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PERFORMANCE CHARACTERISTICS OF VERTICAL PNEUMATIC CONVEYOR WITH A FLUIDIZED BED AS MIXING ZONE

Summary. The conveying system consists of a 450 mm diameter and 2300 mm high cylindrical reservoir, air chamber for fluidization located in the lower part of the reservoir vertical 50 mm diameter transport pipe 9 m in height and a system for separating particles from the air stream. Transport ability of the vertical pneumatic conveyor was investigated with stone dust of 23 μm mean size.

Transport characteristics were investigated by changing the height of material in the reservoir, by changing the distance between the nozzle and the beginning of the transport pipe, and by changing the air flow through the porous bottom and through the nozzle.

In the range in which the mentioned parameters were changed the transport capacity changed from 0,05 kg/s to 0,7 kg/s and the concentration changed from 3 to 30.

1. Introduction

Systems of vertical pneumatic transport in which the mass-flow rate of solids is detemined by a feeding devise (rotary feeder, screw feeder, etc.) are used in various industrial branches. Recently, because they are cheaper to manufacture and run, systems of vertical pneumatic transport which don't have a separate feeding device but in which the solids flow rate depends on air flow and other constructive parameters, are investigated.

Even though there is a lot of research and results in the field of vertical pneumatic transport [1, 2, 3], especially on the pressure drop relations, the results are in adequate in defining the parameters for the design of such devices on an industrial basis. The avaliable experimental data and relations for vertical pneumatic conveyor with a fluidized bed as mixing zone were used with caution since they were obtained on small experimental apparatuses (transport pipe diameter D = 10 mm, maximum bed height of 20 cm, maximum pipe length of 2,4 m), using differently designed systems (without the nozzle) and different materials.

In order to obtain design parameters for a vertical pneumatic conveyor of 10 t/h capacity, 15 m pipe length using stone dust (particle mean size

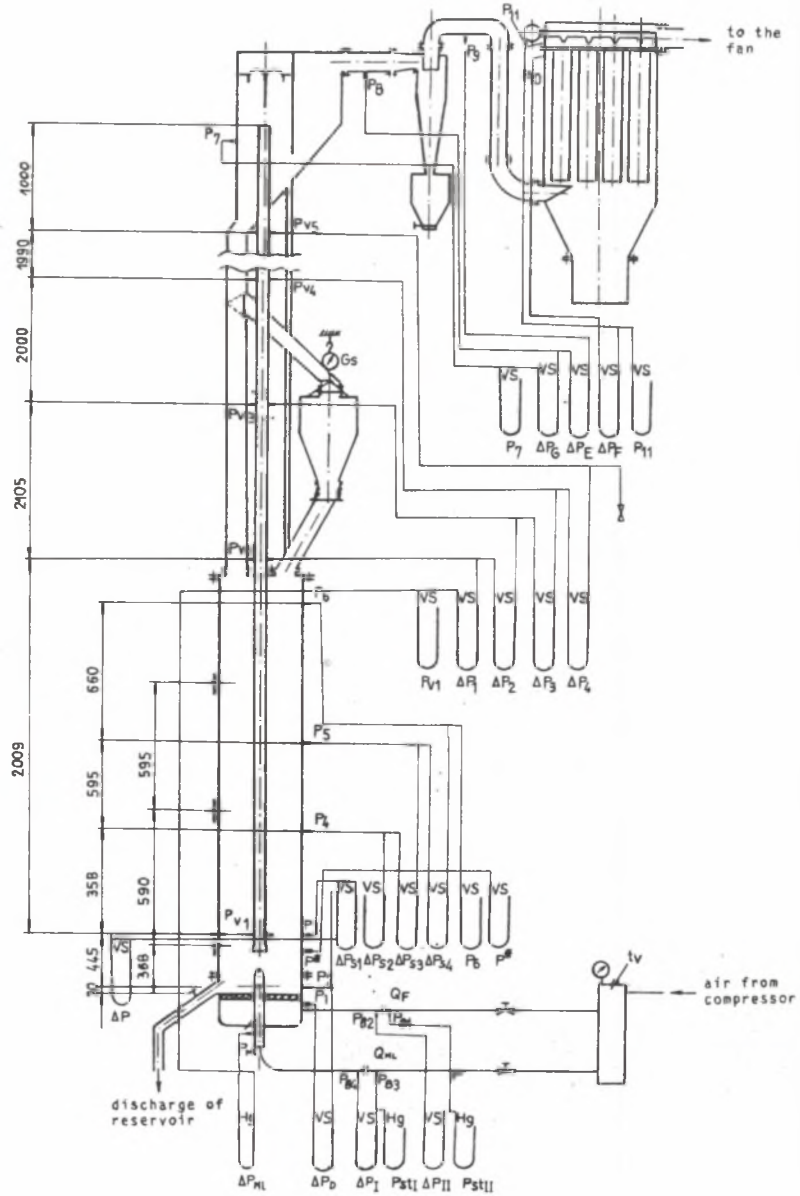

Figure 1. Schematic diagram of experimental apparatus

23 µm, p_s = 2620 kg/m^3, p_ε = 460 kg/m^3), an experimental model as shown in figure 1 was built and tested.

2. Experimental instalation

2.1. Description

Cilindrical reservoir of volume 0,4 m^3, figure 1, has an air chamberin the lower part for fluidizing material through porous distributor and a nozzle through which air is introduced for material conveying.Through the upper part of the reservoir protrudes the vertical transport pipe (D = = 50 mm, H = 9 m) and the distance between the nozzle and the beginning of the pipe can be regulated. Air is introduced to the reservoir by two pipelines. One is used for fluidizing the material while the other introduces air through the nozzle (ϕ 13 mm). The transport pipe is hydraulically smooth, which was determined by previous experiments with air only, and its beginning is aerodynamically designed.

After leaving the pipe the material is being separated from air and returned directly, or through a device for measuring mass flow of solids, to the main reservoir which enables continuous work of the apparatus. Air is further cleaned by a cyclone and a fabric filter. A fan was placed after the filter so that at the end of the pipe atmospheric pressure could be maintained.

2.2. Measured parameters

The following parameters were measured:

- air flow throug every pipeline separately,
- air pressures in the reservoir on six various heights,
- air pressures in the transport pipe in five places,
- air pressures in front of and after the nozzle,
- air pressures in material - separating and air cleaning devices,
- solids flow through transport pipe (capacity).

For air flow measurements, venturi nozzles or capacitance flow meters were used. Pressures were measured by U-tubes or by pressure transducers.

3. Experiment

The aim of the experiment was to establish relationship between solids flow of a certain material and height of material in the reservoir H_{bed}, distance between the nozzle and the beginning of the pipe x, air velocity in the transport pipe v_g, and velocity with which material was fluidized in the reservoir v_{f1}.

The measurements were done in a following way. First a certain bed height of material was selected as well as the distance between the nozzle and the beginning of pipe. When starting the apparatus, the fan was started first and then a small air flow is let through the nozzle to prevent in-flow of material when being fluidised. Then air for fluidizing the material was introduced to a selected value of v_{f1}. Next the air flow through the nozzle was increased until the solid flow war observed through the visible portions of the transport pipe and the return pipe. By further increasing the nozzle (transport) air flow a range of transport air velocities could be obtained. The steady state of transport, because of the continuous work of the apparatus, could be obtained practically immediately. At each steady state all the parameters were noted. Solid flow was measured by diverting the back flow of material in the return pipe to a small reservoir whose weight was measured.

The next steady state was obtained by emptying the material from the small reservoir into the main one and selecting the next transport air velocity.

4. Experimental results

4.1. Parameter range and overall system characteristics

Measurements were done with three bed heights 620 mm, 1200 mm and 1800 mm (corresponding active bed heights from the beginning of pipe to the surface of the bed are 387 mm, 958 mm and 1558 mm). The nozzle was designed so that for nozzle pressure drop from 0,04 - 0,55 bar the mean air velocities could be obtained from 4-20 m/s. Fluidization air velocity was from 0-12 cm/s. The distance between the nozzle and the pipe was 9÷140 mm

Taking not into account previous measurements with air only and material fluidizing measurements, 85 complete measurements were done in order to obtain the characteristics of the vertical pneumatic conveyor.

Some basic overall characteristics of the system can be observed from the results in fig. 2 in which the relationship between solid flow G_s and mean transport air velocity $\bar{v}_g$ is shown. One can see that G_s in the beginning increases significantly with the increase in $\bar{v}_g$ then G_s stagnates or even decreases, so that the optimum $\bar{v}_g$ is around 14 m/s. It is also seen that G_s increases as bed height increases, but the influence of the distance between nozzle and pipe beginning is small. The minimum value for $\bar{v}_g$ for the onset of solids flow is around 4 m/s and is independent of other parameters. The maximum value of G_s obtained in this apparatus was 2,5 t/h with air velocity about 12 m/s, fluidization velocity 6 cm/s, nozzle pressure drop 0,3 bar and bed height of 1800 mm.

From an economical point of view, optimal work of the system is obtained with maximum concentration (phase density) which occured with air

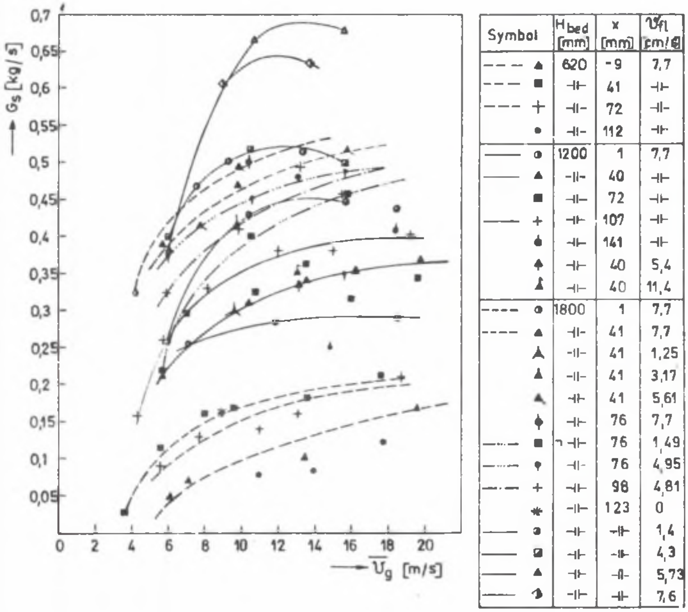

Figure 2. Mass-flow of material versus the air velocity in pipe

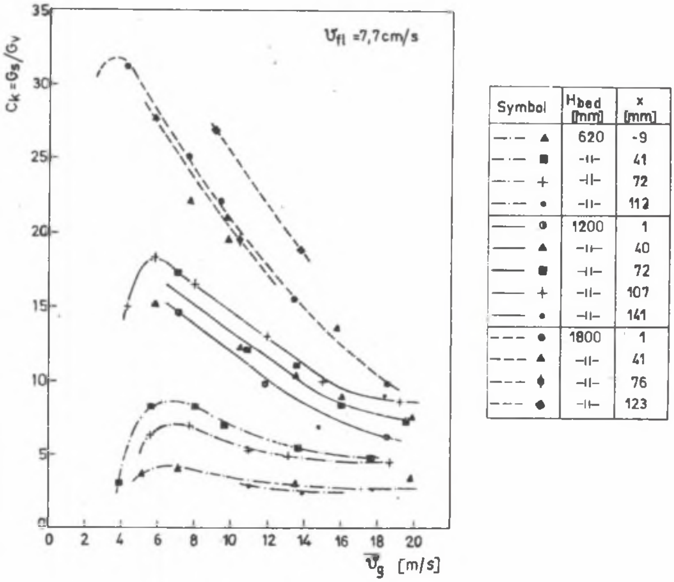

Figure 3. Concentration versus the air velocity in pipe

velocities 5-7 m/s depending on H_{bed}, as seen fig. 3. For a more reliable work of the system and greater transport capacities air velocities should be greater (~ 10 m/s).

4.2. Influence of bed height

Increase in bed height directly influences the increase in transport capacity (if other parameters are constant) as seen in fig. 4. Also given are the mean values of pressure drops through corresponding bed heights. In fig. 5 one can see the change in transport capacity with bed height for constant air velocity, $\bar{v}_g = 10$ m/s. Increase in capacity, G_s, is nearly linear.

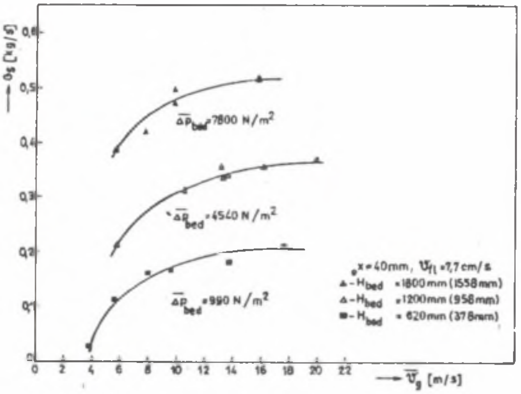

Figure 4. Relationship between mass-flow of material and gas velocity in pipe with height of bed as a parameter

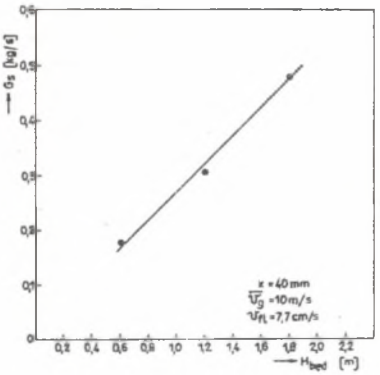

Figure 5. Mass-flow of material versus height of bed

4.3. Influence of nozzle-pipe distance

The extent of experimental work with only one material, which belongs to a group of materials which are difficult to handle, was not adequate to give reliable data on the influence of nozzle-pipe distance on the behaviour of this conveyor. In fig. 6 one can see that the maximum transport concentrations were obtained for the value of x about 5 cm when H_{bed} was 620 mm. For larger bed heights concentration is not greatly influenced as x increases to 8 cm and the starts to increase.

In the range of our measurements the most favourable nozzle-pipe distance, x, was around 6 cm. Greater distances, even if resulting greater capacities, have led to problems when starting the apparatus because the material be-

between the nozzle and pipe unabled the air from the nozzle to reach the transport pipe, but instead formed channels in the material and left the bed beside the pipe.

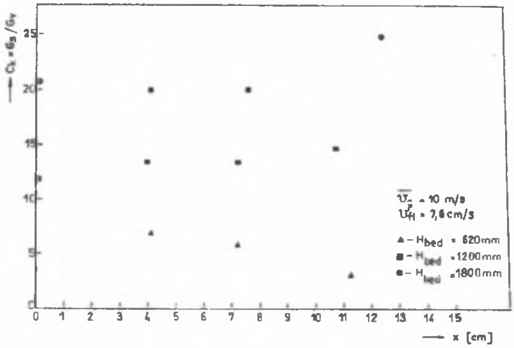

Figure 6. Concentration versus the distance between the nozzle and the beginning of the transport pipe

4.4. Influence of transport air velocity

Results presented in fig. 7 show that the transport capacity increases with the increase in air velocity, going, through a maximum for $\bar{v}_g \approx 12$ m/s and then decreases. This relationship is in an agreement with previous theoretical and experimental relations [4, 5]. But not all results show clearly this behaviour. Reason for this is partly because of the design of the conveyor with nozzle which is not the case in paper [4]. Still, one can conclude that the majority of measurements show increase in G_s with the increase in $\bar{v}_g$ up to a certain air velocity $\bar{v}_g$ = 10-12 m/s and that further changes were smaller whether G_s increases further or decreases which was mostly noticed for higher bed heights where the influence of the nozzle is smaller.

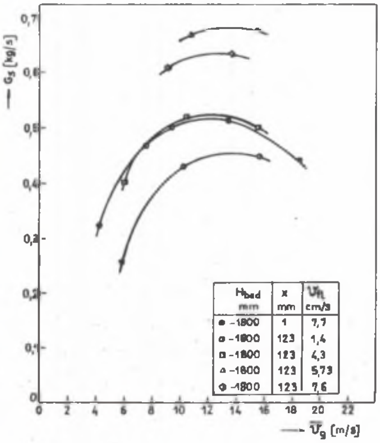

Figure 7. Mass-flow of material versus air velocity in pipe with air velocity through bed as parameter

4.5. Influence of the fluidizing air velocity

In already discussed fig. 7 one can see a considerable influence of fluidizing air velocity, v_{f1}. It is clearly seen that, for other parameters constant, transport capacity G_s increases with v_{f1}. This is even better seen in fig. 8. For low fluidizing air velocities G_s increases rapidly with the increase in v_{f1} up to about 4 cm/s after which the increase of G_s is slower and for $v_{f1} > 6$ cm/s it starts to decrease.

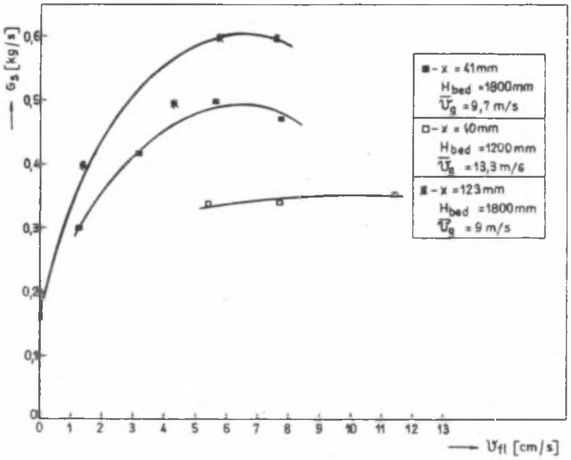

Figure 8. Mass-flow of material versus fluidizing velocity

Taking into account the specific material used in our experiments which could not be fluidized by air in a classical way and which at the same time had great ability to hold air, one has to judge very carefully the influence of fluidizing air velocity. Increase in v_{f1} leads to higher pressure drops through the bed but also to intensified air-solids mixing in the entrainment area of the nozzle.

4.6. Pressure drop in the transport pipe

The range of investigations with only one material is not enough to allow detailed analysis of the pressure drop in the vertical transport pipe but gives enough data for this particular case.

In fig. 9 the results of pressure drop per unit length of transport pipe are shown as a function of mean air velocity for approximately the same transport capacity ($G_s \approx 0,316 \div 0,387$ kg/s). For each of these values three values of pressure drops are calculated according to relations found in literature, rel 1. [1], rel. 2 [6], rel. 3 [2], and curves are drawn through them. For this particular case design can be made, on the basis of obtained results, using relation 1 (curve in the middle in fig. 9) which gives somewhat higher values of pressure drop then measured but is simpler to use.

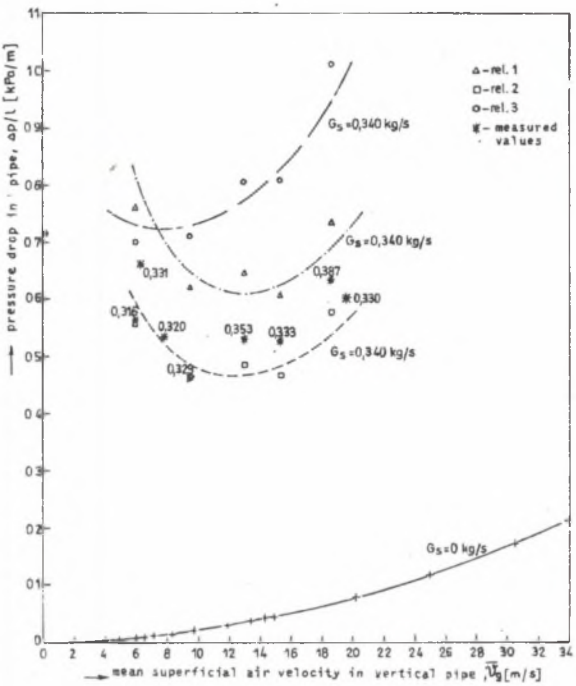

Figure 9. Pressure drop versus air velocity in the pipe

5. Conclusion

Transport characteristics of the investigated pneumatic conveyor depend on many parameters. Some parameters can be varied in a big range and still have little influence on the behaviour of the desired transport capacity. But reliable and economical running of the conveyor as well as technical requirements and manufacturing abilities significantly narrow down the possible range of parameters. For a particular system and a given material the optimal working condition of the system can be determined only experimentally.

Experimental investigations have given enough data for an analysis which can lead to choice of basic dimensions and parameters of the system on an industrial scale: working pressure, nozzle dimensions, bed height in main reservoir, transport pipe diameter, distance between nozzle and pipe as well as necessary air quantities (velocities) for fluidization and transport.

Prototype of the system built on the basis of these experiments has shown better transport characteristics than expected (15% greater capacity than required).

6. LITERATURA

[1] P.C. Richards, W. Wierma: Pressure drop in vertical pneumatic conveying" Proc. of Pneumotrasnport 2, Paper A1, BHRA Fluid Engineering, Cranfield (September 1978).

[2] L.S. Leung, R.J. Wiles: "Design of vertical pneumatic conveying systems" Proc. of Pneumotransport 3, Paper C4, BHRA Fluid Engineering, Cranfield (April 1976).

[3] W.C. Yang: "A correlation for solid friction factor in vertical pneumatic conveying lines" Powder/Bulk Solids Conference Proceedings, May 1977, Rosemont, Illinois, USA.

[4] F. Decamps, G. Dumont and W. Goodssens: "Vertical Pneumatic Conveyer with fluidized bed as mixing zone". Powder Technology, 5, pp. 299-306 (1972).

[5] L.S. Leung and B.F. Towler: "Design of vertical pneumatic conveyor with fluidized bed as mixing zone", Powder Technology, 8, pp. 27-32 (1973).

[6] I. Vušković: "Conveying by pipes". University of Belgrade, Department of Mechanical Engineering, (1965).

CHARAKTERYSTYKA PRACY PIONOWEGO TRANSPORTU PNEUMATYCZNEGO Z WYKORZYSTANIEM SFLUIDYZOWANEJ WARSTWY

Streszczenie

Układ transportowy składa się: z cylindrycznego zbiornika o średnicy 450 mm i wysokości 2300 mm, komory powietrznej umieszczonej w dolnej części zbiornika oddzielonej dnem rozdzielczym, w którym umieszczono pionową rurę o średnicy 50 mm, rurę transportową o długości 9 m oraz z układu oddzielającego cząstki ze strumienia powietrza. Wydajność układu transportowego badano stosując pył kamienny o średnicy średniej 23 μm.

Charakterystyki transportowe uzyskano: zmniejszając wysokość warstwy materiału w zbiorniku, zmieniając odległość pomiędzy dyszą i początkiem rury transportowej oraz zmieniając natężenie przepływu powietrza przez dno rozdzielcze i dyszę. W zakresie zmienności opisanych wyżej parametrów wydajność transportu zmieniała się w zakresie od 0,05 ÷ 0,7 kg/s a stężenie od 3÷30.

ХАРАКТЕРИСТИКА РАБОТЫ ВЕРТИКАЛЬНОГО ПНЕВМОТРАНСПОРТА С ИСПОЛЬЗОВАНИЕМ ФЛУИДИЗОВАННОГО СЛОЯ

Резюме

Транспортная система состоит из: цилиндрического резервуара диамекром 460 мм и высотой 2300 мм, воздушной камеры, находящейся в нижней части резервуара, отделённой разделительным дном, в котором помещено вертикальную трубу диаметром 50 мм, транспортную трубу длинной 9 м а также систему от-

деляющую частицы из струи воздуха. КПД транспортной системы исследовано, применяя каменную пыль с диаметром зерна 23 μм. Транспортные характеристики получены путём изменения высоты слоя материала в резервуаре, растояния между соплом и началом транспортной трубы а также меняя расход потока воздуха через разделительное дно и сопло. В диапазоне высше описанных изменений параметров, кпд транспорта менялся в диапазоне от 0,05 - 0,07 кг/с а концентрация от 3 - 30.