure vessel through which "plane flow" is achieved (fig. 5.0). As such, the reduction in cross sectional area towards the discharge occurs on a single plane/axis, which greatly minimizes the risk of bridging, thus ensuring controlled discharge.

Tank Configuration:-

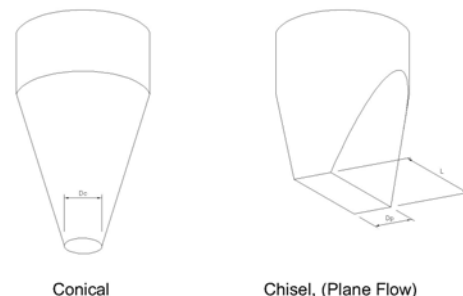


Figure 5.0: Air conveyor tank configuration for optimal flow conditions.

The metering screw is fed via a 780mm x 330mm rectangular opening, while the slider storage tanks utilize a 2500mm x 360mm opening (dimensions taken at metering screw centerline). The slider storage tank metering screw operates in conjunction with a sliding frame. This simple device consists of a hydraulic cylinder that reciprocates across the flat slider tank base. This action continually pushes and pulls the cuttings into the tank center in order to maintain a full metering screw, thus ensuring continuous feed rate control (see Figure 5.1).

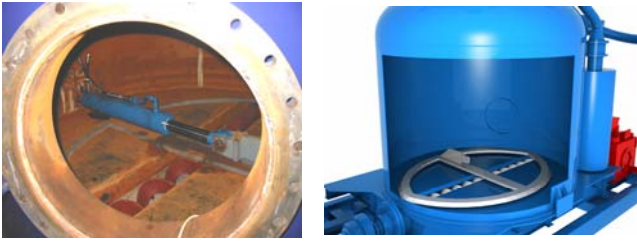


Figure 5.1: Flat-bottomed slider storage tank c/w ram-controlled sliding frame.

In comparison, conical tanks by their nature result in a reduction in cross sectional area over all axes (around 360°). This makes for a more difficult flowpath for the cuttings, which may result in a susceptibility to core flow/rat-holing or cohesive arching/bridging, both of which may induce an erratic discharge. Evidence of this can be seen in several locations on a typical rig and is usually described as “hammer rash.”

Erratic discharge/surges in feed, even though momentary, may increase the feed rate such that the product concentration may rise to a level that is enough to block the line. Cohesive arching may require the tank to be manually emptied in order to clear the blockage.

Due to the poor “flowability” of the drill cuttings, aeration points are often added around the conical tank discharge area. Drill cuttings do not exhibit good aeration properties, thus the addition of aeration points is done in an attempt to disrupt the cuttings and minimize the likelihood of cohesive arching. This additional air supply at the vessel discharge further complicates the feed air proportioning, making a steady discharge unlikely.

## Tests

The performance of both the Air Conveyor and the Slider Storage Tank has been proven through numerous tests with a variety of both “wet” and dried cuttings. Both have exhibited the required feed rate control in order to convey consistently the wide range of drill cuttings expected.

Basing the tests upon a minimum requirement to transfer 25 tons/hour, 5” NB pipe was confirmed as an appropriate pipe size in conjunction with a 750 or 900 scfm air compressor capable of 7 bar. Tests confirmed that dependant upon the cuttings, transfer rates up to 40tons/hour can be achieved with “wet” SBM cuttings and substantially more is achievable with either WBM or dried cuttings. These test also showed that problems associated with the pressure vessel designs such as bridging and rat-holing had been eliminated.

Tests carried out for one major Norwegian Operator involved the conveyance of “wet” SBM cuttings while monitoring the pressure profiles within the convey line. It was proven that a “smoother” and lower pressure profile is achieved via the Brandt NOV FreeFlow metered discharge in comparison with a conical blow tank, and recognized that this represented a more stable and reliable mode of transport. The next phase was the processing of drill cuttings taken from the

rig and successfully processed through a vortex drier prior to pneumatically conveying the dried cuttings to a storage tank.

Tests were carried out for another major Norwegian operator who requested empirical proof of the discharge rates quoted. A test was carried out in Aberdeen, where the Air Conveyor successfully conveyed 40 tons in one hour around the test bed.

The majority of the testing above was carried out with an 85 meter long convey line with both 90° and 180° long radius bends and a vertical lift of approximately 5 meters, which represented a typical rig “run.” From the test results, further increases in conveying distance could be safely predicted within typical rig run distances. However, the full effect of an extreme case of height to transfer and the impact on the convey line conditions was unknown. This was the case until the topic of inter-field transfer was broached.

In order to transfer drill cuttings from one rig to another for disposal by Cuttings Re-injection (CRI), it is necessary to transfer to the supply boat at sea level from the source rig and then from the supply boat up onto the CRI platform approximately 50 meters above sea level. Brandt initially tested this concept at its treatment facility in Lowestoft, whereby a crane was utilized in order to lift various lengths of hose culminating in a 55 meter lift.

Pipework was attached to the hose such that the return leg from the 55 meter lift was connected to a 40 meter horizontal section including long radius bends and a further 5 meter lift in order to return the cuttings to the processing tanks. This was regarded as equating to the pipe runs on board the rig in order to convey the cuttings to the CRI module after the 50 meter lift.

These trials concluded that the metered feed induced a steady state discharge whereby regular slugs were observed exiting the pipe under controlled conditions and at no time was plug phase observed.

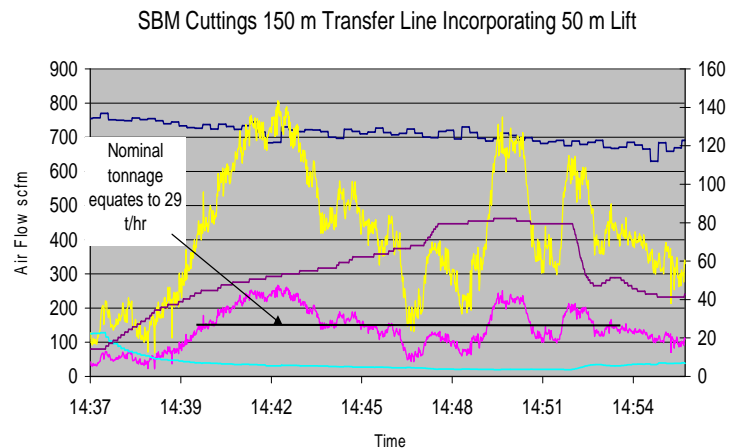


Figure 6.0: SBM drill cuttings, 50 meter lift plus 40 meter horizontal, recorded data.

From the data recorded and shown within Fig. 6.0, a steady build-up in pressure can be seen during which the discharge from the tank peaks at around 45 tons/hour. The

discharge is slowly throttled back, which reduces the pressure and returns the discharge rate to a nominal 29 tons/hour. Typically, the first five to ten minutes when discharging a Slider Tank into a clean line are spent lining the pipe and establishing steady state. Some 10% of the pipe volume on a horizontal leg is typically “bed” material. As discussed previously, once this is established steady state, conditions occur whereby the material is conveyed in a consistent and repeatable manner.

The phase density shown above is simply the ratio between the mass of cuttings transferred and the mass of the air required to transfer. This can be seen to follow the discharge rate trend due to the consistent and steady airflow which is also recorded above. The air velocity shown is applicable to the Slider Tank discharge point only as this is where the pressure is monitored and utilized in order to vary the speed of the metering screw. It can be seen to reduce to a minimum value of around 4 meters/second prior to picking up again as steady state is established. Note the air velocity will vary along the transfer line dependent upon the pressure at any given point.

In collaboration with a major UK operator, the “height” test was repeated. Due to the restraints of working within a berm, a horizontal return leg approximately 25 meters long was utilized after the 55 meter lift in order to return the drill cuttings in a controlled fashion to a skip. Again, steady state conditions were observed and the slugs discharged with minimal force.

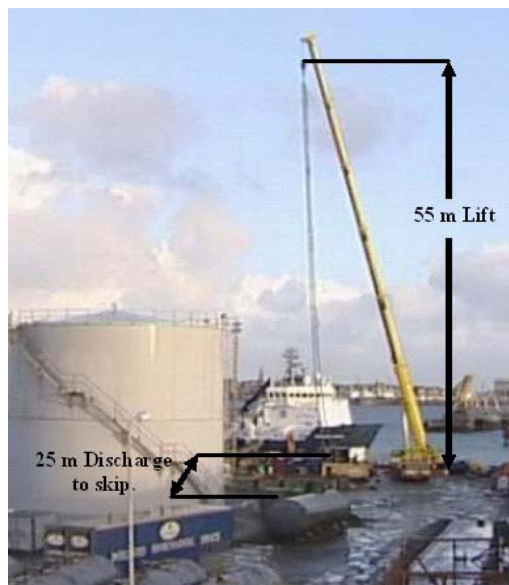


Figure 7.0: Photo of test site showing the 50 meter lift.

While at this location a further test with WBM cuttings was carried out, whereby a Slider Tank was filled utilizing the Air Conveyor and discharged to a skip. Both the Air Conveyor and the Slider Tank processed the WBM cuttings without hang up. Steady state was achieved and a regular, consistent discharge was observed with an exceptionally high

discharge rate achieved when emptying the Slider Tank.

## Conclusions

- Technology ensures the reliable conveyance of drill cuttings at consistently high transfer rates for all current applications including inter-field transfer.
- Variances due to the heterogeneous nature of drill cuttings are automatically accounted for thus minimizing risk and relieving supervisory personnel workload.
- Supervisory personnel requirements therefore minimized.
- “Wet” or dried drill cuttings are conveyed reliably.
- Cuttings conveyance is achieved without the need for fluid additions.
- Cuttings conveyance is achieved without reliance upon air assists / boosters.
- Slider Tanks are designed to be located directly on the deck and contain the necessary diverter valves etc to be self sufficient.
- Slider Tanks are designed as modular ISO tanks for ease of transportation.
- Air Conveyor designed to fit through a standard doorway for quick installation.
- Hardware internal flow problems such as cohesive arching or rat holing eliminated through design.
- Remote control option including discharge rate control available for Slider Storage Tanks thus simplifying interface with processes such as CRI and thermal.
- Brandt NOV FreeFlow designed specifically for drill cuttings.
- The system is safe and reliable.

## Acknowledgments

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## References

1. C R Woodcock, J S Mason (1987) Bulk Solids Handling, Leonard Hill, Glasgow and London
2. Glasgow Caledonian University, School of Engineering, Science and Design  
MSc/PgD Bulk Solids Handling Technology  
B6: Pneumatic Conveying – Systems and Components  
B6: Pneumatic Conveying – System Design (Part One)  
B6: Pneumatic Conveying – System Design (Part Two)  
B6: Pneumatic Conveying – Problem Solving
3. R. Morris and S. Seaton “Unique Drilling Waste Handling and Transport System Offers Advantages to Drilling Operators” SPE 94194 SPE/EPA/DOE Exploration and Production Environmental Conference March 2005