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EXPERIMENTAL INVESTIGATION OF PNEUMATICAL UNLOADING OF THE GRAIN MATERIAL IN FLAT BOTTOM SILOS

Summary. The subject of investigation, presented in this paper is unloading process in silos with flat bottom. Nowadays for emptying of the rest of grain material, horizontal or vertical air channels are very common. Comparing these two possibilities horizontal channels turn out to be two to three times more economic.

PREFACE

Economy of store house space improves considerably if flat botom silos are used instead of conical bottom silos, because the useful volumen increases, (e.g. silo of 20 m diameter and of 30 m high, with conical part inclination of 60°, has 13% greater volumen). Quantities of material that remain in flat bottom silos after gravitational discharge, are considerable, and rather great consumption of energy is necessary to unload the silo completely. Pneumatical ways of unloading have an advantage in comparison with the others, partially because the necessary equipment is nearly identical with ventilation equipment without which one cannot imagine the storage of material in modern silos. Two aspects of this kind of unloading are in daily use in practice (the necessary equipment is shown in fig. 1). What they have in common is that at the bottom of silos there are distributive channels for air wich are parallely disposed (fig. 2) and are connected to the air source (fig. 3) by joint collector; and on the perforated surfaces, lateral and horizontal; the contact is realized between the air stream and grain material. First the research work was carried out with almost vertical and then horizontal row of slots (i.e. distributive channels) on which forms kinetic energy of plane's air jets by whose action the unloading performs. Researches on pneumatic unloading with almost vertically placed slots are less advanced, and are carried out only in the extent that is sufficient for comparison with other method, and these researches have been suspended when advantages of horizontal slots were noticed.

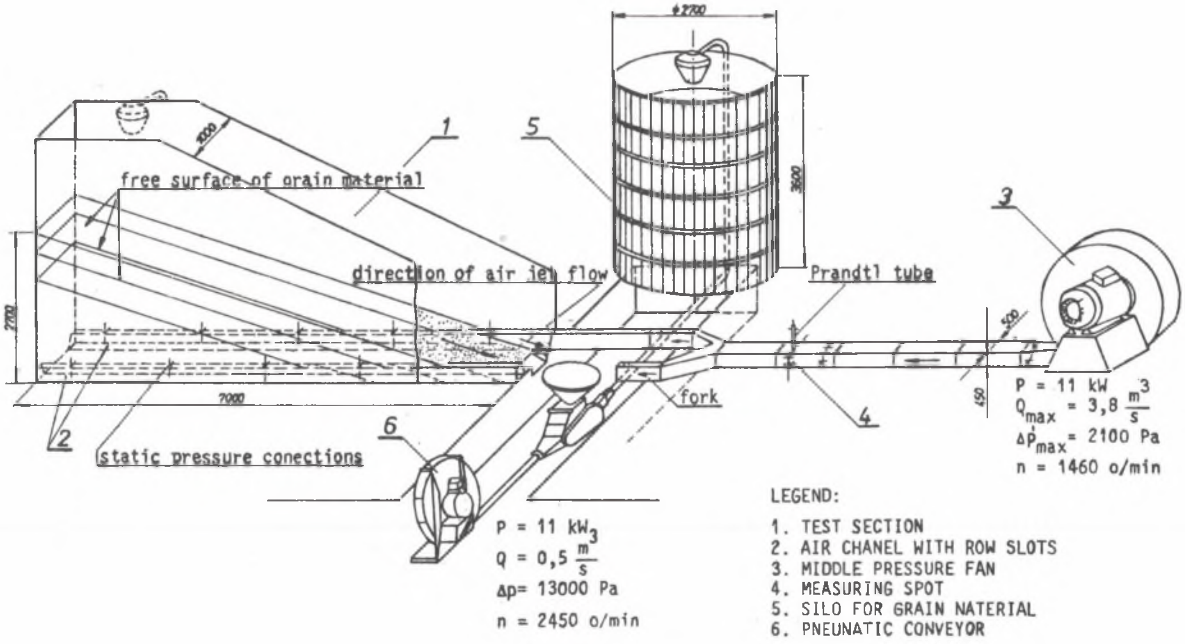

Fig. 1. Experimental plant for unloading the rest of grain material in flat bottom silos

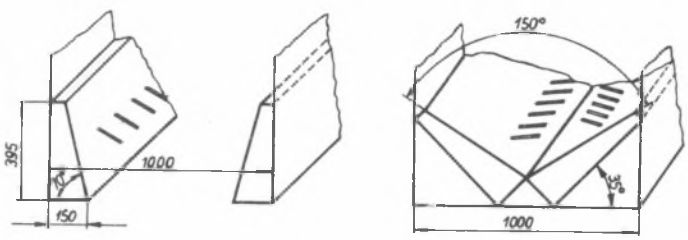

Fig. 2. Disposition of distributive channels

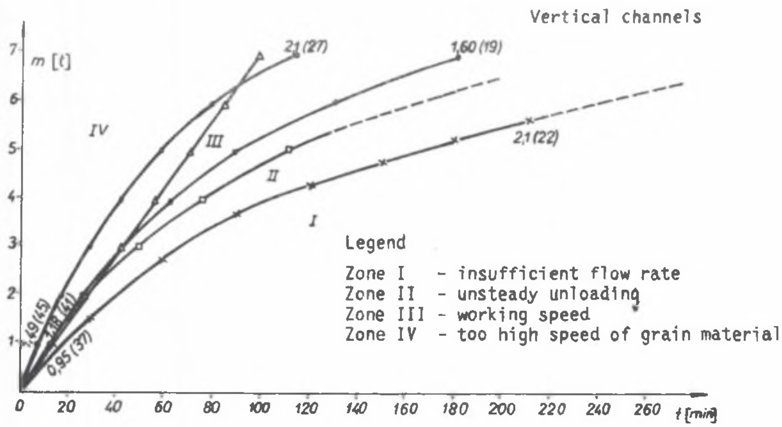

Fig. 3. Total amount of material dependent on time

Connections for measurement of static pressures in channel are arranged along the channel. At output section of a slot, the air jet velocity was measured by Pitot tube. The butterfly valve for regulation of flow rate is arranged at the suction side of the ventilator. Gauge and vacuum pressures were recorded during the measurement - behind and in front of the ventilator. Measuring spot for air flow rate was installed at the end of the rectilinear section of supply channel, before the fork. The air flow rate was determined by velocity disposition along the channel cross section. Velocity profiles were taken in three vertical and three horizontal directions, at the same channel cross section, by Prandtl tube. Dynamic pressure was measured by Betz - differential gauge which accuracy is 0,5 (Pa); the other pressures were measured by electronic instrument which accuracy is 1 (Pa).

BASIC PHYSICAL CHARACTERISTICS OF MATERIAL AND UNLOADING CHARACTERISTICS

Experiments were carried out with wheat which properties are as follows:

- density of material $\rho_s = 1350$ [kg/m^3]
- filling density on free surface $\rho_{nsg} = 870$ [kg/m^3]
- porosity on free surface $\varepsilon_o = 0,38$
- humidity of material 8,5%
- average equivalent diameter of grain $d_c = 3,6$ [mm]
- first critical velocity of fluidization at big filling altitude of grain material $v_{k_1} = 0,6$ [m/s]
- filling angle of grain material $\alpha = 22,5^o$

During the unloading process of examined section i.e. during the unloading process of the exploitated silo, one can notice several stages which are identical for both ways of unloading. At the beginning of unloading the air flow rate is rather small (per section 0,9 - 1,5 [m^3/s], the output velocities from the slots are rather high ($\approx$ 40 [m/s]) , and unloading capacity is also high ($>$ 10 [t/h]). This fact points out the control necessity or necessity of flow rate limitation at the beginning of unloading process, depending on capacity of transportation line of a silo installations. Speed of grain material is low and there does not exist a danger of grain material breakage. The shape of slots and angle of air stream jet do not influence the capacity, while the amount of air does. For the first period of unloading one can say that the initiator of unloading is the stream of air jet, and gravitational force which action is present because of filling angle of material is dominant, or at least, value of the same class.

In the further unloading of the rest, when the inclination of filling angle had moved off from the edge of aperture for unloading, one can notice several zones of which the most important one is the zone of active contact between the air stream and material. This zone begins from first free edges of the slots and stretches itself to the output aperture. The length of this zone is approximately 1,3 - 1,8 [m] depending on the amount of air. The exchange of the kinetic energy of air stream and already oriented grains of material mass takes place, directly on this length, by perforated part of the side of transfer channels, so that grains get acceleration.

RESULTS, ANALYSIS OF MEASURES AND CONCLUSIONS

Researches had shown that quality of unloading was determined by time of unloading in most experiments, so that all characteristics of unloading are very often shown depending on it. As the possibility of pneumatic unloading is out of the question, so the consuption of energy ist the most important value the full atentions is payed to it. Components which determine energy; as the total air flow rate and kinetic energy of air in active part of a slot, in addition to the amount and capacity of unloaded material, all together were also the subject of interest.Basic measurings of both ways of unloading were realised at full length of section with horizontal bottom and full cross of a slot 2B/b = 8,69, in function of different initial air flow rates. (B - width of tested section, b = total width of a slot). Results are shown on fig. 3 and 4. After the comparison

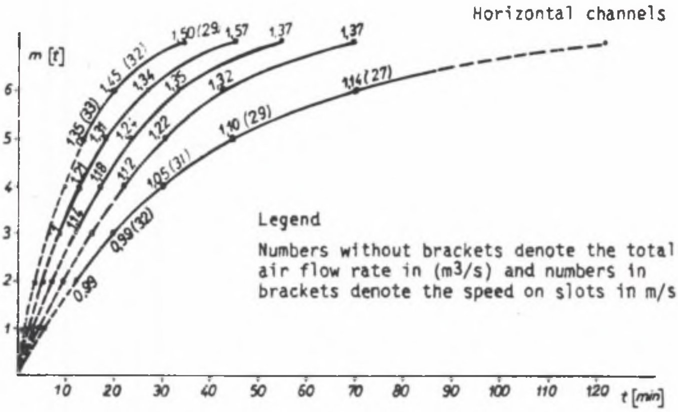

Fig. 4. Totally unloaded amount of material in dependence on time
2B/b = 8,69

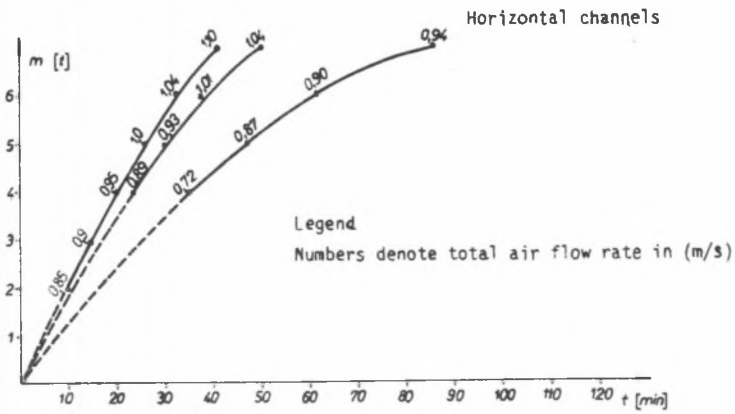

Fig. 5. Totally unloaded amount of material in dependence on time
2B/b = 18,18

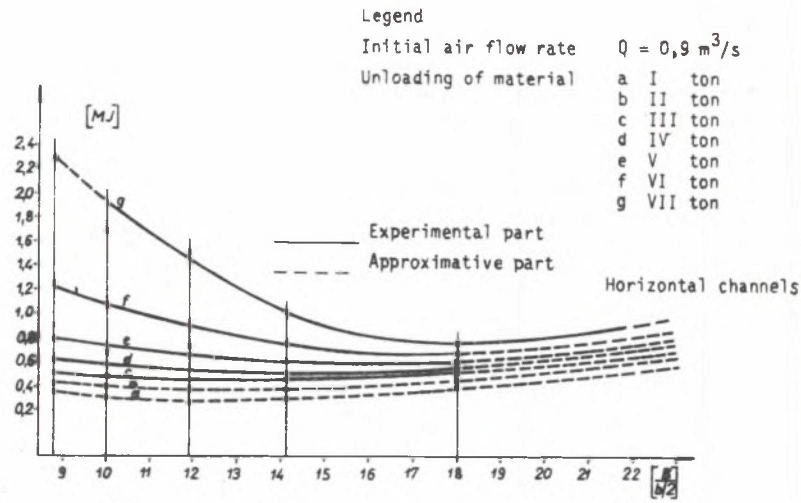

Fig. 6. Dependence of effective work vs. 2B/b

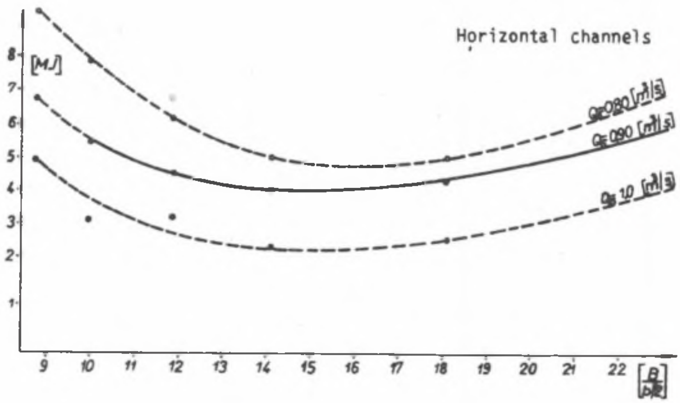

Fig. 7. Dependence of total effective work on 2B/b for different initial air flow rates

of energies' consumptions of both ways of pneumatic unloading (according to the fig. 3 and 4) the experiments with horizontally arranged slots were continued. The smallest consumption of energy when the air is at constant initial flow rate - without regulation - was determined depending on relation 2B/b. In fig. 5 there are shown the results of measurings for 2B/b = 18,18. There were six series of measurings realized. The last series of measuring was realized with different cross of a slot along the tested section. The optimal area 2B/b in relation to the effective energy is shown in fig. 6 for each ton of unloaded material. Effective energy is determined by product of Pm and Q (Pm . Q) where Pa denotes gauge pressure at the beginning of a distributive channel, and Q denotes the air flow rate. One can clearly see the need for particularly great effective work for last tons of material. The total efective work depending on initial flow rate and depending on relation 2B/b is shown in fig. 7. The decrease of effective energy with the increase of initial flow rates, which is obvious according to the curved lines for three different initial flow rates is shown in fig. 7, it is limited by maximal initial flow rate, during the final part of transportation, the grain material is so much accelerated that we can notice the breakage of grain. Efficiency of pneumatic unloading of material was also examined for the inclined silo bottom. Comparisons with coresponding curves from experiments with horizontal bottom had shown that total energy for e.g. $\alpha = 4^{o}$ was decreased by 21%. Measurings of unloading capacity for decreased length of tested section (5[m] 2,5[m]) were also realized.

The results had confirmed that, on the basis of the measurings of unloading characteristics of one length of tested section, it is possible, with sufficient accuracy, to determine the parameters of unloading during the different lengths of section. Kinematic characteristics of planes air jets which are dependent on air flow rate and on geometry of a slot, are measured during the unloading time. Change of active speed, which is a result of kinetic action of air jets, is identical for both ways of unloading. Their effects are different as it is shown in fig. 8 and 9.

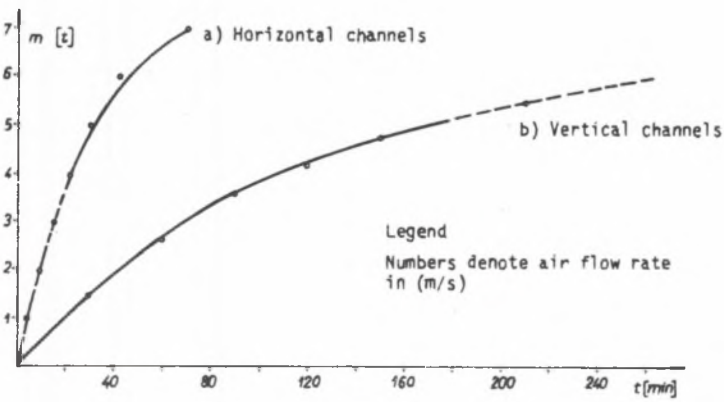

Fig. 8. Unloaded amount in dependence on time for horizontal and vertical channels

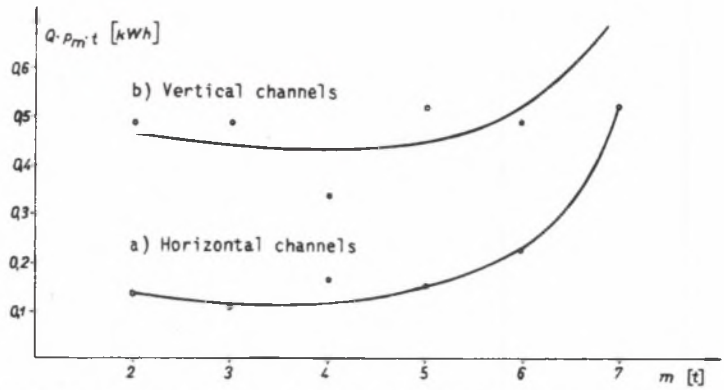

Fig. 9. Dependence of effective work on unloaded amount

Unloading in conditions of "lateral fluidization" which can be registered and defined when channels are placed vertically, is obviously more ineffective than unloading in conditions of "normal fluidization" which occur when slots are horizontally arranged. When using horizontal slots, there appears to a certain degree known stream line figure of fluidized layer of grain material which moves by action of gravitational and kinetic energy. In particular periods of unloading, the dominant influences are changing. With regard to existing meager theory on pneumatic transportation of fluidized layer of powderlike materials, it is hard to expect the possibility of assumption of uniform theoretical analyses of total unloading process of grain material. Theoretical assumptions should dwell upon the realizing of macroscopic influenced values, without deeper subject matters and with limited application. For tested case of unloading one can set satisfactory accurate analytic expression by which one can come into contact with important elements in exploitating conditions which enables dimensioning of ventilator's installations in dependence on chosen regulation and unloading regime.

Nomenclature

- B - width of test section
- b - total width of slot
- L - length of test section
- p_m - gauge pressure
- Q - air flow rate
- Q_o - initial air flow rate
- t - time of unloading process
- m - mass of unloaded material
- E - efective work

DOŚWIADCZALNE BADANIE PNEUMATYCZNEGO OPRÓŻNIANIA
Z MATERIAŁÓW ZIARNISTYCH SILOSÓW Z PŁASKIM DNEM

S t r e s z c z e n i e

Przedmiotem badań przedstawionych w referacie jest proces opróżniania silosów o płaskim dnie. Obecnie do opróżniania silosów z resztek materiałów ziarnistych często wykorzystywane są poziome lub pionowe kanały powietrzne. Porównanie obu rozwiązań pozwala na stwierdzenie, że kanały poziome dają korzyści ekonomiczne dwu- trzykrotnie większe.

ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ ПНЕВМАТИЧЕСКОЙ РАЗГРУЗКИ
СЫПУЧИХ МАТЕРИАЛОВ ИЗ СИЛОСОВ С ПЛОСКИМ ДНОМ

Р е з ю м е

В работе рассматриваются вопросы касающиеся процесса разгрузки силосов с плоским дном. Сравниваются два метода разгрузки остатков сыпучего материала; первый - с использованием горизонтального воздушного канала, второй - о использованием вертикального канала. Результаты сравнения показывают, что горизонтальные каналы в два до трёх раз экономнее вертикальных.