UNIVERSITY of GREENWICH

The Wolfson Centre
for Bulk Solids Handling Technology

Providing cost-effective solutions to industry’s problems

Report No: R/3780/1

Review of Extraction Technologies for Subterranean Deposits of Consolidated Arsenic Trioxide Dust

for

GMOB

NW Territories

February 4, 2021

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SYNOPSIS

This report has been prepared by The Wolfson Centre for Bulk Solids Handling Technology, University of Greenwich, London, at the request of Mr Green of GMOB, NW Territories, following discussions with Mr R Farnish of The Wolfson Centre, to report upon a programme of work to evaluate a range of options for the extraction of consolidated dust deposits within roughly hewn mine chambers.

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1. INTRODUCTION

1.1 Contractual

The proposal relating to this work was Wolfson Centre reference P/3780/1 of 21 September 2020, in respect of which GMOB verbally authorised the work.

1.2 General technical requirement

The goal of this short study is to provide an overview of technologies that could be employed to extract subterranean stores of arsenic dust from within roughly hewn chambers.

Additionally, developmental routes to minimise the risk of applied technologies will be provided.

This study will be based on historic experience with designs of various types of equipment employed across a range of industrial sectors and system troubleshooting (for bulk solids in their dry to damp conditions).

Specifically excluded at this stage are any detailed technical recommendations on equipment sizing, power, costs etc, since to produce such detailed recommendations will require further studies including materials testing, design analysis and proof of concept trials (at scale).

1.3 Arsenic trioxide storage behaviour and factors to be considered

1.3.1 Bulk Solids

It is understood that the mine currently holds approxiamtely 273,000 te of arsenic trioxide dust in fourteen subterrainian chambers. This material has been captured from the gold refining process through the use of cyclones and electro-static precipitators (ESP). The material stored in the chambers is assuemd to date from the commencement of industrial scale extraction activities dating back to the late 1940's. It is assumed that the fourteen chambers have been filled sequentially over the last eight decades and that (correspondingly) the composition of the dust and possibly its size dsitribution are likley to be a reflection of the level of hardware technology, geological yield and general operating conditions employed at any given point in the mines operating history. With respect to this last point it may transpire that each chamber may have its own dust 'characteristic' which may, to a greater or lesser extent, infuence the extraction efficiency for any given technique employed.

Currently no information regarding the specifics of the dust deposits has been provided, but it assumed that the deposits represent all of the captured material from the processes and as such will consist of relatively coarse (>150µm) material captured in cyclones, finer material captured from bag houses (<150µm,>10µm) and output from the ESP (<10µm).

The nature of the size distribution is one of several factors that will determine what are termed as the 'bulk characteristics' of the deposits.

1.3.2 Storage conditions

Key factors that will dominate the condition of the particle deposits will include:

Particle size distribution
Time in undisturbed storage
Moisture content
Latent chemical reactions
Temperature (mainly in concert with moisture content)
Particle shape variation
Stresses acting within the deposit (i.e. head of material)

The range of particle sizes present in any given bulk particulate has a very strong influence over the way in which the material will handle or respond to flow initiation. A material that is dominated by 'coarse' content (i.e. granular or >250µm) is very likely to exhibit what is known as free-flowing behaviour. Materials that are considered free-flowing can be subjected to considerable stress (with minimal change in volume resulting) and upon removal of the applied stress they will revert back to a free flowing state (i.e. they gain no residual strength). Materials that are composed predominantly of 'fines' (>90µm for the purposes of this explanation) usually have a cohesive behaviour, which is typified by a gain in residual strength in response to an applied stress). See Fig 1.

Free-flowing
Negligible forces of attraction between particles

Cohesive
Significant forces of attraction between particles

Fig 1 Illustration for the concepts of free-flowing or cohesive behaviour

Thus, in considering the handling behaviour of bulk materials it is very important to bear this distinction for behaviour in mind. Free flowing material is likely to remain relatively easy to work (whether in context of extraction or subsequent handling steps), whilst cohesive materials will not only settle to a much higher bulk density (by virtue of particle re-packing over time) but will gain increasing strength as the settlement takes place. A useful example to consider is the behaviour of fly ash which in its instantaneous state (i.e. tipped into a bucket) has a low bulk density and low strength (to the extent that it can be moved within the bucket by rocking back and forth). As the air that was entrained during filling dissipates during settlement and the ash settles to a lower volume / higher bulk density, the number of contact points between particles in the bucket increases exponentially – producing a progressive increase in frictional contact with the ash. If left undisturbed overnight, it is quite likely that the volume of the bucket contents may have reduced by ~30% and now presents itself as an almost immovable mass of material.

It is highly likely that cohesive conditions will be encountered in many, if not all, of the chambers. The magnitude of cohesive behaviour will be further exacerbated by the uptake of moisture into the dust and would move the threshold for the onset of cohesive dominated behaviour towards less fine dominated particle size distributions (i.e. even more disadvantageous bulk behaviour will be present). Depending upon the homogeneity (or lack thereof) of the dust deposit, by particle size dominance, in a given chamber and the amount of moisture ingress it is possible that local concentrations of moisture may occur. If such a concentration does occur and is trapped between two fines enriched (impermeable) strata, it is possible that bed instability may occur during reclamation (approximating to the phenomena know as 'cargo liquefaction' in bulk carrier ships).

2. TECHNOLOGIES FOR SUBTERRAINAN EXTRACTION

A consideration of the range of conditions likely to be encountered across all fourteen chambers is essential in benchmarking the operational range of possible technologies. The contents of Section 1 should be understood by the reader before proceeding.

It is considered that the main criteria that any extraction method should aim to meet is as follows:

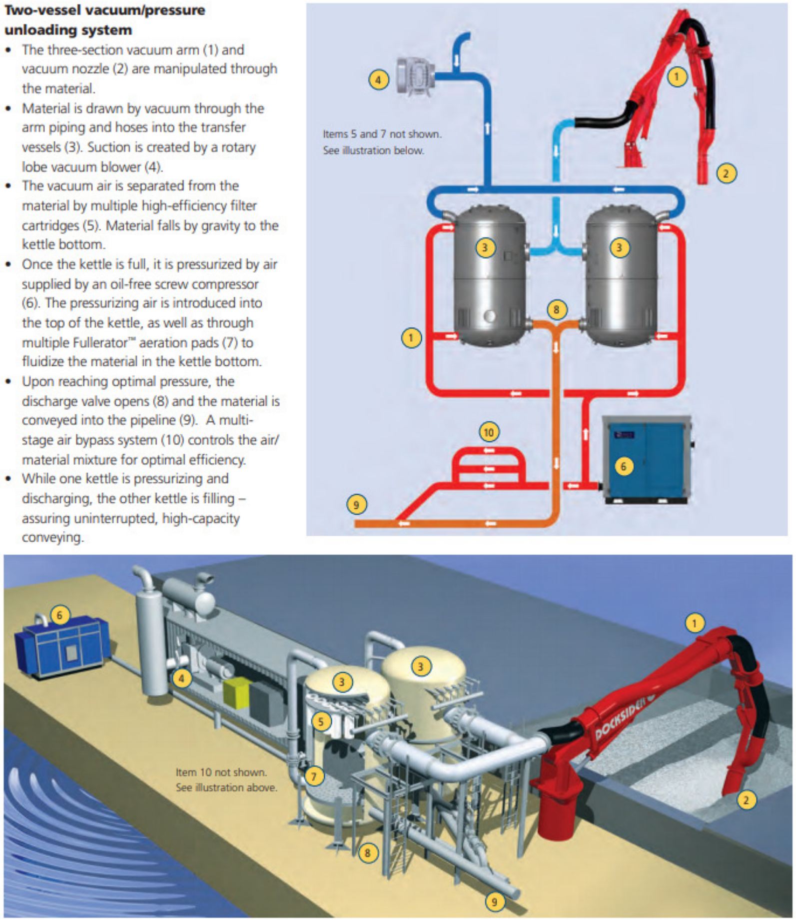
Maximised extraction from chamber>95%	Minimised support plant footprint on surface
Minimal manual intervention	Outloading to haulage vehicles?
Transfer rates t.b.c	Acceptable energy consumption per tonne extracted
Ability to traverse horizontally and vertically	Minimised overall process energy consumption
Insensitivity to extremes of dust bulk condition	High plant availability when on site

The fundamental options for extraction of the deposits fall into either a liquid based or dry extraction approaches.

2.1 Dry extraction

2.1.1 Negative/positive air pressure systems

Methods for dry extraction will likely employ vacuum to develop the necessary pressure drop in the transport line by which solids will be transferred to either the surface or an interim booster arrangement that can employ positive pressure gas movement to transfer over a longer distance (or at a higher solids loading ratio) than would be possible under vacuum. Such combined pressure units can be found extracting material under vacuum from rail tankers / ships into a receiving vessel from which the positive pressure side of the air mover provides pressurised gas flow to transport from the receiving vessel into a truck or storage vessel (Fig 1). For transporting a given quantity of material, the limited level of pressure drop that a vacuum air mover can develop limits the distance or routing employed in the pipework. Factors that contribute strongly to the line pressure drop are distance, pipeline routing, total number of changes in direction and, of course, the transfer rate of bulk solids. Longer transfer distance can be obtained using positive pressure (vacuum = ~300mbar v positive = ~ up to 1 bar). Thus. the indirect accessibility for the chambers will likely dictate the use of a combined pressure system – noting that should pipeline puncture or accidental disconnect occur on the positive pressure side of the system, then a hazardous expulsion of arsenic dust into the environment will occur. Note that such ship unloaders can have up to a 300te/h extraction capability.



Two-vessel vacuum/pressure unloading system

- The three-section vacuum arm (1) and vacuum nozzle (2) are manipulated through the material.
- Material is drawn by vacuum through the arm piping and hoses into the transfer vessels (3). Suction is created by a rotary lobe vacuum blower (4).
- The vacuum air is separated from the material by multiple high-efficiency filter cartridges (5). Material falls by gravity to the kettle bottom.
- Once the kettle is full, it is pressurized by air supplied by an oil-free screw compressor (6). The pressurizing air is introduced into the top of the kettle, as well as through multiple Fullerator™ aeration pads (7) to fluidize the material in the kettle bottom.
- Upon reaching optimal pressure, the discharge valve opens (8) and the material is conveyed into the pipeline (9). A multi-stage air bypass system (10) controls the air/material mixture for optimal efficiency.
- While one kettle is pressurizing and discharging, the other kettle is filling – assuring uninterrupted, high-capacity conveying.

Items 5 and 7 not shown. See illustration below.

Item 10 not shown. See illustration above.

Fig 1 Example of vacuum/positive pressure system applied to port operations
(image c/o www. https://www.flsmidth.com/en-gb/products/pneumatic-ship-unloaders)

2.1.2 Extraction point

Dry extraction has the potential to be undertaken from the top downwards within the chambers or from the bottom (allowing material to descend by gravity towards the extraction point). Considerations for either extraction from the tops or bottom are:

a) Floor extraction assumes that the dust is at a sufficiently low level of compaction strength than flow can develop when material extracted below is removed from the chamber. There are significant 'unknowns' with regards to the condition of the consolidated dust. The greatest risk exists in the initiation of extraction (by methods described later in this document), whereby only a small region local to the pick-up point is activated by the extraction method. Typical stoppages that can result from excessive bulk strength and/or poor chamber geometry (both of which are highly likely to exist at Giant Mine) are the formation of cohesive arches or 'rat-holing' (see Figs 2 & 3 respectively)

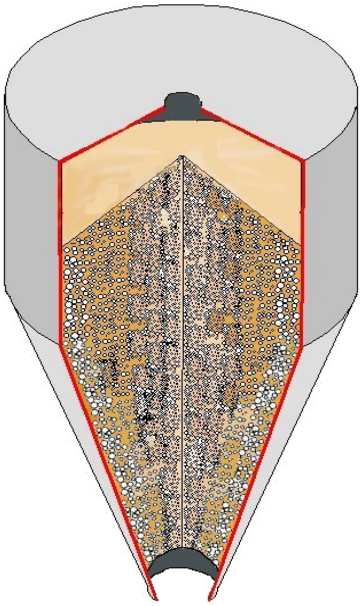


Fig 2 Cohesive arch

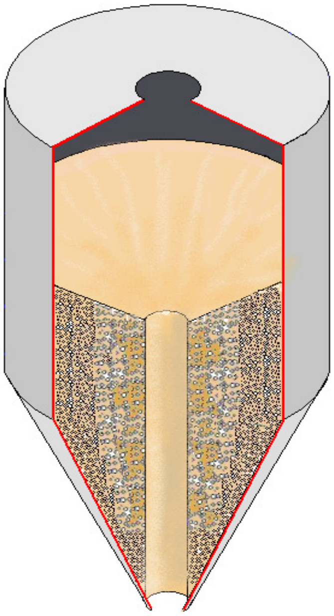


Fig 3 "Rat-hole"

The stability of such stoppages will vary according to local conditions within the bed of dust. Whilst the development of such stoppages is highly undesirable due to the significant challenges associated with re-stablishing flow within a chamber hewn from rock, one of the potentially biggest issues occurs under conditions where the stoppage is unstable. If the flow obstruction is relatively weak, collapse of the arch or rat-hole can occur unpredictably and substantial quantities of the dust will have the opportunity to entrain air and possibly change state to a fluidised condition whereby the bulk solid can flush past the extraction point and 'flood' into adjacent galleries. This risk also exists if a stoppage is intentionally collapsed.

It is accepted that generically the form of the chambers employs a rough hewn convergent section and (typically) irregularly shaped forms above the convergences. A reliance on gravity discharge to give efficient emptying of the chambers is considered to be a very high risk strategy for a number of reasons:

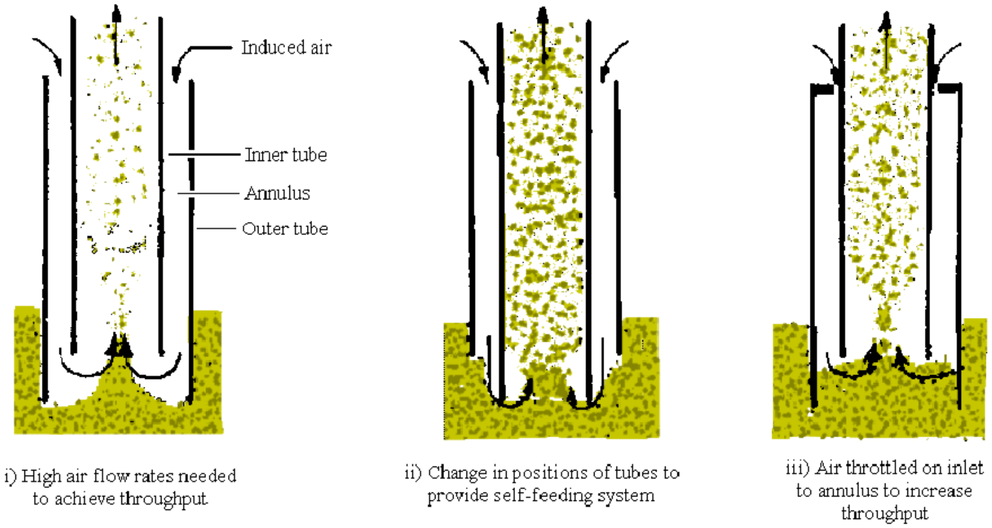
- The irregular and rough internal surfaces will not support 'drain down' as the chamber empties and large volumes of retention of material is considered to be a common theme to all chambers.
- The rate of dust entering into the vacuum extraction is likely to be very poorly controlled and over feeding due to flow stoppage collapse may occur frequently – with the knock-on effect of overwhelming the vacuum line – leading to a blockage (a distinct possibility if high moisture content material is encountered)
- Extraction from the base of the chambers will add significant distance to the conveying line (compared to extraction from the upper surface – but accepting that ultimately the extraction point will also end up in the base of the chamber) – leading to a long conveying path and correspondingly increased pressure drop requirement. The longer route will have less pressure drop for conveying with once the air only losses have been taken into account.

b) Surface extraction considers the removal of dust from the top of the chamber followed by a progressive cross-sectional removal to floor level. The fact that material is removed by cross-section overcomes many of the issues indicated previously for floor extraction. The positive aspects of surface extraction are:

- Cross-sectional extraction will give scope for removal of material keyed into the walls of the chamber – thus a more complete dust removal can be achieved in the initial phase of operations.
- Dust feed into the extraction system can be controlled at the pick up point to keep the extraction rate in line with the operating point for the pneumatic conveying line.
- Issues of cohesive arching and rat-holing do not apply (equally 'flooding' of powder is no longer possible)
- Initially, extraction pipeline length to surface will be significantly shorter than for floor extraction – giving more pressure drop availability for conveying.

On the negative side, the vacuum pick up point will need to be guided autonomously on some form of guided chassis. Care will be needed in consideration of such a chassis due to the load bearing capacity of the receding surface being an unknown (indeed such engineering challenges have been met in the past for exploration of the polar regions and, indeed, the planets – where surface conditions were considered variable or completely unknown). The exact nature of access into the ullage of the chambers is not clear – but will be an influence over the form of the chassis.

The require ability of the chassis to be navigated dictates that the vacuum line will need to be attached in some form of gimble mount such that low angle entry into the chamber can occur initially, but rotate to high angle entry as the inventory level decreases. The interface within the chassis will need to accommodate an air bleed to allow the introduction of gas for conveying with at the pick-up point. The importance of the air bleed is shown below in Fig 4.



i) High air flow rates needed to achieve throughput

ii) Change in positions of tubes to provide self-feeding system

iii) Air throttled on inlet to annulus to increase throughput

Fig 4 Examples of extraction rate manipulation using controlled air bleed (vertical pipe shown, but principal also applies to inclined pipe work)

Due to the unknown nature of the dust deposition, it is likely to be the case that some form of agitation around the intake point will be required to reduce the strength of the material into a deagglomerated form (noting that if the agitation takes the form of bristles attached to rigid arms, scope will exist to more thoroughly remove deposits from the walls of the chamber – provided proximity sensors are employed to prevent 'crashing' of the rigid lengths of the sweep arms). The principle behind the use of agitators to bring material to a fixed pick-up point exists for street cleaning equipment as well as ship unloaders.

Fig 5 An example of small-scale sweep arms being used on a ship unloader with wood pellets.

(c/o www. https://www.theglobeandmail.com/report-on-business/economy/canada-competes/the-long-journey-of-a-canadian-wood-pellet/article8445947)

It should be borne in mind that one of the main design requirements for ship unloaders is a high extraction rate. This results in the use of very large diameter pipework and correspondingly high air flow rates – usually over a very short distance (to reduce pressure drop). In the case of extraction from the chambers, the main criteria should be reliability of transfer (a blocked line having the potential to represent an emission hazard if manual intervention is required to clear it) and not absolute transfer rate. The maximum rate that can be achieved will be function of pipeline bore (bearing in mind that the flexible pipe will need to comply with the movements of the extract chassis as it navigates), solids extraction (which may be controlled by sweep arm speeds or air flow rate) and overall system pressure drop (controlled by operating point of the air mover and solids concentration within the pipeline).

Assuming that the inventory surface can be reduced whilst maintaining a generally level profile and that the pipeline length does not become excessive (the extraction rate may have to be reduced with increasing pipe length in order to control the pressure drop) it may be possible to clear down as far as the floor of a given chamber.

So far consideration has only been given to vacuum extraction, due to the flexibility offered by such system. Mechanical extraction using augers or bucket elevators has been discounted due to the (assumed) vertical access restrictions, complexity and (likely) poor extraction efficiency. Such mechanical approaches would require substantial openings through the roof of the chamber in order to allow full traverse over the cross section of the chamber. A transfer of material into a vacuum line would still be required to transport the dust in a contained way to the surface. Also, such mechanical units would still require navigation within the chamber, but the need to avoid collision with the walls would result in significant dust retention around the inside of the chamber.

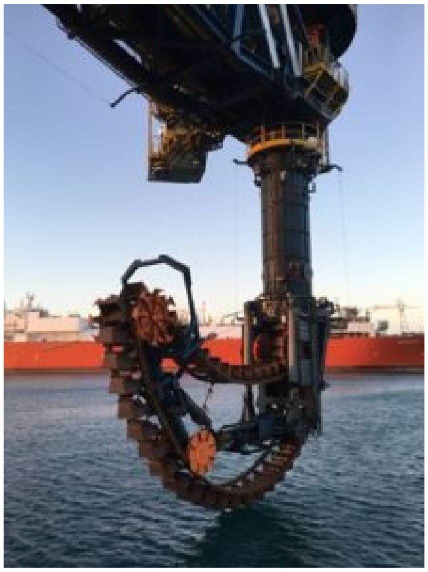


Fig 6 An example of a bucket reclaimer used in ship unloading (other styles of this equipment also exist)
(c/o http://resourceworld.com/successful-delivery-continuous-ship-unloader)

2.1.3 Surface infrastructure

The use of pneumatic transfer (assumed to be at positive pressure above ground level) of dust will lead to the need to disengage dust from the conveying dust and for the exhaust gas to be clean (at least to some specified minimum PPM for arsenic). In this respect it is likely that a three stage approach will be required. Primary disengagement can be obtained from cyclone(s) which may be in series or parallel (the latter being a useful option if height constraints apply on site). The function of the cyclone(s) will be to disengage the majority of the dust prior to the exhaust from the cyclones passing forwards into a bag house (Fig 7) within which high efficiency filters (likely arrays of pleated cartridges) will be installed. The need for good filtering efficiency and reliability, dictates that great care must be taken in the cleaning mechanism employed to remove dust from the filters and in this respect a reverse pulse system combined dedicated solenoids with eductors installed into the throats of the filters would represent best practice (but also carry a high price tag if done correctly). Although the cost for such system will be high, the alternative approach commonly employed (solenoids external to the bag house and distributed pulse lines with no eductors) is cheaper but carries the risk of poor cleaning efficiency and reduced service life. If blinding of the filters begins to occur, then manual entry into the bag house to replace failed units will be required – with obvious multiple health and safety risks. Cleaning of such filters should be controlled by monitoring pressure drop across the filter, whereby once a peak pressure drop is detected (i.e. dust loading onto/into the filter), the cleaning cycle is triggered. Cleaning on a timed basis is not recommended due to energy wastage if triggering before optimum dust loading has developed, and sub optimal cleaning of overloaded filters if the timer triggers cleaning too late. Depending upon the efficiency of the baghouse an electro-static precipitator (ESP) may or may not be required to capture any break through from the filters. ESPs are commonly used to clean up flue gasses and tend to be very large pieces of equipment – although the actual size of such units is dictated by the air flow rate that requires cleaning. It is quite possible that such a unit used with the conveying gases could be considerably more compact than that shown in Fig 8.

Fig 7 An example showing cyclones (right) feeding forward into baghouses (left)
(c/o impactairsystems.com)

Fig 8 An example of a large electrostatic precipitator in use at a power station (cleaning a large volume gas flow)

The dust extracted from the conveying air will be mechanically extracted from the cyclone/baghouse/ESP by using rotary valves or screws. Having captured the dust above surface, a contained method to convey dust into holding silos will be required. Vacuum transfer from the mechanical feeders would provide good containment and the distances to holding silos is likely to be fairly short (and hence well suited to vacuum conveying lines). The holding silos will also require careful consideration of filtering requirements (media specification, sizing and cleaning method). A major consideration for the convergences under the baghouse, ESP and holding silo will be the ability of these pieces of equipment to discharge reliably and self-drain. Again, the need for manual intervention (or even enclosed space entry) should be considered unacceptable. All convergences and outlet sizes must be based on a measurement of the likely range of flow properties of the dust and the equipment (convergences and mechanical extractors) designed on the basis of calculations using this information. It is almost certain that 'standard' equipment types will bring reliability issues that will require intervention.

Depending upon the next steps in the process (which are assumed to relate to outloading into road tankers – and thus a gravity discharge from storage vessel into the road tanker), great care must be taken when considering the method of transfer into the tanker. Specifically, a dispersed delivery must be avoided (noting that this will increase the dust loading onto the venting filter) in order to a) minimise fugitive dust, and b) reduce the overall filling time for what is likely to be an air retentive material (i.e. if the dust retains air, then the wagon will reach its volumetric capacity well before it reaches its target weight. A standard aerated discharge of material through a cascade bucket arrangement will not be suitable and is advised against.

2.2 Wet extraction

2.2.1 Liquification

The authors does not have an in depth understanding of the specific pieces of equipment that could be deployed to locally liquify and pump the material from within the chambers. However, it is clear that whatever equipment could be employed would not have the same restrictions of distance or routing that exist for a pneumatic system. In this respect extraction from the base upwards or the top downwards seem to be possible – accepting that the ability to navigate the pick up point would still be required.

The major draw back with a pumped extraction is the need for dewatering plant at the surface which would likely include centrifuges and filter presses. Recirculation of contaminated water to use as the transport medium would serve to minimise the final quantity of water for processing to quality suitable for disposal.

2.3 Hybrid extraction

If it is accepted that overall water usage should be minimised, it could be the case that dry extraction is employed to remove the maximum possible mass of dust, followed by liquified removal for the lesser amount of material inaccessible/immovable to dry extraction. In this way the target of less than 5% dust retention after emptying each chamber might be achieved.

3. LIMITATIONS ON REPORT

The general technical recommendations, are based upon experience gained in the storage and handling of bulk materials and the recommendations clearly relate to this experience.

4. BUDGET

This report was completed as per proposal P/3780/1 at a cost of £1,580 for professional fees as quoted.

Any further work to review drawings, specifications etc., if required, will be additional based upon a pro-rata basis at our normal engineer day rate of £790 ex. VAT; a closer estimate can be provided upon request.

Report prepared for:-

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