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The Storage of PVC Powders

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Summary

The authors describe the properties of PVC powders which are relevant to their storage, consider some of the bulk storage options available and describe the approach which is being adopted by BP Chemicals at its factory in Barry, South Wales.

1. Introduction

The consumption of poly (vinyl) chloride (PVC) in Western Europe is approximately 3.5 million tonnes. Manufacturers of the basic PVC powder handle most of their product by pneumatic conveying and bulk storage in silos. It is common for a PVC manufacturer to have storage capacity in excess of 5,000 tonnes. The processor who converts the PVC powder into final products such as pipe, profiles, film, cable covering and shoe soles and uppers, often receives, conveys and stores his raw material in bulk. Thus most PVC powders are conveyed in at least two pneumatic systems and stored in at least two bulk silos before being finally processed into an artifact.

2. The Nature of PVC Powders

2.1 Types

When considering the bulk handling properties of PVC powders it is convenient to classify these powders according to their method of manufacture and intended applications (Table 1).

In view of their similar easy bulk handling properties, suspension and mass types may conveniently be considered together.

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Table 1: Classification of PVC powders

Usual description	Manufacturing process	Application	Bulk handling properties
Suspension PVC	Suspension	General purpose material used in a wide variety of flexible and rigid products	Free flowing powder. Easy to bulk handle
Mass PVC	Mass	Generally used only in the manufacture of rigid products	Similar to suspension PVC
Paste forming PVC	Emulsion or micro-suspension	Confined to products manufactured from PVC Paste (a mixture of PVC powder, plasticiser and other additives). Examples include coated fabrics and products made by dipping processes.	Fine cohesive powder having very poor flow. Generally difficult to pneumatically convey and discharge from silos

2.2 Particle Size and Shape

Typical particle size distributions for suspension and paste PVC are shown in Fig. 1. Mass PVC generally has a similar distribution to suspension PVC, though sometimes has a tail of fines which is too small to significantly affect its bulk handling properties.

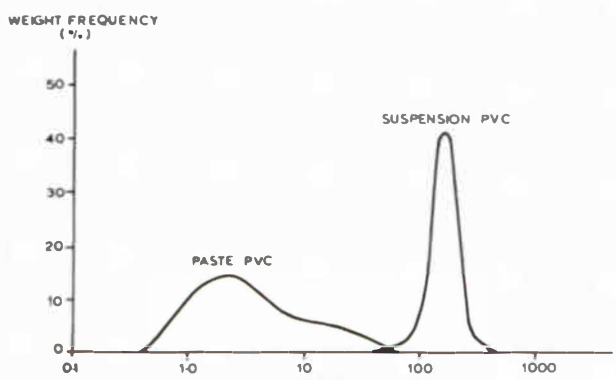


Fig. 1: Typical particle size distributions of suspension and paste PVC

Compared to suspension PVC, paste PVC is seen to have a significantly smaller mean size (typically 5 µm compared to 140 µm) and a broader size distribution.

Suspension and mass PVC particles are rough but essentially spherical. Paste PVC is usually ground and, therefore, is of irregular particle shape.

It is well known that easy flow is favoured by large particle size, narrow size distribution and spherical particle shape. The poor flow properties of paste PVC are, therefore, readily accounted for.

Several European PVC manufacturers have introduced paste PVC of larger particle size and more regular particle shape to give improved bulk handling properties.

2.3 Shear Cell Analysis and Jenike Silo Design

The differences in the flow properties of suspension, mass and paste PVC particles are readily quantified by measurements in a shear cell such as the Jenike cell [1] or rational annular or ring cell [2]. The powder under test is consolidated in the shear cell by the application of a normal consolidation load.

A range of lower normal stresses is then applied to the consolidated powder and the shear stress which causes the material to fail at each normal stress is then measured. A graphical plot of normal stress vs shear stress is termed the yield locus and is unique to the particular consolidating load used. The operation is repeated using a number of different consolidating loads to give a family of yield loci, one locus for each consolidating load. Typical families of yield loci for dry samples of suspension and paste PVC are shown in Fig. 2.

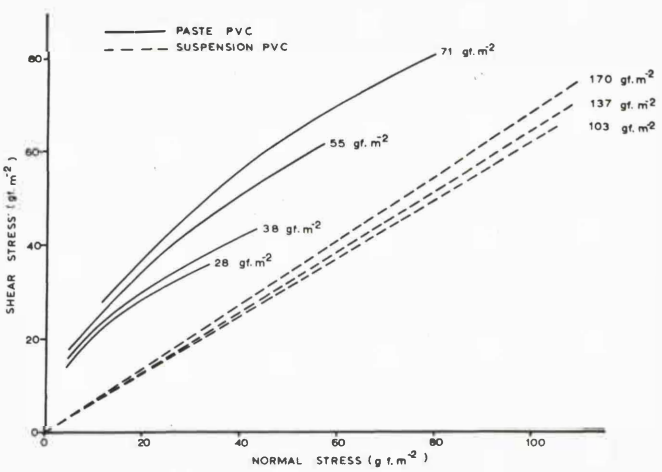


Fig. 2: Typical families of yield loci for paste and suspension PVC

The intercept of these yield loci with the shear stress axis is a measure of cohesion. Paste PVC is seen to have high cohesion and suspension PVC zero cohesion. These yield loci data can be used to calculate the minimum silo orifice diameter necessary to avoid blockage and the method is described by Jenike [1]. The orifice requirements for suspension and paste PVC are as follows:

Paste PVC: For a mass flow silo, the minimum orifice required to avoid blockage due to arch formation is about 4 m. For a core flow silo, the orifice is required to be considerably larger.

Suspension PVC: The material has zero cohesion and in theory arching and rat-hole formation are impossible. All that is required therefore is that the orifice should be at least ten times the diameter of the largest particle.

These results imply that typical paste PVC cannot be discharged from a gravity flow silo without the use of some discharge aid such as fluidisation since an orifice of 4 m is impracticable. The results with suspension PVC imply that this material can be discharged from an orifice of around 2.5 mm. However, some grades of suspension PVC do have modest cohesion and all can be cohesive due to moisture. The recommended minimum silo orifice to allow for this is 250 mm. Most commercial grades of suspension and mass PVC will discharge through an orifice of this size without fear of arching or rat-hole formation.

A shear cell may also be used to measure the angle of external friction between the powder and the silo wall. A sample of the silo wall surface is inserted in the shear cell and the powder in contact with the wall material is subjected to a number of normal stress values. The shear stress which enables the powder to flow over the surface at each normal stress value is measured. The slope of the graph of normal stress vs shear stress is the angle of external friction ϕ_w. Jenike describes in detail the measurement of ϕ_w and describes the determination of the required hopper slope for mass flow from ϕ_w [1]. A less precise but simpler and often used relationship between ϕ_w and hopper slope for mass flow is given by the following equation

$$\theta = 45° + 1.2\,\phi_w$$

where θ is the hopper angle to the horizontal.

Application of this simple equation to a typical suspension PVC powder in contact with aluminium, stainless steel and mild steel is given in Table 2.

Table 2: Mass flow hopper angles for suspension PVC

Wall material	Angle of wall friction	Hopper angle to the horizontal for mass flow
Aluminium	8°	55°
Stainless Steel	12°	60°
Mild Steel	15°	63°

These values have been determined using dry suspension PVC and polished metal. In practice, allowance would be made for the polymer possibly containing moisture and the wall losing its polish. These considerations would add at least another 10° to the hopper angle.

A hopper angle less than that required for mass flow will give funnel flow. Generally, gravity funnel flow hopper angles are at least 45° which ensures that the hopper is self-emptying.

2.4 Aerodynamic Properties

The aerodynamic properties of suspension, mass and paste PVC follow a predictable pattern. The suspension and mass types which are free flowing respond readily to fluidisation. Paste PVC, on the other hand, is difficult to fluidise and tends to form air channels rather than becoming fully fluidised. The design of a paste PVC silo discharge system based upon fluidisation is difficult.

2.5 Electrostatic Properties

In common with most organic polymers, PVC has a high resistivity and easily aquires electrostatic charge which is not readily dissipated on storage. Work by the authors has shown that the acquisition of high charge levels has only a modest influence on flow properties. For example, increasing the overall charge on mass PVC from -1.4×10^{-7} to -1.6×10^{-4} C.kg^{-1} resulted in a reduction in the flow rate by 15%.

Of much more significance is the electrostatic agglomeration which occurs when mass and suspension PVC powders are blended. When these two free flowing powders are blended they agglomerate to form a cohesive poor flowing powder mix which can cause blockages in pneumatic conveying lines and silos. Work by BP has shown that this agglomeration is associated with opposing electrostatic polarities. The implication of this effect is that these two types must not be used in the same bulk handling system, without a thorough clean down before changing from one type to the other.

2.6 Fire and Explosion Properties

Pure PVC powders can support and propagate flame, but only with extreme difficulty. Bartknecht [3] has shown that PVC can generate a significant rate of pressure rise in a dust explosion (up to 168 bar m s^{-1}). However, the minimum ignition energy of pure PVC powder is extremely high and probably of the order of 100 J. Such a high energy would not normally be encountered within a plant handling this material. It is generally accepted, therefore, that plant handling pure PVC requires no explosion prevention or protection measures. For example, in Britain, H.M. Factory Inspectorate require no such measures to be taken and the authors are aware of no industrial dust explosion associated with pure PVC. It should be noted, however, that the addition of flammable additives to PVC such as phthalate plasticiser can change this situation.

3. Some Options Available for Storing PVC Powders

3.1 Suspension and Mass PVC

It is quite clear from the foregoing discussion that suspension and mass PVC powders present few problems in bulk handling. Both types are easily conveyed by lean, medium or dense phase pneumatic conveying systems. Both suspension and mass PVC powders can be stored in gravity flow mass and funnel flow silos and discharge presents no problems providing the orifice is of adequate size (normally at least 250 mm). This type of storage is, in fact, the most commonly used. Other designs of silo can be used and, as will be seen in the next section of this paper, an essentially flat-bottomed silo with air fluidisation discharge aid is suitable.

3.2 Paste PVC

Paste PVC, by contrast, presents considerable problems and the available options are limited. The consumption of paste PVC is considerably less than that for the other types. Most manufacturers have been able to avoid the problem, therefore, by avoiding bulk handling and supplying the product in 25 kg bags. None of the British PVC manufacturers supply paste PVC in bulk. At least one major user in Britain, however, has introduced bulk handling based upon de-bagging followed by pneumatic and silo storage. Some manufacturers in mainland Europe do supply paste PVC in bulk.

Most grades of paste PVC are not suited to dense phase pneumatic conveying and lean and medium phase systems easily become blocked if special precautions are not taken. One approach to this problem is to employ an intermittent system in which conveying, say for 45 seconds, is followed, by an air blast, say for 15 seconds, to clear any blockages. This intermittent system is being employed successfully.

Another approach to this problem has been developed by Waeschle GmbH of West Germany. In their 'Pneumo split' system detectors are located at regular intervals in the conveying pipe line and when the onset of a blockage is detected, additional air is supplied to the region of the blockage by means of a secondary air line.

Probably the most common approach to the silo storage of paste PVC is to employ an aerated hopper to give air assisted discharge. It is usually necessary to maintain the fluidisation continually otherwise the material will consolidate and discharge will be impossible. One particular design of fluidised hopper which has been successful with paste PVC has a segmented cone with a progressively increasing cone angle towards the orifice.

Leversen and Dahl [4] describe a design for a mass flow silo for paste PVC which is used successfully in Sweden. The silo is fitted with a bin activator of diameter equal to the orifice diameter required by the Jenike design method for mass flow.

4. Recent Approaches Adopted by BP Chemicals

4.1 Background

The manufacture of suspension and paste PVC at the BP Chemicals factory at Barry in South Wales has been conducted over the last 30 years. Current production capacities now amount to about 20,000 t/a for paste PVC and 130,000 t/a for suspension PVC. In common with the other British manufacturer, paste PVC is supplied to the customer only in bags. BP Chemicals does, however, carry out limited internal bulk handling of this material which is based upon lean phase conveying feeding vibrated bagging hoppers.

Suspension PVC has been bulk handled by BP Chemicals over many years and this has included a combination of lean and dense phase and air slide conveying and silos up to about 50 tonnes capacity, some of which had virtually flat bases and required air assisted discharge. Within the last four years it has been necessary to construct a new suspension PVC bulk storage facility as part of an expansion of suspension PVC production.

This new bulk handling system for suspension PVC was built in two phases. Firstly, four aluminium silos and a weighbridge were installed. Conveying systems to transfer the product from each of the existing three flash dryers were included. A further conveying system capable of a high throughput permitted material to be transferred from the aluminium silos to a highly automated packaging line.

The second phase of the development consisted of two more aluminium silos and another weighbridge and four large concrete silos. Another flash dryer was built at this time and the network of conveying systems extended to permit a considerable degree of flexibility. The large concrete silos were intended to provide a substantial stock of good quality PVC of the main grades produced. This would minimise interaction between despatch to customers and production. A general view of the silo installation is shown in Fig. 3.

Fig. 3: View of silo installation

4.2 Design Details

4.2.1 Small silos

The six smaller silos are constructed in aluminium which combined moderate capital cost with very low maintenance. They were sized to take 150 tonnes of the lowest bulk density grade produced. To avoid site welding of aluminium, the diameter was kept below 4.5 m to permit delivery by road. This resulted in a somewhat tall, thin shape, the dimensions being 4.4 m diameter by 20 m straight side. The bases have 60 ° cone angles and 300 mm outlets. They are mounted on steelwork to allow gravity discharge into road tankers. The steelwork is designed to take up to 250 tonnes to cater for high bulk density grades. Four of these silos are arranged over an 18 m long electronic load cell weighbridge. Another two silos are located over a second weighbridge.

Each silo is equipped with a falling weight type level indicator, a reverse jet filter and a pressure and vacuum relief valve. The design of the foundations had to take into account the high wind loadings on these silos and the steelwork is held down by ground anchors which are bonded into the underlying rock.

The silos can be discharged directly into road rankers or via an air slide to a conveying system which feeds a high speed bagging line. It has been found that the selection of valves for the discharge of silos into tankers is important. The four original silos were fitted with 300 mm butterfly valves, whilst the later silos had 250 mm square blade valves, with inflatable seals. The butterfly disc in the former valves restricts the flow to 20 to 40 t/h. Silos equipped with the blade valves will discharge at instantaneous rates of 70—100 t/h.

4.2.2 Large silos

A different approach was adopted for these silos. A nominal capacity of 4 x 1,000 tonnes was required. It was obviously not practicable to design silos of this size for gravity discharge, nor to construct them off site. The design was in two parts:

i) The foundations and base incorporating the discharge arrangement.

ii) The walls and top.

The method of discharge chosen was based upon a system already successfully used in the cement industry. The bases are 12.3 m in diameter and consist of a shallow cone constructed in concrete resting on piles. Recessed into the cone are a number of radial fluidising pads like the bottom half of an air slide. The angle of slope is 7°. The general arrangement is shown in Fig. 4.

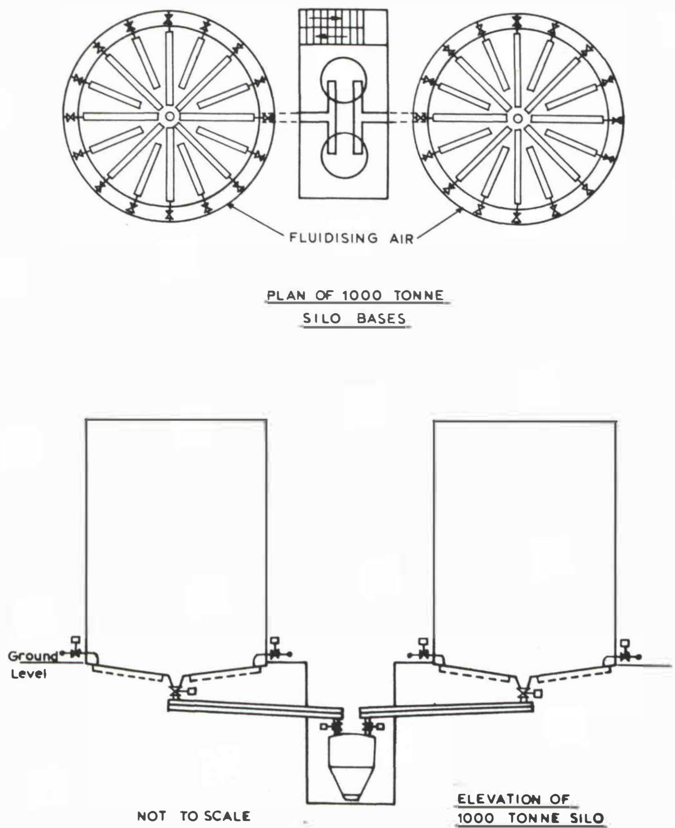


Fig. 4: Silo discharge system

Air is supplied to the underside of these pads, when the silo is discharging, with two diametrically opposed pads being fluidised simultaneously. A timing system causes the fluidising air to be switched from one pair of pads to the next every few seconds. The powder flows down a central outlet via a 250 mm square blade valve to an air slide in a tunnel. This, in turn, feeds the powder to the conveying equipment located in a 6 m deep pit alongside the silo. One conveying system is shared between two large silos. This arrangement permits all but about 40 tonnes of product to be removed. Since these silos are normally dedicated to one grade, this presents no particular problem. It was decided that to contour the spaces between the fluidising strips with concrete would have been too costly and could not be justified.

The walls of the silos could have been epoxy lined mild steel, aluminium or concrete. A comparison of the costs showed that slip form concrete was competitive in terms of capital cost. The foundations and bases took many weeks to construct but the walls were continuously poured with the shuttering being raised as the concrete set. It took only 36 hours for each 19 m high wall to be erected. A flat concrete roof completes each silo. They are fitted with reverse jet filters, relief devices and each has three falling weight level indicators, to enable an assessment of the contents to be made. The interiors are lined with epoxy paint to bind any loose sand and prevent contamination of the product.

4.2.3 Conveying system

The present arrangement consists of four dryers, six aluminium silos, four concrete silos, a small "off spec" silo and a high speed bagging line. A number of conveying systems are installed to transfer PVC between these locations. Because of the distances involved (up to 300 m) and the high throughputs (up to 40 t/h) the only practicable mode of conveying was dense phase pneumatic. The chosen systems are powder pumps operating at 3.5 bar. Details of the powder pump systems are shown in Figs. 5 and 6.

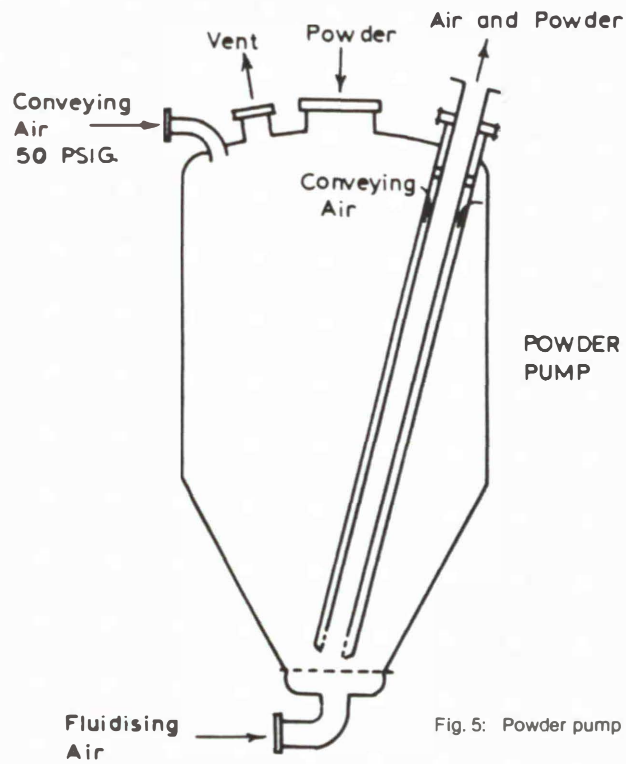
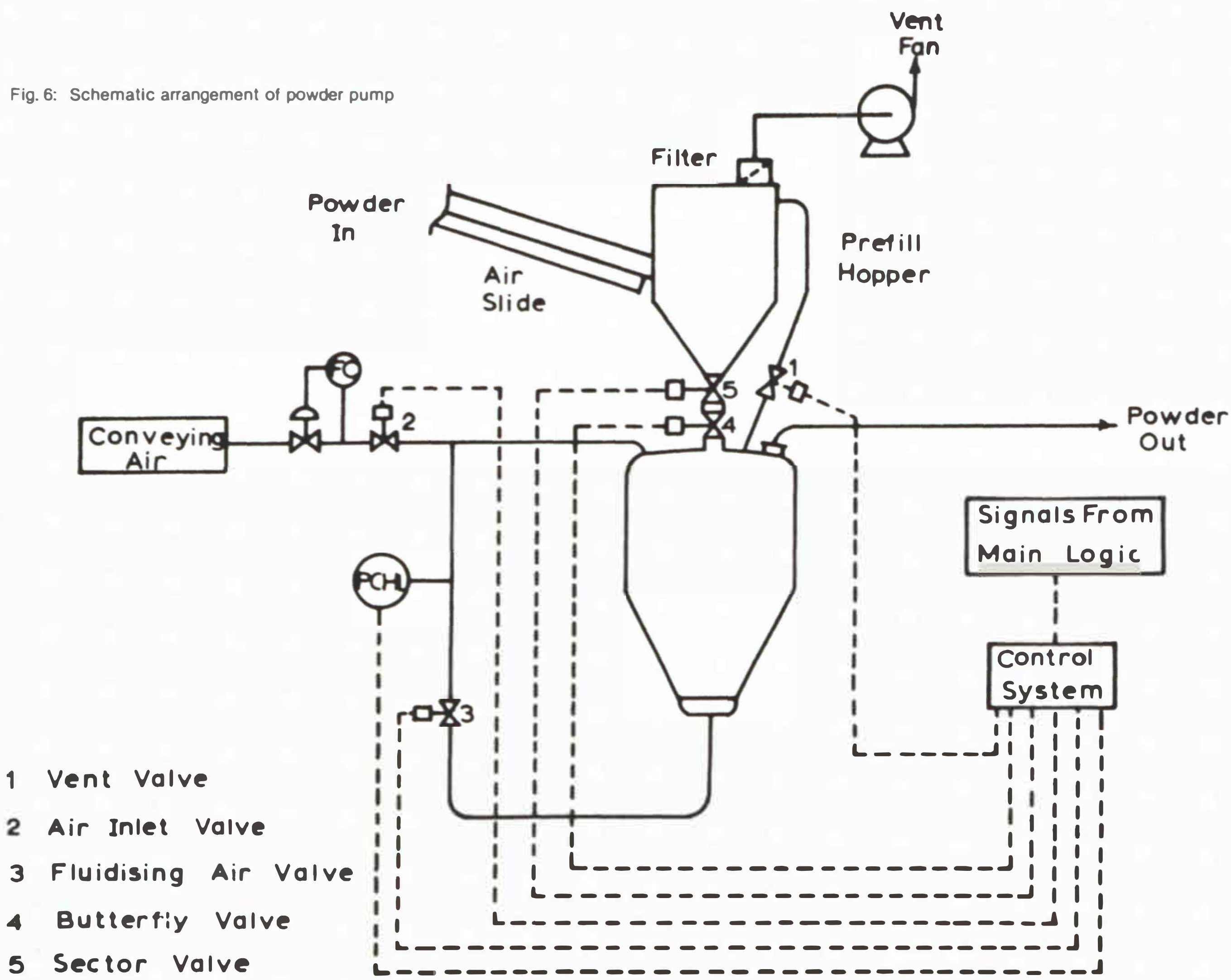


Fig. 5: Powder pump

Fig. 6: Schematic arrangement of powder pump



The vessels vary in size (2 m^3 or 4 m^3) and are either single or double, depending on throughput. The double powder pumps are arranged so that one discharges down the line whilst the other fills. This increases the capacity of the conveying line and also evens out the demand on the compressed air system.

The conveying air is compressed centrally by 5 single stage 'V' compressors having a capacity of 1700 nm^3/h at 4 bar. Air is stored in two 60 m^3 receivers. The conveying systems use between 300 and 1800 nm^3/h of air depending upon throughput and distance. Compressors are started, stopped, loaded and unloaded automatically. A main of up to 200 mm diameter distributes the air to the powder pumps.

4.2.4 Control

Two microprocessors are used in the control of this system. One is utilised to maintain the supply of conveying air by monitoring the pressure in the receivers and the air flow out. This unit also ensures that the compressors are operated within design limits and are not subjected to too many starts per hour. The other microprocessor is used in the control of the conveying routes. When a particular route is required, it can be selected by pressing a single button on a control panel matrix in the weighbridge room. The microprocessor sets all the diverter valves along that route to the appropriate position and checks that they have moved correctly. The high level probe in the destination silo is routed to the control system of the relevant powder pump, to avoid the possibility of overfilling the silo.

5. A Brief Look to the Future

Since the techniques for storing and conveying mass and suspension PVC are now so well established, it is likely that future developments will be involved for paste PVC. This material can be conveyed over several hundred metres with medium phase equipment, but very high velocities are required to prevent build-ups on the walls of the pipe. Techniques have been devised to overcome this problem as described in Section 3.2. The added complexity of these systems increases the capital cost but may well be offset by energy savings.

The storage of these grades in normal conical base or fluidised silos is not possible. However, techniques such as those described under 3.2 could be utilised. Another device which may be used is the Hogan discharger by Alval Engineering Limited. This consists of a number of louvres in a square or rectangular frame. The whole device vibrates horizontally and the angle of the louvres can be varied to control the rate of discharge. The largest unit currently available is 1.2 m x 1.2 m. For really large silos, a planetary screw discharger might be utilised. As the name suggests, this consists of a screw parallel to the base and situated in the base of the silo which conveys the material towards a central outlet. The length of screw is equal to the radius of the silo and it rotates about the centre of the silo thus covering the whole base in one revolution.

There appear to be no technical difficulties which cannot be overcome in the bulk storage and conveying of paste PVC. However, the market for this product is such that few users can justify the cost of installing bulk handling facilities at present.

References

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