Experimental Investigation of Parameters and Performance Characteristics in Dense Phase Pneumatic Conveying of Alumina Fine Dust

Gulammohammed R Desai
Department of Mechanical Engineering,
AMC Engineering College, Bangalore.
Bangalore, India

***Abstract*— This paper reviews the necessary parameters and considerations of dense phase pneumatic systems for the conveying of bulk solids over large distances. The experiment was carried out using alumina fine dust as the convey material, alumina has non-free flowing properties. The material properties and composition of alumina fine dust are considered during the investigation. The factors affecting the system design are stressed upon. Certain changes or additions in the design are implemented to accommodate the process requirements. The effect of conveying time, velocity requirements and the amount of air supplied on the rate of conveying are monitored. Selection of an inlet valve that is suitable for operating at higher temperature conditions, capable to cut through flowing or static material and also provide an efficient sealing during the conveying process. The pipeline construction is done considering the horizontal length, vertical length and the bends in the pipeline, for achieving higher rates of material conveying. The dense phase system can be optimized to achieve efficient conveying by using a stepped diameter pipeline. Extra pipelines or air boosters can be used to attain sufficient air velocity inorder to avoid blockages in the convey line. Unblocking techniques such as fluidizing the convey material to decrease the friction and vibrating the material to loosen the cohesive powders, can be applied.**

Keywords*— *Dense Phase; Pneumatic Conveying; Alumina Fine Dust; Flowability; Unblocking Techniques; Rate Of Conveying.

I. INTRODUCTION

Dense phase pneumatic conveying systems are employed in order to transfer materials at high pressure, low velocity and lower air volume. They consume less energy to convey products over a large distance, with minimal damage to the convey material. Several bulk solids; granules, powders and irregularly shaped materials with different particle properties such as size distribution, density and surface hardness can be transferred pneumatically without degradation and segregation [2]. Dense phase conveying is apposite for transferring materials that have friable or fragile characteristics; it also reduces the chance of separation of blended materials. Some bulk solids that are fine powders have excellent air retention ability and coarse granular solids have a high degree of permeability [2]. These materials work well with lower energy requirements and smaller convey lines. There is reduced bend wear and minimal particle damage.

Dense phase pneumatic conveyors that are designed according to international industrial regulations and ASME codes are less harmful to the environment and are easy to operate as they have very few moving parts. Efficient transfer either from storage into process or from process into storage can be carried out effectively. Conveying can be carried out from a single point of collection to either single or multiple reception destinations. The pneumatic transfer must be carried out in a dense phase medium, where the pipeline is almost full of material that moves in a plug fashion. Air requirements are reduced by establishing a high phase density and operating on a fluidizing technique.

The conveying pressure for dense phase is higher than in dilute phase systems, operating at a pressure of 1-6 bar. Conveying velocities of 1-10 m/s can be achieved. Properties that involve particle or air interaction namely permeability, air-retention and de-aeration affect the flow mode for a bulk solid material [2]. The material characteristics such as cohesion of the powder (kPa), compressibility index, loosely packed bulk density (kg/m³) are also considered. Material has to be conveyed below its minimum pick up velocity. Conveying at a low velocity reduces convey line abrasion and material degradation.

II. CASE STUDY

As a part of the study, carried out on the denseveyor units at the alumina refinery, similar to those as shown in Fig.1, the alumina fine dust having an average particle size of 3.5 to 5.0 micrometers (µm) and bulk density 1.0 g/cm³, was to be conveyed from the electrostatic precipitator units (ESP) to the collection tank. The composition of alumina fine dust is detailed in Table I.

The process is a continuous conveying operation, with the conveyor working on cycles of convey and discharge. The temperature at which the material had to be transferred was about 230°C. The Dense phase units are connected to the hopper that is filled by the material coming through the electrostatic precipitators and it was required to convey this material though the denseveyor units, from the hopper to the collection tank, so that it can be fed back to the Rotary Kiln for further Calcination process.

The average distance for the material to be conveyed was 62 m. Dense-phase conveyors with vessel volume 0.11 m³ and 0.34 m³ were used for the conveying purpose. The conveying process is fully automated with the help of a centralized PLC based control panel with a (control voltage of 230V.AC) hooked to the PC.

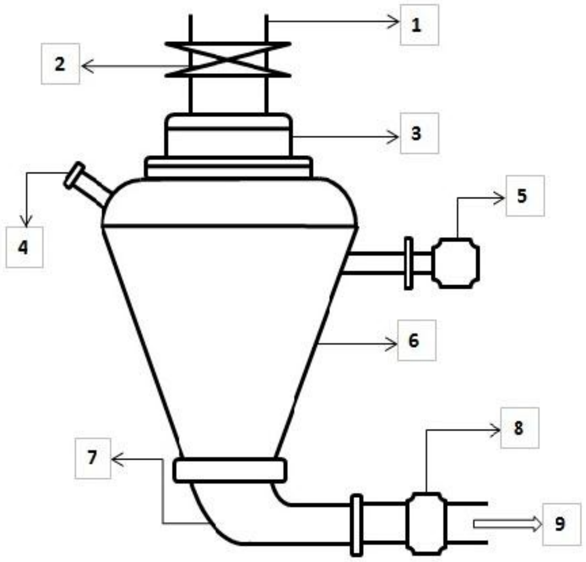

Fig.1. Pressure vessel configuration.1-charging hopper; 2-inlet valve; 3-dome valve; 4-fluidizing air; 5-compressed air; 6-vessel/tank; 7-discharge elbow; 8-outlet valve; 9-material flow.

TABLE I: COMPOSITION OF ALUMINA FINE DUST

Contents	Percentage by weight %
Al_2O_3	82.52
SiO_2	0.1
Na_2O	1.3
Fe_2O_3	0.09
CaO	0.04
SO_3	0.9
TiO_2	0.02
P_2O_5	0.03
LOI(moisture)	15

III. CONVEYING OF ALUMINA MATERIAL

The Dense-phase systems at the facility are generally operated on a batch basis. The sender unit is filled with the product to be conveyed. The vessel is pressurized with compressed air. Discharge valve is open until the product has been conveyed out (the valve is operated to open/close). The discharge valve is closed and the vessel is refilled.

In the facility where the experiments were conducted, pneumatic conveyors are employed to convey Alumina fine dust. The dust is obtained after the process of Calcination of the alumina hydrate (Al_2O_3).The properties of the materials conveyed at the facility using dense phase are given in Table II.

TABLE II: FEED MATERIAL PROPERTIES

Material properties	Feed material		
	Coarse alumina	*Fine alumina*	*Alumina fine dust*
Nature of material	Highly abrasive in nature	Highly abrasive in nature	Highly abrasive in nature
Mohs hardness	9	9	9
Flowability	Floury (normal flowing)	Floury (not free flowing)	Floury (not free flowing)
Alpha content	>85%	>85%	>85%
Specific surface area (m^2/g)	7-15	7-15	7-15
Specific gravity	3.60 min 3.98 max	3.60 min 3.98 max	3.60 min 3.98 max
Average particle size (µm)	90 to 120	1 to 5	3.5 to 5.0
Particle density (g/cm^3)	3.8	3.8	3.8
Operating temperature (°C)	50 to 60°C	50 to 60°C	220 to 250°C
Moisture content	<0.2%	<0.3%	<0.16%
Bulk density (g/cm^3)	0.8 loose 1.2 packed	0.7 loose 1.0 packed	1.0
Sphericity (Ψ)	0.9	0.9	0.9

Rotary kilns are used for the process of Calcination or the removal of free and combined moisture of the hydrate and roasting of the alumina until it attains an anhydrous state at which its adsorption power becomes limited. At the end of the kiln process, fine under calcined hydrate escapes with the kiln exhaust gases and therefore requires to be separated out.

The de-dusting process is done by the use of poly-clones and a multi-clone. The exhaust gas from the multi-clone is discharged to an electrostatic precipitator (ESP). Ionization occurs at the ESP and this phenomenon is known as CORONA discharge. The CORONA discharge charges the dust particles negatively; these charged particles migrate towards the earthed electrodes. On reaching the collecting plates these particles lose their charge and get deposited. The deposited dust layer is dislodged into the ESP hoppers by rapping at fixed intervals. The collected dust is then conveyed back to the feed end of the kiln through the collection tank by the use of dense phase pneumatic conveying systems (DPU).

The material is transported through a dense phase regime. The conveying system is multi-feed to single reception, where Alumina was conveyed from a series of dense phase conveyor units to the collection tank. The process flow is as shown in Fig.2.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 12, December-2016

Alumina from a series of bins is transported with help of air slides into a small hopper called surge hopper. It then enters the bellow of the conveyor and enters the vessel through the open valve, usually dome valves are used. The alumina dust fills the pressure vessel. After the denseveyor vessel is full, the valve is closed and the vessel is sealed at the inlet i.e. the dome valve, whereas the convey pipeline discharge is open. A supply of compressed air is metered into the vessel; this air moves forward in the direction of least resistance i.e. outwards of the convey pipeline discharge. By pressurizing the vessel, a product plug is forced through the convey lines.

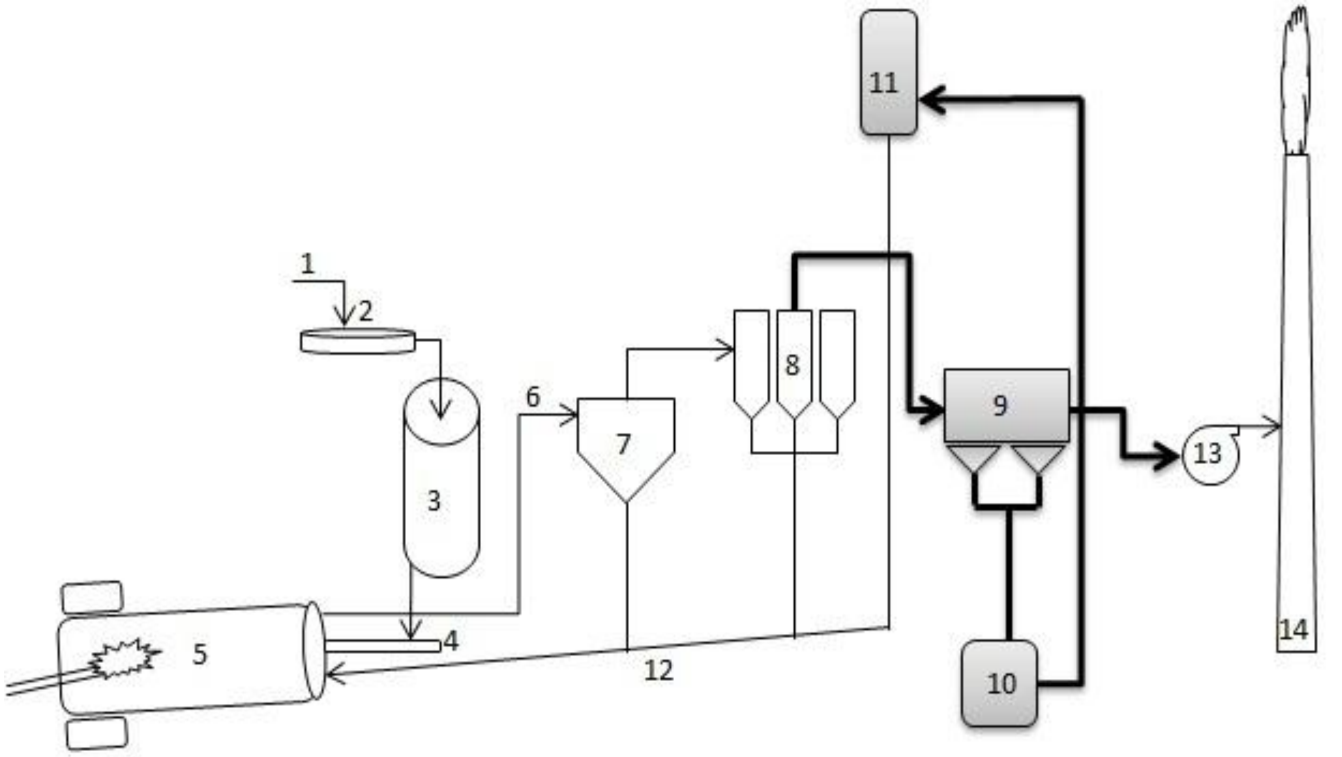

Fig.2. Schematic diagram of the process flow system 1-hydrate slurry from Hydrate storage tank; 2-pan filter; 3-combin; 4- screw feeder to Kiln inlet; 5-rotary kiln; 6-exhaust gases and under-calcined hydrate; 7-polyclone; 8-multiclone; 9-electrostatic precipitator; 10-dense flow conveyors; 11-collection tank; 12- alumina fine dust sent back to the kiln; 13-induced draft fan; 14-chimney for exhaust gases.

The compressed air distributes the endless plug into smaller plugs, the flow resistance is reduced. The alumina dust is forced out of the pressure vessel into the convey pipeline and its flow velocity also increases. As the material exits the convey pipeline and reaches the collection tank, the pressure within the system decreases. The sensors recognize the drop in the pressure and send signals that the material has been conveyed to its destination and the sequence will start over.

Systems using the company's technology are connected to full size pipelines running in the building. Conveying operation is completely automated, with a centralized PLC based control panel hooked to a computerized data acquisition system, instantaneous operating data can be obtained for the analysis of necessary performance parameters.

IV. DESIGN CONSIDERATIONS AND THE AFFECTING FACTORS

Essential factors have to be considered while selecting dense phase as the mode of conveying materials. While dense phase pneumatic systems convey materials at a high pressure and low velocity. In cases, when dealing with materials of large vertical and high bulk density, it is noted that higher than the expected pressure and energy is required. This accounts for excessive velocities during conveying, lower system consistency and inadequate transfer capacity. Further leading to blockages and unexpected material build up along the convey line, resulting in system erosion.

To overcome these setbacks during the convey process, a number of modifications and developments on dense phase pneumatic conveying have been carried out by considering certain operating and design parameters.

Testing the convey ability of a bulk solid is essential. The performance of the dense phase conveyor depends absolutely on the physical characteristics of the bulk solid material that is to be conveyed.

The flow properties or the flow index of the material whether free flowing, sluggish or non-free flowing are major factors that are vital to be measured [7]. Reference [7], the flow index for different materials is as noted in Table III.

If there is a considerable change in the bulk solids such as variation in size distribution or size segregation within the material, it possesses a significant risk for dense phase conveying. Similarly, in case of alumina, the properties of alumina undergo a change according to different grades of the same material and their operating temperatures. As alumina dust was being conveyed at the facility, the flow properties of alumina at a temperature of 230°C were noted as floury (not free flowing).The physical properties and flow characteristics of the alumina material being conveyed are as detailed in Table IV.

TABLE III: FLOWABILITY OF BULK MATERIALS

Material	Flow index
Very cohesive	<2
Cohesive	<4
Easy flowing	<10
Free flowing	>10

TABLE IV: PHYSICAL PROPERTIES OF ALUMINA FINE DUST

Material properties	
Test powder	Alumina fine dust
Particle size (µm)	3.5 to 5.0
Particle shape	Hexagonal
Surface area (m²/g)	15
Specific gravity (g/cm³)	3.95
Bulk density (g/cm³)	1.0
Knoop hardness	2000
Mohs hardness	9
Sauter mean diameter (µm)	4
Moisture content	0.16%

Risk of blockages and uncertainty in conveying is much higher in cases where, the bulk material does not possess a natural dense phase capability or if the capability is too low. The amount of air required to move the material can be calculated by taking into account the material properties. Bulk density can be used to determine the required air supply in order to convey the material [1]. Materials with bulk densities 0.4 g/cm³ to 0.88 g/cm³ are easier to transfer. Heavier materials require more power. The bulk density of alumina dust at a temperature around 230°C was found to be 1.0 g/cm³ and the air required was calculated at 3.5 m³/min FAD theoretically, the air consumed experimentally was found to be 3.6 m³/min FAD at a pressure of 7 bar, where FAD (free air delivery of the compressor) is the actual quantity of compressed air converted back to the inlet conditions of the compressor.

The degree of permeability is also a critically important factor and even small changes in the permeability can affect the system performance considerably. Alumina dust has relatively smaller size distributions. It is highly abrasive, non-hygroscopic, non-explosive and non-corrosive.

Vessel design is another significant aspect. Referring to the ASME boilers and pressure vessel codes, parameters such as the type of material to be conveyed, amount of load that has to be carried, chemical reactions of the material with the denseveyor substance and temperature thresholds, affect the vessel design. Stainless steel can be used for the construction of dense flow vessels for sanitation requirements or corrosion resistance. The dimension and sizing of both the pressure vessel and the convey pipeline is critical in order to obtain optimal conveying rates. Dimensions such as inner diameter (ID), thickness (T) and outer diameter (OD) of the pressure vessel and conveying pipelines are calculated accordingly. For the pressure vessel construction, the cone section of the vessel is fabricated using a press break. The bottom of the pressure vessel is designed to have a 60° cone section. This section can be formed by making multiple bends or breaks. The wall thickness of the cone section must be uniform all the way through the inlet to the outlet of the vessel.

Designing the pickup point or the inlet through which the product enters the conveying system is also relevant; essential for feeding material into the convey vessel, it is the most customized component in a pneumatic conveying system. The pickup point may be either a hopper, bagging point, docking point or a material unloader.

Rate of Conveying or the art of moving material through the system determines the efficiency of the convey system. Conveying rates that are achieved depend on the distance to be conveyed. Larger the conveying distance, higher the pressure required as it needs more air flow to push the material through the conveying line. The overall conveying distance is much significant to achieve optimized conveying. The limitation is imposed by the compressibility of air and the pressure drop limit in the pneumatic systems. For a given pressure drop, longer the conveying system lower the mass flow rate of the material.

Greater the distance to be covered lower is the solids loading ratio. Higher velocity is required to convey at low solid loading ratios. Also, the number of bends and straights in the structure of the convey pipeline effect the rate of conveying. The pneumatic conveying system can be configured with bends to fit around existing equipment or to minimize the convey distance. For pneumatic conveying systems, the total conveying distance is calculated by considering the materials moving vertically same as the materials conveyed horizontally and for every 90° bend in the system, 20 linear feet or 6.096 m is calculated.

Hence, if the material is to be conveyed for a distance of 50 m horizontally, 50 m vertically and there are five 90° bends in the convey line, then the total distance to be conveyed would be approximately 130 m. The conveying distance from the dense phase units to the collection tank is detailed in Table V.

TABLE V: CONVEYING DISTANCE.

Conveying distance (m)	DPU-A	DPU-B	DPU-C
Horizontal	40	43	45
Vertical	20	20	20
Total	60	63	65
Headroom	2.1	2.1	2.1

Considering all the affecting factors and the process requirements, the design can be modified, by fixing components such as supplementary air injectors or air boosters, feeders, blending and mixing equipment's, electro pneumatic controls and pressure regulators to predict pressure drop with good accuracy.

Additional valves can be designed to fit wherever necessary. Providing of adjustable leg supports allowing easy access for inspection and maintenance of vital internal components. The design should provide a controlled and efficient discharge of material. Dense phase system also requires a comparatively larger dust collector system as the pneumatic system has to separate the materials from the conveying air at the systems end [1]. Standard vessel capacity for conveying alumina material ranges from $0.11m^3$ to $0.57m^3$ at a temperature rating of $T \geq 250°C$.

V. EFFECT OF CONVEYING TIME AND AIR SUPPLY ON THE CONVEYING RATE

For a given material flow, a certain pressure gradient is necessary for moving the products through the pipeline. Pressure gradient or the pressure drop per unit length of the convey pipeline [6]. For larger distances, the pressure drop will be higher to maintain a particular pressure gradient [6]. Different flow modes exist during conveying, depending on the combination of solid flow rate, amount of air flow and pressure gradient [4]. Experiments were carried out, with each trial having different air supply requirements, amount of air pressure supplied and vessel conveying time.

The rate of conveying for each trail was obtained and the most efficient combination was noted. A dense flow vessel with a vessel capacity of $0.11m^3$ was used. The compressed air was obtained through a standard air compressor, the distance to be conveyed was 65 m and the temperature of the alumina to be transfer was about 228°C.The amount of compressed air pressure supplied to the DPU is 3.6 m^3/min FAD at 6-7bar. The vessel cut off pressure was set at 0 kg of air. The conveying time was maintained at about 30 sec. When the dense flow system was taken in operation, it was observed that excess air was supplied along with the material from the dense flow vessel into the collection tank. This caused a number of punctures in the conveying line and dusting at the collection tank.

There were frequent gasket leakages, conveying line and bend punctures, leakage at the collection tank man door and leakage at the flanges. In order to overcome the frequent leakages, trails were carried out at different air pressures, vessel cut off pressure and vessel conveying time limit. The conveying parameters were maintained as mentioned in the Table VI.

TABLE VI: CONVEYING PARAMETERS OF THE DENSE FLOW SYSTEM.

Parameters	DPU-A	DPU-B	DPU-C
Vessel volume (m^3)	0.34	0.11	0.11
Material conveyed	Alumina fine dust		
Conveying distance (m)	41	43	45
Seal pressure maintained (kg)	6.5	6.5	6.5
Vessel pressure maintained (kg)	4	4	4
Compressed air required	3.6m^3/min FAD at 6-7 bar(g)		
Instrument air pressure (0.3m^3/min)	0.3	0.3	0.3
Control voltage (V AC)	230	230	230
Dome valve open time (sec)	8	12	12
Conveying time (sec)	18-20	30	30
Idle time/Gap time (sec)	55	120	120

Trail 1:

Alumina dust had to be transferred over a distance of about 65 m using a dense flow vessel. The compressed air was supplied at a pressure of 5 bar; the conveying time was set at 30 sec, the vessel cut off pressure was set at 0 kg.

During operation of the system the convey cycles were observed and the readings were noted, the average conveying rate per cycle was found out from the readings. There was a decrease in the conveying rate at 32.09 kg/min.

Trail 2:

For the 2nd trail alumina dust was supplied, with compressed air at 7 bar, the conveying time was reduced from 30 sec to 15 sec. The vessel cut off pressure was also increased to 1.5 kg to reduce the time required for conveying.

Operating cycles were observed, and the rate of conveying was noted at 39.44 kg/min, but there occurred a lot of leakages at an air pressure of 7 bar. There was return of pressurized air from the collection tank to DPU conveying lines resulting in punctures and leakage from the collection tank man-door, causing obstruction of the maintenance jobs.

Trail 3:

At the same amount of compressed air at 7bar, the conveying time was set at 10 sec. But the vessel cut off pressure limit was increased from 0 kg to 1.5 kg to reduce the conveying time. The rate of conveying was found to be 42.20 kg/min.

The punctures were eliminated. This abetted appropriate conveying. Dust reduction from the collection tank was achieved, by reducing DFV vessel conveying pressure and reducing conveying time. DPU conveying line punctures that occurred on a daily basis were eradicated, hence process disturbances were reduced and optimized conveying was achieved. Decreasing the conveying time from 30 sec to 10 sec ensured that there would be no conveying air supply even after the vessel was emptied.

VI. VELOCITY REQUIREMENTS

Apart from the parameters such as material properties, amount of air flow, pressure gradient, total distance for the material to be conveyed, the velocity of the air supplied in the pipeline is the key parameter for dense phase conveying systems [6]. Pipeline blockage in fluidized materials occurs due to de-aeration. The granular materials that convey in plugs, pipeline blockage is due to insufficient air flow necessary to move the plug [6]. Hence, velocity is probably the most important parameter in pneumatic conveying and in particular the velocity at the feed point. If the velocity lower than the critical velocity is supplied, it results in clogged pipelines, inefficient system performance or a system that will not convey at all. Supplying velocity much higher than the required velocity may lead to unnecessary energy losses, material degradation, particle abrasion and excessive erosion along the convey line [6]. The amount of velocity that is required is to be determined before conveying.

The minimum conveying velocity that is necessary for the operation is highly dependent on the properties of the bulk material being transferred [6]. The least amount of the velocity required at the inlet depends on the saltation velocity of the bulk solid or the minimum velocity that is required to maintain the particulate flow [3]. The determination of the saltation and pick up velocities is critical for an efficient design of a dense phase pneumatic system [3]. Both pickup and saltation velocities are functions of the particle properties, such as size range and distribution of the bulk solid, particle density, sphericity and also the solid mass flow rate [3]. For alumina sphericity, $\Psi = 0.9$, particle density (ρp) = 3750 kg/m3 and particle diameter (dp) = 0.45 mm.

Hence, the minimum transport velocity that will be required is the velocity below which pipeline blockages occur. In general practice, the average minimum velocity is 300m/min for a fluidized dense phase. For each cycle of the denseveyor about 15 m^3/min quantity of air was supplied at a velocity of 0.63 m/s. The rate of conveying was about 7.6 t/hr.

VII. INLET VALVE SELECTION

The type of valve used at the inlet being a principal component of the dense vessel selection. When considering the use of butterfly valves or slide-gate valves at the inlet of a pressure vessel, several problems can be caused. Since, the material flows between the valve disc and the seat. Butterfly valves and slide gate valves are not capable of cutting through a falling or static column of material because the valve operation is not complete. It also prevents effective sealing of the pressure vessel. Also the valve discs are directly involved in the flow of material when the butterfly valve is in open position; this may cause the valve to undergo wear and also slow down the flow into the pressure vessel. Due to higher temperature at the inlet, the valve wears out at an increasing rate and the sealing becomes ineffective.

In order to check the poor sealing quality of the valves, they need frequent conditioning and maintenance and may also require replacing of the valve. Hence to overcome these issues, all the dense pneumatic vessels were fitted with a dome valve at the inlet. The dome valve is capable of operating or cutting through moving or static material. The dome valves works efficiently in pressurized lines. It consists of a dome shaped closure mounted on shafts at the ends and can be moved through 90° by the use of a pneumatic actuator. An inflatable rubber seal is mounted on the valve at the upper side, this rubber seal when inflated by compressed air provides a fastening enclosure at the inlet when the dome is in a closed position and also holds the dome valve in its place.

When the valve is to be opened, the seal is deflated and the dome then moves to open position. Effective isolation of the material and a pressure tight sealing is maintained during its operation. Also there is no metal to metal contact of any parts during the valve operation; no direct friction between any parts of the dome valve, the seal or the vessel, due to the air inflatable seat and the sealing provided against the dome surfaces. Hence, wear and abrasion of the valve can be avoided.

They valve is operated to open and close by means of a pneumatically functioning actuator. A supply of compressed air is provided to operate the actuator and also to assist the sealing action of the inflatable rubber seal. Given that, the dome valve is tightly sealed and completely enclosed with an inflatable gasket, inflated by the air supplied. The valve torque noted is very low. The inflatable seal also controls the quantity of air injection.

The Dome valve and the rubber must be installed accurately; if not heavy leakages may occur in the conveying line. If seal air pressure drops to near conveying pressure, it is required to check air supply line, air pressure and also if there are gaps between the dome and the seal. The seal also gets damaged or hardened due to temperatures higher than the normal material temperature. This causes air leaks through the dome valve during conveying and leads to improper sealing. The dome valve OPEN and CLOSE timer, needs to be under a check and must be set as per the process requirements and the vessel capacity. It should be synchronized so that it only opens for the time till which the denseveyor is filled up and no material enters the conveying line. Also the limit switch setting is to be checked.

The seals used for dome valves at the facility were neoprene and nitrile rubbers, suitable to convey alumina. Following parameters such as the line header pressure maintained at > 6 kg/cm², dome valve seal pressure set at > 6 kg/cm², vessel pressure variation during conveying maintained at 0 to max 1.5 kg/cm² were checked prior to conveying. The control air pressure must be 1bar higher than the operating pressure. The other parameters are as mentioned in Table VII.

TABLE VII: DOME VALVE OPERATING PARAMETERS

Dome valve parameters	
Maximum operating temperature (°C)	300°C
Maximum operating pressure (bar)	8 bar
Seal pressure	6 bar to 10 bar

VIII. SETBACKS DURING CONVEYING

When considering long distance conveying applications, the minimization of air flow, conveying velocity, loss of pressure and hence, power consumption are the necessary parameters required for achieving optimal conveying. As the flow of the material cannot be seen, it is hard to check out for convey errors and blockages [6]. For fine fluidized powders pipeline blockages occurred when they become de-aerated. In case of coarse granular solids, they tend to stop moving below a certain gas velocity. However, in both cases the materials will often resume to move after higher gas velocity is achieved. The fine powders with good aeration properties are conveyed as fluidized dunes. Whereas, coarse granular solids are conveyed as full bore slugs or plugs of material.

In cases where alumina with unconditioned cohesive properties had to be transferred, higher than the expected pressure was required to push the alumina material through the delivery line, resulting in excessive velocities during the transfer process. This causes blockages and unexpected material build up along the conveying pipeline, leading to system erosion.

As the dense flow vessel operates or cycles, the pressure of the air and entrainment of alumina with the air, forces the alumina dust in the denseveyor vessel to flow into the pipeline. To convey more alumina material in a plug, air pressure higher than the available pressure that is developed by the air compressor is required to convey the material. The excessive velocities caused by the high pressure air supply would result in blockages. This problem was solved with better conditioning of the alumina powder by vibrating to loosen the cohesive powders prior to conveying, fluidizing the material to reduce friction and breaking up the product flow into discrete plugs. Extra pipelines or line boosters were provided to supply pressurized air for achieving sufficient velocity to prevent blockages and assist conveying along the convey route. The addition of air through the boosters if not regulated accordingly, may result into increased material velocity much higher than that desired. The flow resistance in the conveying line was reduced by providing supplementary air injectors that were located along the convey line.

Considering, a case where the system starts to convey, then stops after a few cycles. This happens if the conveying pipe gets blocked. Firstly, the air and power supply were to be checked. The blow valve was checked for any malfunction. Air supply to the blow valve must be checked, if satisfactory repair or replace valve. If no air supply, check the blow solenoid operation. The conveying air inlet valve to the denseveyor was isolated, the air release valve of the denseveyor was opened and after the pressure dropped down to the atmospheric pressure, the line was purged. The above operation was repeated for 2-3 times. For the line blockage still persisting, the pipe was tapped to locate block point. Air and electricity were isolated allowing the air to decay. Pipe in the area of blockage was stripped, cleaned and the probe fault was investigated.

In case the dense vessel gets blocked. The air and electricity have to be isolated, pipe from the outlet of denseveyor to be removed and investigated possibly for foreign objects. The conveying line blockage may also occur due to the high level probe of the silo in operation, i.e. the Silo tank is already filled and will not occupy any more material. This requires checking of the level in the collector tank.

The other reasons can possibly be incorrect regulator setting or a faulty regulator which requires adjusting or replacing the regulator. To avoid such blockages a few modifications had to be carried out on the convey pipeline. The pipeline configuration is as shown in the Table VIII.

The convey pipeline was also blocked when there was slow conveying of the alumina material. To prevent line blockage due to slow conveying and to compensate the high pressure requirement, the plug length was reduced in the convey pipeline and the material flow was made better by modifying the vessel outlet bend. Through experiments it was found that about 20 m of a plug length would efficiently convey the material at a low velocity and with low air consumption at about 2-3 bar of pressure. The vessel outlet bend was modified and fabricated with a standard 90° bend so that the material would flow easily into the pipeline.

TABLE VIII: CONVEY PIPELINE CONFIGURATION.

Pipeline measurements	DPU-A	DPU-B	DPU-C
Diameter, NB (mm)	100	100	100
Total length , L(mm)	60	63	65
Number of bends	4	5	5
Number of straights	5	6	6

At higher velocities of flow, the chances of pipeline wear are increased, more commonly in the pipeline bends. In order to reduce the increase in velocity during the conveying, the bore of the convey pipeline can be increased in the direction of flow. Stepped diameter pipelines can be used in order to reduce the pipeline wear and achieve optimized conveying. [1,5] The terminal velocities are reduced when pipelines with stepped diameters are used. The abrasion caused due to material contact is also decreased, preventing material degradation [1,5].

Considering the flow parameters and material characteristics a more convenient stepped diameter pipe can be designed to obtain more efficient transfer of the materials over longer distances of about L ≥ 3 km. By modification of the convey pipeline, the amount of pressure loss, air consumption can be reduced, this also reduces the flow velocity avoiding pipeline or bend wear.

IX. CONCLUSIONS

Based on the studies carried out the following conclusions are drawn:

1. Trail 3 is found to be most suitable for continuous conveying of alumina fine dust. The compressed air was supplied at 7 bar and the conveying time was set at 10 sec. About 42.20 kg/min of conveying rate was achieved.

2. Bulk density and the flow ability index are the important parameters that govern dense phase conveying. Hence, it is essential to test the material and measure its

suitability to be conveyed in a dense phase medium. Bulk properties such as particle size, particle density and cohesive index are necessary to be calculated. Bulk density can be used to determine the flow modes for a particular material. Understanding the flow patterns and their variability is important for an optimal design and efficient pneumatic conveying process.

3. The overall conveying distance has a much significant effect on the rate of conveying. Longer the distance to be conveyed lower is the solid mass flow rate and lower solid loading ratio. Hence, higher air velocity is required to convey.

4. If velocity of the conveying is much higher it results in high wear rates on pipelines, high particle attrition and excessive air consumption. The required conveying velocity depends on the bulk properties such as sphericity, density and solid mass flow rate.

5. The material must be preconditioned to loosen the cohesive particles and fluidize the convey material, to reduce friction and dividing the product flow into discrete plugs.

REFERENCES

[1] Peter W.Wypych, "Pneumatic conveying of powders over long distances and at large capacities", Powder technology 104(1999) 278-286.

[2] R.Pan, "Material properties and flow modes in pneumatic conveying", Powder technology 104(1999)157-163.

[3] L.M.Gomes, A.L.Amarante Mesquita, "On the prediction of pickup and saltation velocities in pneumatic conveying", Brazilian journal of chemical engineering, vol.31, No.01, pp.35-46, 2014.

[4] Xingliang Cong, Xiaolei Guo, Xin Gong, Haifeng Lu, Weibing Dong, "Experimental research of flow patterns and pressure signals in horizontal dense phase pneumatic conveying of pulverized coal", Powder technology 208(2011) 600-609.

[5] O.C.Kennedy, "Pneumatic conveying performance characteristics of bulk solids", Thesis, pp.241-242.

[6] Powder bulk solids, "Understanding dense phase pneumatic conveying", Article, 16-06-2014, http://www.powderbulksolids.com.

[7] Abhaykumar Bodhmage, "Co-relation between physical properties and flowability indicators for fine powders", Thesis, pp.43, July 2006.