APPLICATION OF DILUTE PHASE PULL PUSH TYPE PNEUMATIC CONVEYING SYSTEM FOR CONVEYING OF POWDERED AND GRANULAR MATERIAL

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ABSTRACT
Pneumatic conveying is a material transportation process, in which bulk particulate materials are moved over horizontal and vertical distances within a piping system with the help of a compressed air stream. Pneumatic conveying is a very practical method for in-plant distribution of large amounts of dry powdered, granular, and pelletized materials. Using either positive or negative pressure of air or other gases, the material to be transported is forced through pipes and finally separated from the carrier gas and deposited at the desired destination. The main advantage of pneumatic conveying system is that material is transferred in close loop, thereby preventing the environmental effect on the material and vice versa. No standard procedure is available for the design of pneumatic conveying system. As the configuration of the system changes, variable involved also changes, and one has to change the design considerations based on the applications. So there is wide scope for experimentation and analysis in the field of pneumatic conveying system. In this paper experimental analysis of pull push type of pneumatic system using reciprocating compressor and centrifugal blower is presented.

KEYWORDS: pneumatic conveying, dilute phase, suction effect, venturi feeder.

1. INTRODUCTION
Pneumatic conveying is the transport of solid materials from one place to another using a transporting gas. The materials can be moved through the pipe with air, mainly used to transport these materials, but sometimes nitrogen is used for materials that could cause a chemical reaction with the air. Virtually, all powders and granular materials can be transported using this method. In Ref. 1 (http://www.air-tec.it/index_materialitransp_uk.html), a list of more than 380 different products, which have been successfully conveyed pneumatically, is presented. It consists of very fine powders, as well as the big crystals such as quartz rock of size 80 mm. The pneumatic conveying is widely used in the different industries such as the coal industry (transport of coal from mine to transportation vehicles and from vehicles to factories that utilize the coal), the food industries (transport wheat, rice etc.), the chemical industries (transport of plastic pellets), etc. Many experimental and analytical studies have been done to understand the flow characteristic of different particles in dilute phase pneumatic conveying system by applying different methods of analysis. The flow pattern seen in pneumatic conveying can vary widely depending on the gas velocity, the solid feed rate and the characteristics of the solid. Therefore the system requirements viz. a source of compressed air/gas, a feeding device, conveying pipeline as per the requirement of the layout, and a receiver to separate the conveyed material and carrier air/gas are very important. The performance of the system mainly depends on the system configurations. Design approach differs as the configuration changes. So there is a vast scope for the experimentation and analysis in the field of pneumatic conveying system.

Recent work on pneumatic conveying falls into the more general framework of powder technology and gas-particle flow. (Tsuji [2] discusses the multi-scale modeling of dense phase flow. Takei, Ochi, Saito, and Horii [3] and Takei, Ochi, and Saito [4] experimentally investigate the mechanism of plug flow. Hirota, Sogo, Marutani, and Suzuki [5] examine the mechanical properties of powders on the dense-phase flow in an inclined pipe. Futamura [6] discusses the design of plug conveying lines. Li and Tomita measures particle velocity and concentration in horizontal (Li & Tomita,) [7] and vertical (Li & Tomita,) [8] dilute swirling flow pneumatic conveying, and examines the characteristics of horizontal swirling flow including curved pipe (Li, 2000) [9]. (Li) [10] proposes application of wavelet multi-resolution analysis to pressure fluctuations of gas-solid two-phase flow in a horizontal pipe. As related topics, there are numerical simulations of tribo-electrification (Tanoue, Tanaka, Kitano, & Masuda,) [11] and electrostatic charge (Watano, Saito, & Suzuki,) [12], control of electrification (Watano,) [13], attrition of granules (Konami, Tanaka, & Matsumoto, 2002) [14] and snow conveying (Kobayashi, 2005) [15], Murilo D.M. Innocentini et al [16] experimentally investigated the dehulling process of cracked soybeans in 2008 and it has been shown that the efficiency of the pneumatic device to remove hulls from the cracked soybean was very high, with the recovery of meats with purity around 99%. Lot of experimental work has been carried out on the bulk transportation using pneumatic conveying system. R. Pan and P.W. Wypych presented test design procedure for low-velocity slug flow pneumatic conveying of bulk solid materials with irregular-shaped materials like muesli, maize germ [17]. Based on the particle properties and data from a simple vertical test chamber, the pressure drop and slug velocity in low-velocity slug flow can be predicted accurately by this method in large-scale systems. Experimental analysis was carried out by Jens Reppenhagen, Arwed Schetszchen, and Joachim Werther [18] to find the optimum cyclone
size with respect to the fines in pneumatic conveying systems. Two different design aspects for cyclones were considered. The first aspect was to keep the product as free of fines as possible and the second one was to minimize the cyclone loss rates. Besides the mechanisms of the true gas-solids separation, the production of fines due to particle attrition was identified to affect these two aspects. A first approach of a new design procedure was therefore provided, where an attrition model is implemented in a conventional cyclone model. P. Guiney, R. Pan, J.A. Chambers used Scale-up technology in low-velocity slug-flow pneumatic conveying [19]. The mechanisms involved at the boundaries were investigated. Based on the understood mechanisms, a small and specific test rig was designed and built. As long as a sample of the conveyed product is tested in such test rig, the boundaries for the product can be determined directly and accurately. Hence, by combining the procedure for predicting the total pipeline pressure drop and the method for locating the boundaries, a simple and reliable scale-up technology was presented for the design of low-velocity slug-flow pneumatic conveying systems. This is the present status of experimental work, which has been carried out by researchers in the recent time. The use of venturi feeding system is very popular in the field of pneumatic conveying system. Mostly venturi feeder is used where manual feeding is used. The objective of the work was to develop the venturi feeding system to create automatic suction effect, and to convey material further in the stream of air. This paper deals with the experimental work related to the identification of use of such suction effect to convey material further in the stream of air. Such type of feeding system can be then used for many industrial applications, for example automatic feeding of bulker with powdered or granular material. The five systems having different configurations were fabricated for the analysis purpose, reciprocating compressor and centrifugal blower was used as a source for air and trials were taken for the powdered as well as granular material.

2. PIPELINE FEEDING DEVICES:
Many diverse devices have been developed for feeding pipelines. Some are specifically appropriate to a single type of system, such as suction nozzles for vacuum systems. Others, such as rotary valves, screws and gate valves, can be used for both vacuum and positive pressure systems. The approximate operating pressure ranges for various pipeline-feeding devices is shown in figure 2.1. [20]

It will be seen that there is no scale on the vacuum side of figure 2.1. This is because the pressure of operation is only atmospheric and there will be essentially no pressure difference across the feeder, regardless of the type of feeder. In some situations a small resistance may be built into the system but this is generally only to help promote flow into the feeding device. Developments have been carried out on most types of feeding device, both to increase the range of materials that can be successfully handled, and to increase the operating pressure range of the device. Each type of feeding device, therefore, can generally be used with a number of different types of conveying system, and there are usually many alternative arrangements of the feeding device itself.

Figure 2.1 Approximate operating pressure ranges for various pipeline-feeding devices

2.1 Venturi feeders:
The basic problem with feeding positive pressure systems is that the air leakage arising from the adverse pressure gradient can interfere with the flow of the material into the pipeline; this situation can be improved, to a certain extent, by using venturi feeders. Venturi feeders work on the principle of reducing the pipeline cross-sectional area in the region where the material is fed from the supply hopper, as shown in figure 2.2. It will be seen that there are no moving parts with this type of feeding device, which has certain advantages with regard to wear problems. There are, however, no inherent means of flow control either, and so this has to be provided additionally.

3. VENTURI FEEDING SYSTEM FOR PULL-PUSH TYPE PNEUMATIC CONVEYING SYSTEM:
If venturi feeding is required to be used for the pull push type pneumatic conveying system, the feeding system has to perform two functions viz. to create the suction effect followed by the pushing the material through the pipeline in the stream of air. The reduction in flow area results in increasing the entraining air velocity and a corresponding decrease in pressure in this region. For the venturi throat is the section of least cross section, so the least pressure will be at the throat, if we can reduce the throat pressure below atmospheric pressure, then suction effect can be achieved. Then inlet provided at the throat will create the suction effect of the material. As the air passes towards the divergent section, air pressure will go on increasing; this pressurized air will convey the material further into the pipeline. Thus the pull push effect will be achieved with the
help of venturi feeding system. The venturi for the pull push type conveying system is designed considering general considerations as Convergent cone of venturi has a total included angle of $21^\circ \pm 1^\circ$, length of convergent cone parallel to axis = $2.7(D-d)$, Where D-diameter of inlet section, d-diameter of throat. Diameter of throat varies from $1/3$ to $3/4$ of the pipe diameter (Generally $1/2$ times diameter of pipe). Length of throat was taken equal to the diameter of inlet section. The divergent cone has a total included angle lying between $5^\circ$ to $15^\circ$. Length of inlet pipe kept as 1500mm whereas the length of outlet pipe was kept as 2000mm for all the systems.

4. EXPERIMENTAL TRAIL AND ANALYSIS USING RECIPROCATING COMPRESSOR

Single stage reciprocating compressor was used for taking trial. The systems used for the experimentation purpose using reciprocating compressor is shown in fig. 4.1.

![Fig. 4.1 Experimental Setup using Reciprocating Compressor](image)

The inlet section is connected to the compressor side through which high pressure air was supplied inside the pipe. At the convergent section there was suddenly decrease in the cross sectional area due to which the pressure get reduced and velocity increases. At the throat section which is the smallest cross section area, negative pressures was developed and mean pressure goes below the atmospheric pressure. At the divergent section increase in cross section area results in increase of pressure and decrease in velocity causes the high pressure difference in throat and outlet of device. Reciprocating compressor and rotary compressor were used for checking which of the system is more efficient. For this purpose we made an arrangement of venturi device with reciprocating compressor. Venturi inlet is connected with compressor outlet. Vacuum tube is inserted inside the material storage side. U tube manometer is used for taking reading which is fixed at inlet side and second at the throat of venturi. Start the compressor and stop it reach 8 bar pressure. Now make the compressor constant at pressure of 5 bar, 4.5 bar, up to 2 bar and readings were noted.

### Table 4.1 Experimental Readings Using Reciprocating Compressor

<table>
<thead>
<tr>
<th>Compressor Output Pressure</th>
<th>$h_1$</th>
<th>$h_2$</th>
<th>Suction Pressure at throat</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>13.9</td>
<td>13.6</td>
<td>0.984</td>
</tr>
<tr>
<td>4.5</td>
<td>13.8</td>
<td>13.5</td>
<td>0.984</td>
</tr>
<tr>
<td>4.0</td>
<td>13.8</td>
<td>13.5</td>
<td>0.984</td>
</tr>
<tr>
<td>3.5</td>
<td>13.8</td>
<td>13.5</td>
<td>0.984</td>
</tr>
<tr>
<td>3.0</td>
<td>13.7</td>
<td>13.7</td>
<td>1.0032</td>
</tr>
<tr>
<td>2.5</td>
<td>13.7</td>
<td>13.7</td>
<td>1.0032</td>
</tr>
<tr>
<td>2.0</td>
<td>13.7</td>
<td>13.7</td>
<td>1.0032</td>
</tr>
</tbody>
</table>

Calculations:

\[ P = \rho \times g \times h \]

\[ = 1 \times 9.81 \times (13.6 - 13.9)/100 \]

\[ = 0.02943 \text{ bar} \]

Pressure at throat = $(1.013 - 0.02943) = 0.9835 \text{ bar}$

Experimental result depicted that the output was not constant because reciprocating compressor was not able to give the constant pressure output with time. The suction was available at throat and it increased with increasing pressure input. High pressure ratios were obtained during the trial. But the main difficulty associated with this system was interrupted supply of air. Therefore we switched to blower which has a continuous discharge.

5. EXPERIMENTAL TRAIL AND ANALYSIS USING CENTRIFUGAL BLOWER

The main objective of the work was to develop suction at the venturi throat. The results of the trails on reciprocating compressor shown negative pressure developed at the throat. The attempt was to find out the maximum suction effect. Venturi suction effect is not used for transportation of material so far or no such results were available so went for trial and error method. Therefore we fabricated five systems with different throat to diameter ratio. The experimental results of the trails on blower are shown in the table below.

### Table 5.1 Experimental Readings Using Centrifugal Blower

<table>
<thead>
<tr>
<th>System No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio (inlet-to-throat)</td>
<td>2.70</td>
<td>2.0</td>
<td>1.65</td>
<td>1.5</td>
<td>1.3</td>
</tr>
<tr>
<td>Inlet dia ‘D’ (mm)</td>
<td>126</td>
<td>82</td>
<td>69</td>
<td>82</td>
<td>82</td>
</tr>
<tr>
<td>Throat dia ‘d’ (mm)</td>
<td>47</td>
<td>41</td>
<td>42</td>
<td>55</td>
<td>63</td>
</tr>
<tr>
<td>Outlet dia (mm)</td>
<td>100</td>
<td>82</td>
<td>69</td>
<td>82</td>
<td>82</td>
</tr>
<tr>
<td>Convergent angle</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Divergent angle</td>
<td>10</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
<td>7.5</td>
</tr>
<tr>
<td>Convergent length</td>
<td>165</td>
<td>80</td>
<td>100</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>Inlet pressure(bar)</td>
<td>1.0492</td>
<td>1.046</td>
<td>1.0423</td>
<td>1.046</td>
<td>1.046</td>
</tr>
<tr>
<td>Throat pr.(bar)</td>
<td>1.0067</td>
<td>0.9987</td>
<td>0.9928</td>
<td>0.9910</td>
<td>0.9915</td>
</tr>
<tr>
<td>Jawar (kg/hr)</td>
<td>150</td>
<td>140</td>
<td>164</td>
<td>260</td>
<td>240</td>
</tr>
<tr>
<td>Flour (kg/hr)</td>
<td>82</td>
<td>70</td>
<td>90</td>
<td>105</td>
<td>100</td>
</tr>
<tr>
<td>Wheat (kg/hr)</td>
<td>140</td>
<td>130</td>
<td>164</td>
<td>240</td>
<td>225</td>
</tr>
</tbody>
</table>
5.1 Graphical representation of throat pressure v/s ratio of inlet diameter to throat diameter:

![Graphical representation of throat pressure v/s ratio of inlet diameter to throat diameter](image)

5.1.1 Graphical representation of throat pressure v/s ratio of inlet diameter to throat diameter

Experimental results shown that the suction at throat section increases with decreasing inlet to throat diameter ratios up to the critical point of 1.5 ratios. Suction effect decreases as the D/d (Inlet diameter/Throat diameter) ratio increases beyond 1.5. Therefore maximum suction effect is possible at 1.5 D/d ratio.

5.2 Graphical representation of discharge of wheat v/s ratio of inlet diameter to throat diameter:

![Graphical representation of discharge of wheat v/s ratio of inlet diameter to throat diameter](image)

5.2.1 Graphical representation of discharge of wheat v/s ratio of inlet diameter to throat diameter

Wheat discharge was maximum at D/d ratio 1.5. Material discharge decreases if D/d ratio drops below 1.5 as well as if D/d ratio increases above 1.5. So the best possible result from the suction effect and material flow point of view is at 1.5 D/d ratio.

6. CONCLUSION

The main objective of the work was to use venturi-feeding system for the pull push type pneumatic conveying system, thereby developing the suction effect at the venturi throat. This will help to create the automatic suction of the material into the system through the inlet provided at the throat. This system then can be operated by the single person and has numerous practical applications for the automatic transportation of powdered and granular material. Reciprocating compressor was used for the initial trials. The suction effect was developed but it was not possible maintain air supply at constant pressure. Therefore the centrifugal blower was tried so as to maintain the air supply. The experimental results for blower shown that the maximum suction effect as well as material flow rate is possible at 1.5 D/d ratio. But the material flow rate not satisfactory and suction effect is also required to be increased. So efforts are required to increase suction effect thereby increasing quantity of air and by changing the dimensions of the system.

REFERENCES


