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DESIGN OF VERTICAL PNEUMATIC CONVEYOR WITH A FLUIDIZED BED AS MIXING ZONE

Summary. Design of pneumatic conveying systems are generally based on "rules of thumb" and on actual experience with similar systems. There are recently certain cevelopments of quantitative design procedures but with varying results.

On the basis of experimental results and presented analysis, a design procedure is given for vertical pneumatic conveyor with fluidized bed as mixing zone with particular attention on the height of material in the reservoir, transport capacity and pressure drop.

1. Introduction

System of vertical pneumatic conveyor with fluidized bed as mixing zone is considered among the simplest systems of pneumatic transport since it has no moving parts and works with relatively low pressures. Apart from that, this system is convenient because of its continuous work, high reliability and it also can be used for other purposes as mixing various bulk materials or powders. These advantages can more than compensate the disadvantages of this system which are: somewhat lower efficiency and a need for air cleaning devices which is the case in all systems with low concentrations (phase densities). Capacity (solid flow rate) of these types of conveyors mainly depend on air flow and fluidized bed heights.

Vertical pneumatic conveyor having capacity of 10 t/h, transporting stone dust ($\bar{d}$ = 23 μm, ρ_s = 2620 kg/m^3, ρ_ε = 460 kg/m^3) with a wertical distance of 16 m was designed. Design and construction was based on analysis of such conveyors and on experimental investigations. Apart from desired capacity and transport height, maximum working pressure was limited to be less than 0,3 bar.

Two basic concepts were analysed. In the first system (figure 1a) solid is fed to the riser via a bell-shaped chamber connected to the riser and in the second (figure 1b) solid is fed by a nozzle. Using results and relations given by F. Decamps et al.[1] and L.S. Leung [2] all the parameters of such a conveyor were calculated. Experimental verification was done on a model with a nozzle and its influence of the transport characteristics was investigated.

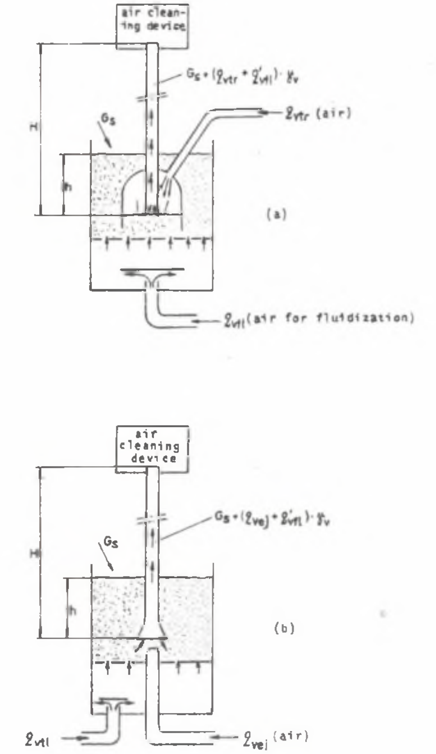

Figure 1: Vertical pneumatic conveyor
a) system I, b) system II

2. Design of the system

In order to design this kind of a system, one has to take into account the following:

a) If the pressures above the fluidized bed and at the end of the transport pipe are the same, the pressure drop in the pipe is $L \cdot \gamma_\varepsilon$, in systems with bell-shaped chamber where L is the height of the bed above the beginning of pipe and γ_ε is the mean specific weight of the bed. If the system has a nozzle the pressure drop can be somewhat larger.

b) Total air flow through the pipe, q_v, is the sum of the air flow for pneumatic transport and part of air flow used for fluidization which is entrained in the bell-shaped chamber or by the nozzle.

c) It is logical to expect that the anticipated flow of the mixture in the pipe can be obtained since it can be regulated by air flow parameters, and if confident correlations for pressure drop exist, relationships between pressure drop and air velocity can be calculated for required capacity and various pipe diameters.

d) Using same correlations it is possible to calculate relations air flow-solid flow for various heights of bed (or pressure drops) and various pipe diameters,

By analysing these relations, optimal combination of parameters can be chosen to give required performance.

Calculations are made for two cases of transport: for the model, G_s = = 4 t/h, H = 8 m and for the prototype G_s = 10 t/h, H = 16 m for various pipe diameters and bed heights. Bed density was assumed to be ρ_ε = = 1000 kg/m^3. In order to calculate pressure drops many correlations were analysed and three were chosen since they gave relatively similar results. Values that are obtained with these correlations for the pressure drop for the model and prototype are shown in figure 2a and 2b for constant solid flow, transport height H and air velocity $\bar{v}_g$, and various pipe diameters. For complete calculations, correlation by Leung [3] was used.

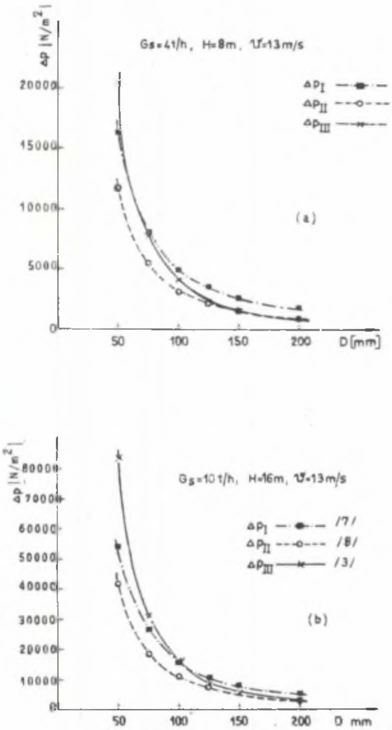

Figure 2. Relationship between pressure drop of flow of mixture
a) model, b) prototype

Using the method described above under a), b), c) and d) and the chosen correlation for pressure drop, relationships shown in figures 3, 4, 5 and 6 were obtained.

Figures 3 and 4 show that there exist an infinite number of combinations of bed height, pipe diameter and air flow which will yield required capacity. Minimal transport air velocity (based on whole crossection of pipe) are also marked. That velocity is determined as $v_{gmin} = 1,5\ v_{gc}$ where v_{gc} denotes critical minimal air velocity at which the character of flow is changed (initiation of plug flow or blockade). In figure 3 that velocity is related to pipe diameter 50 mm and capacity 4 t/h and in figure 4 to pipe diameter 100 mm and capacity 10 t/h but in both cases terminal velocity of 0,3 m/s was used. Criterions and correlations used for the calculations were those given by Yang [4, 5] and Yousfi and Gau [6]. Also determined are the corresponding critical values for voidage and concentration (for ϕ 50 and $G_s = 4$ t/h, $\varepsilon_c = 0,954$ and $C_{kc} = 79,58$, and for ϕ 100 and $G_s = 10$ t/h, $\varepsilon_c = 0,9728$ and $C_{kc} = 47,35$). For other pipe diameters other values for ε_c and C_{kc} would be obtained. From figures 3 and 4 it can be seen that the air transport velocity in both the model and prototype should be around 11-13 m/s. Satisfactory capacities would be obtained, according to these calculations for both the model and prototype with similar pressure drops (for the model $\geq 0,2$ bar and prototype $\geq 0,15$ bar). From these figures it is also evi-

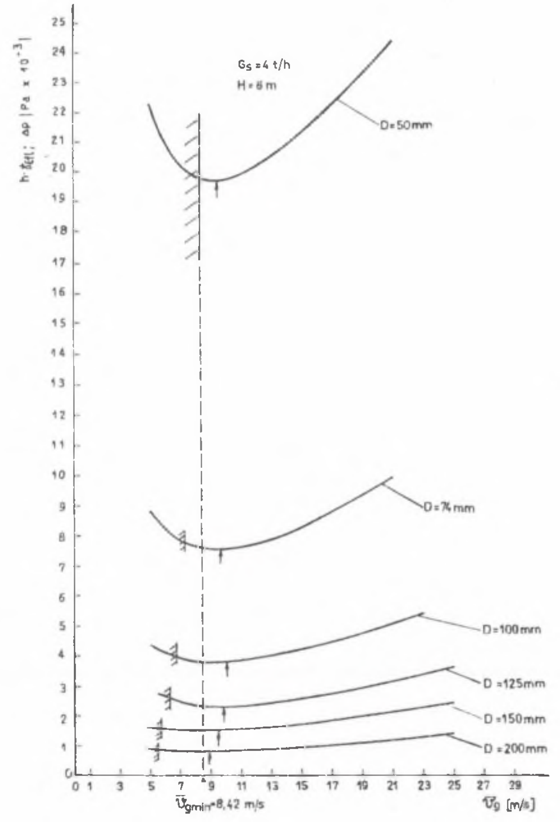

Figure 3. Relationship between pressure drop of mixture flow and air velocity in pipe (model) (relation III [3])

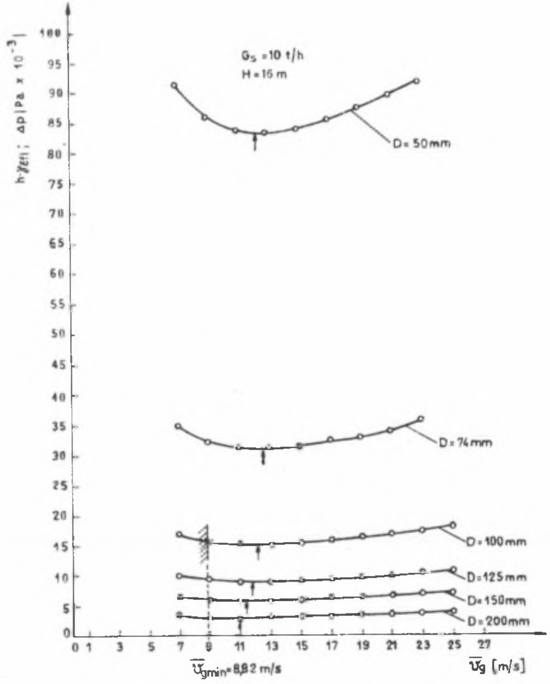

Figure 4. Relationship between pressure drop of mixture flow and air velocity in pipe prototype) (relation III [3])

dent that in order to keep the required capacities while increasing velocity, one must increase bed (or transport pipe) pressure drop.

If the bed pressure drop is kept constant, which hapens in real conditions, increase in air velocity would lead to decrease in capacity as shown by figures 5 and 6. Fluidized bed height, that is the bed pressure drop, is a parameter in these figures. It can be seen that capacity G_s has a maximum value for a certain air velocity $\bar{v}_g$ and bed height h. Working conditions of the conveyor should be chosen according to these diagrams so that air velocity, for reliability reasons, should be about 10% greater than that which gives maximum capacity.

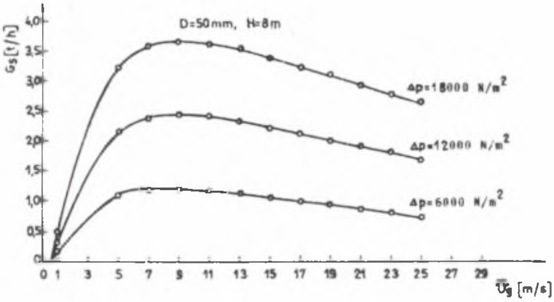

Figure 5. Solid flow (capacity) versus air velocity in pipe (model)

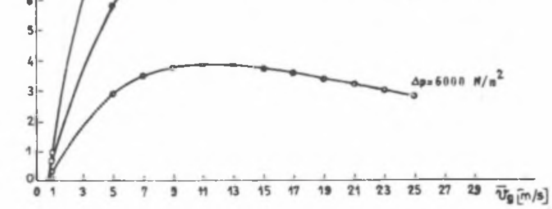

Figure 6. Solid flow (capacity) versus air velocity in pipe (prototype)

Curves in figures 5 and 6 represent the performance characteristics of the conveyor and their experimental determination or verification is the principal aim of experimental investigation. Influence of the nozzle should be taken into consideration during calculations which was not done in this case.

3. Experiment

3.1. Experimental apparatus

Experimental investigations were done in a apparatus (model) shown in figure 7. Vertical transport pipe, 50 mm in diameter and 9 m in height, was bell-shaped at the beginning for easier entrance of material. Reservoir in which the material was fluidized enabled bed heights up to 2 m.

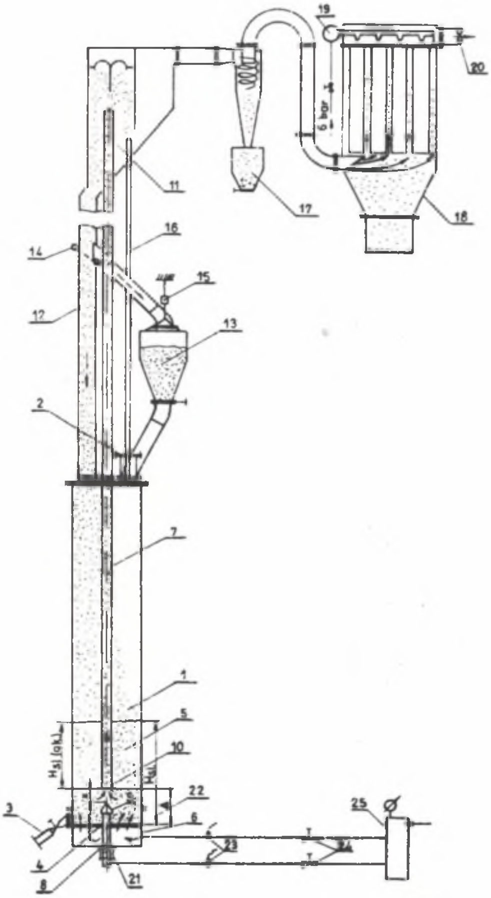

Figure 7. Experimental model of vertical pneumatic conveyor

1 - main rezervoir, 2 - opening for filling of material, 3 - pipe for emtying bed material, 4 - porous didistributor, 5 - bed material, 6 - air for fluidization, 7 - transport pipe, 8 - transporting air, 9 - nozzle, 10 - beginning of pipe, 11 - separater, 12 - return pipe, 13 - solid - flow measuring rezervoir, 14 - solid back-flow switch, 15 - weighing device, 16 - venting pipe, 17 - cyclone, 18 - fabric filter, 19 - rezervoir of compressed air for bag cleaning, 20 - fan, 21 - axial adjustment of nozzle, 22 - air chamber for fluidization, 23 - air flow measurements, 24 - regulation valves, 25 - air chamber, x - nozzle-pipe distance, H_{bed} - bed material height

The reservoir and the air cleaning devices were connected by the transport pipe, return pipe and venting pipe which ensured that the pressures above the fluidized bed and at the end of the transport pipe are equal. Fan was mounted after the air cleaning devices in order to keep this pressure at a required level (atmospheric).

While designing the apparatus special care was dedicated to the design of the nozzle since the requirement was that the apparatus must work with pressures lower than 0,3 bar. Four nozzles with various diameters were constructed and tested. Their characteristics are shown in figure 8. On the ordinate marked are the nozzle air flow and the corresponding air velocity in the transport pipe. On the basis of this diagram nozzle ϕ 12,8 (13 mm) was chosen which for 0,3 bar gave transport air velocity of about 16 m/s. While working with the material this velocity will decrease with the increase in capacity, that is with increase in pressure at the beginning of transport pipe.

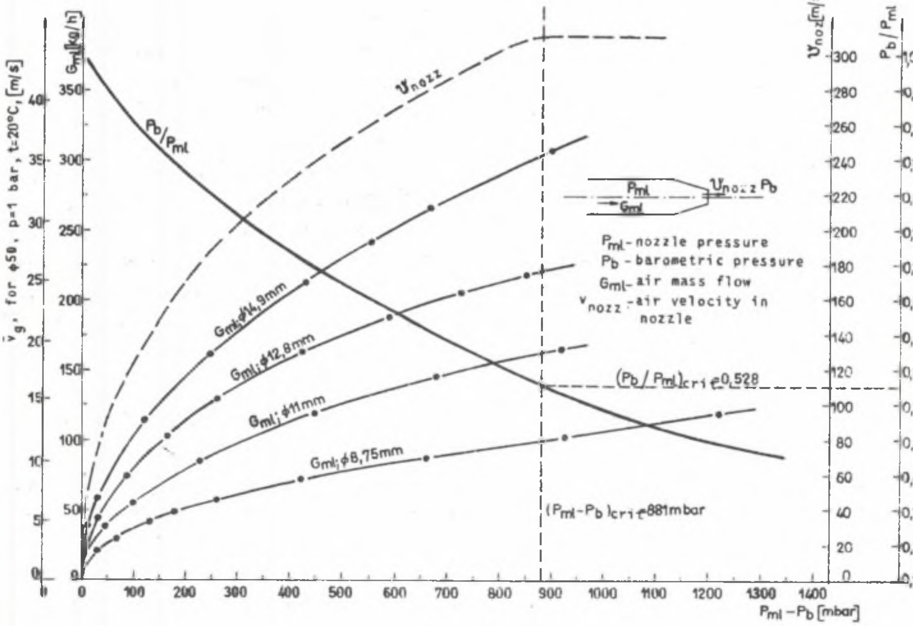

Figure 8. Nozzle flow characteristics; experiment

3.2. Experimental results

Experimental measurements were done with three active bed heights (1558 mm, 958 mm and 378 mm), with transport air velocities from 4 m/s to 20 m/s, nozzle pressure from 0,04 bar to 0,55 bar and fluidization velocities up to 11,5 cm/s. For this range of parameters, concentration varied from 3 to 30 and capacity varied from 0,03 kg/s to 0,7 kg/s (~ 2,5 t/h).

Main reason for the lower measured than calculated capacities for the model is because of different material ($\rho_{\varepsilon\,calc} = 1000$ kg/m^3, $\rho_{\varepsilon\,exp} = 460$ kg/m^3).

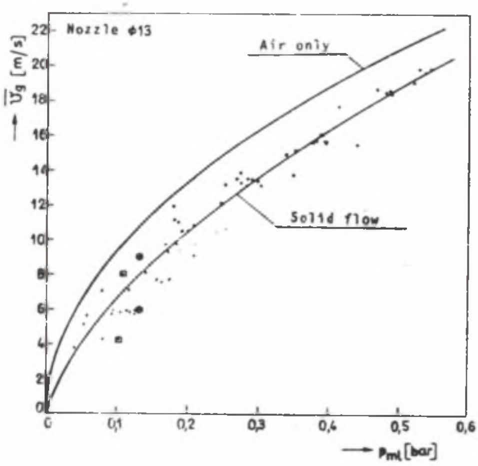

Figure 9. Air velocity in pipe versus air pressure in nozzle

As shown in figure 9, choice of the nozzle was statisfactory since in ensured required air velocities for conveying and transport capacities for pressure drops of 0,3 bar. Curve that shows the change of transport air velocity as a function of nozzle pressure when there is solid flow, represents a mean value, that is it corresponds to some mean solid flow rate. Experimental data that fall nearer to the curve, which represents air velocity when there was no solid flow, were for the case of lower concentration and capacity transport whereas data that fall farther from that curve having lower velocities, were in case of higher concentration and capacity transport. This is clearly the effect of pressure change in the nozzle (or at the beginning of pipe). It can be seen that, in case of solid flow, air velocities can be for 3 m/s lower than in case of air flow only, and this fact has to be kept in mind when designing these conveyors.

Measurements of pressure drops in the transport pipe have shown that the correlation [3], which was used for pressure drop calculations, gives significantly higher pressure drops than the measured ones. This is shown in figure 10, using few experimental values for clearity. For each experimental point correspond three values calculated by pressure drop correlations [3, 7, 8], using measured values for air and solid flow rate. Experimental values mostly fall between correlations [7] and [8], which give higher and lower values than the measured ones. Since the experiments were done with only one material, it is not suggested to use a correlation which could be obtained from these measured values but instead to use correlation [7] for the sake of reliability.

On the basis of the above analysis, calculations of the relationship between capacity G_s and air velocity $\bar{v}_g$ were done again, using correlat-

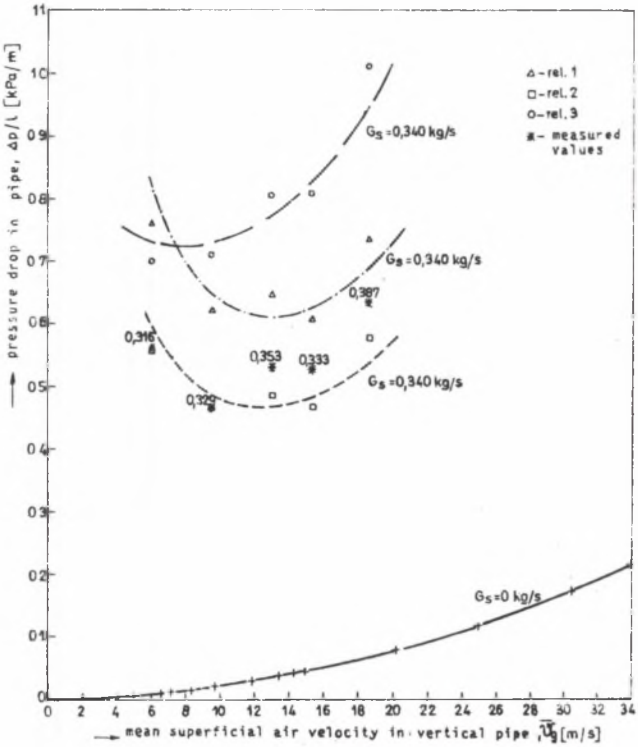

Figure 10. Pressure drop versus air velocity in the pipe

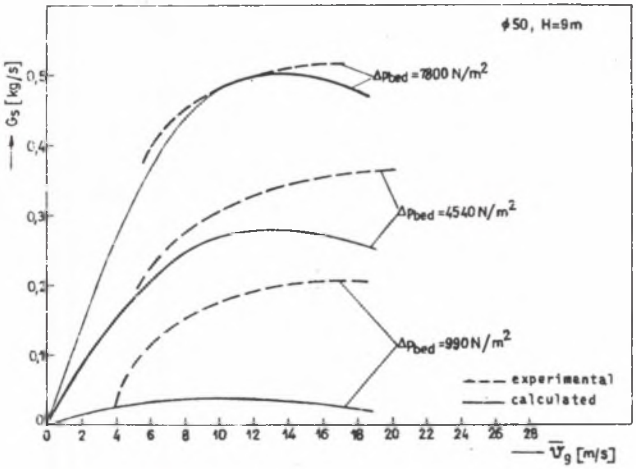

Figure 11. Comparison between experimental and calculated relations $G_s = f(\bar{v}_g)$ for the model

ion [7] and the measured value for $\rho_s = 460$ kg/m^3 was used. These relationships should be in good agreement with the experimentaly obtained ones. Any dissagrement in this particular case would be a result of the influence of the nozzle. As can be seen from figure 11, where a comparison between calculated and measured values of capacity is given, influence of the nozzle is different for various bed pressure drops, or bed heights. As the bed height is increased the influence of the nozzle decreases. For the bed pressure drop of about 1000 N/m^2, this influence is great (increases capacity about five times), but it is negligible for bed pressure drop about 8000 N/m^2, in region of recommended transport air velocities. This influence of the nozzle, if verified in further investigations, could be useful in stabilising the funning of the conveyor since it can enable constant capacity regardless on certain changes in bed height due to any instability of material inflow into the main reservoir.

For the prototype of the vertical pneumatic conveyor, G_s = 10 t/h and H = 16 m, the same analysis was used in chosing the nozzle diameter, transport pipe diameter and bed height while the maximum pressure requirement of 0,3 bar was the same. Correlation [7] was used for pressure drop calculations. Initial measurements on the prototype showed good performance characteristics of the conveyor and good agreement with the previous calculations.

4. Conclusion

The outlined design procedure of the vertical pneumatic conveyor, in which the solid flow rate depends on a number of parameters, and experimental verification of the calculations, shows that the outlined quantitative procedure can be used with great reliability. Using the nozzle in these conveyors necessitates one more equation in the procedure.

Since the experimental investigations were carried out with only one material, more experimental data is needed using other materials in apparatuses of similar size. This would enable formation of a general design procedure for these conveyors which would be reliable and simple to use.

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KONSTRUKCJA PIONOWEGO TRANSPORTU PNEUMATYCZNEGO Z WYKORZYSTANIEM WARSTWY FLUIDYZACYJNEJ

Streszczenie

W konstrukcji pionowego transportu wykorzystano wskazówki praktyczne oraz aktualne doświadczenie z podobnym układem. Stwierdzono pewne osiągnięcia w konstruowaniu przy jednoczesnych zmiennych wynikach.

Na podstawie badań doświadczalnych i przedstawionej analizy zaproponowano metodę projektowania dla pionowego transportu pneumatycznego, ze szczególnym uwzględnieniem wysokości warstwy materiału w zbiorniku, wydajności transportu i spadkiem ciśnienia.

КОНСТРУКЦИЯ УСТРОЙСТВА ВЕРТИКАЛЬНОГО ПНЕВМОТРАНСПОРТА С ИСПОЛЬЗОВАНИЕМ ФЛУИДИЗАЦИОННОГО СЛОЯ

Резюме

В конструкции устройства вертикального транспорта использовано практические указания, а также актуальный опыт с аналогичными устройствами. Отмечены некоторые достижения в конструировании при одновременных переменных результатах. На основе экспериментальных исследований и данного анализа предложен метод проектирования вертикального пневмотранспорта, в котором учтены высота слоя материала в резервуаре, кпд транспорта и понижение давления.