DEVELOPMENT OF A PNEUMATIC SCREW CONVEYOR DESIGN AND SUBSTANTIATION OF ITS PARAMETERS
/
РОЗРОБКА КОНСТРУКЦІЇ ПНЕВМО-ШНЕКОВОГО ТРАНСПОРТЕРА ТА ОБГРУНТУВАННЯ ЙОГО ПАРАМЕТРІВ

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Keywords: *pneumatic screw conveyor, loose material, screw feeder, air pressure.*

ABSTRACT
The paper presents the developed design of a research prototype of a pneumatic screw conveyor and the research methodology aimed at determining power characteristics for moving various types of loose materials depending on the influence of pressure and air volume. The dependences of pneumatic screw conveyor efficiency on the change in the area of a hopper hole, the rotation frequency of a screw feeder and the value of an operating air pressure in a technological line have been determined. The influence of the form and the geometrical parameters of a central replaceable nozzle on the distance of loose materials transportation has been determined.

РЕЗЮМЕ
В статті представлено розроблену конструкцію дослідного взірця пневмо-шнекового транспортера та методику проведення досліджень для визначення силових показників переміщення різних типів сипких матеріалів в залежності від впливу тиску та об'єму повітря. Встановлено залежності продуктивності пневмо-шнекового транспортера від зміни площі отвору бункера, частоти обертання шнекового живильника та величини робочого тиску повітря в технологічній магістралі. Встановлено вплив форми та геометричних параметрів центрального змінного сопла на відстань транспортування сипких матеріалів.

INTRODUCTION
The conducted analysis of recent scientific and patent literature (*Lyashuk O.L. et al., 2015; Rogatynska O. et al., 2015; Loveikin V. and Rogatynska L., 2011; Lech M., 2001; Manjula E.V.P.J. et al., 2017; Naveen Tripathi, 2015*), which covers the design of operating devices and the ways of loose material transportation in closed casings along both rectilinear and curvilinear routs, shows that they satisfy most of the requirements for the process quality to a certain extent. But the issues connected to the improvement of conveyor efficiency, the reliability of operating elements, the reduction of energy consumption and minimization of loose material damage during its transportation etc. have not been fully investigated yet. This paper presents further investigation of the issues, covered in paper *(Hevko R.B. et.al., 2014; Hevko R.B. et al., 2016; Hevko R.B. et al., 2017)*.

MATERIALS AND METHODS
In order to conduct experimental investigations, a research prototype of a pneumatic screw conveyor (Fig. 1) has been designed and developed. It contains a frame *1*, where there is an electric motor *2*, which is connected to a V-belt drive *3* with a reducer *4*. With the help of a chain drive *5*, a take-off shaft of a reducer transmits torque to the shaft of a screw feeder 6. Loose material is loaded into a hopper *7*. A centre shaft of a screw feeder is connected to a pneumatic system with the help of pneumatic pipelines *8*. A splined shaft of a screw feeder is arranged with the possibility of angular displacement in bearing assemblies and is spring biased *9*. Pressure of the compressed air is delivered through a pneumatic transmitter *10* to a pneumatic distributor *11* in the central opening of a screw feeder, where there is a replaceable nozzle *12* arranged.

Loose material comes through a hopper into a conveyor body and gets onto a screw feeder, which carries out a rotational motion. If there is an overload, which is caused by the accumulation of a certain amount of loose material in the process chamber of the conveyor body, due to its spiral surface a screw feeder is axially displaced in the direction opposite to the one of loose material transportation with the help of a splined joint and it compresses a spring. Here, air from the pneumatic distributor reaches the central opening of the screw feeder splined shaft, which causes further transportation of loose material.

At the first stage of the experimental research, actual efficiency of a pilot plant without air feed has been defined and initial escape of material transportation or steady provision of accelerated material transportation after its rolling off the flights have been determined.

In order to determine the influence of the hopper discharge hole area and screw rotation frequency on the efficiency of a pilot plant, investigations without high-pressure air feed were conducted based on the implementation of a multi-factor experiment, and searching experiments were conducted based on the implementation of a single-factor classical experiments.

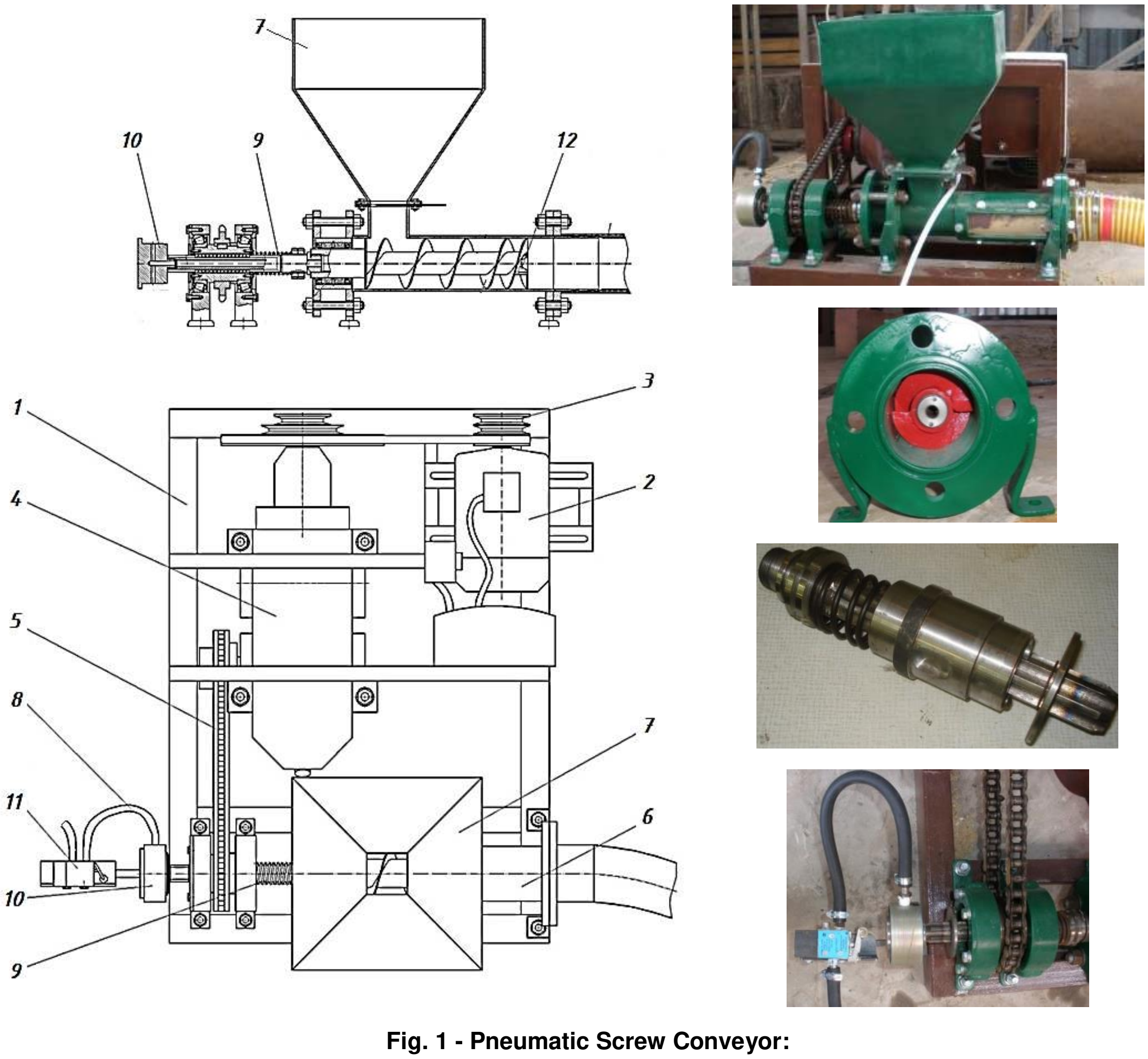


Fig. 1 - Pneumatic Screw Conveyor:

1 – frame; 2 – electric motor; 3 – V-belt drive; 4 – gear box; 5 – chain drive; 6 – feeder housing; 7 – hopper; 8 – pneumatic pipelines; 9 – spring; 10 – pneumatic adapter; 11 – pneumatic distributor; 12 – interchangeable nozzle

A response function or an optimization parameter of a pilot plant efficiency Q_1^e without high-pressure air feed, which was determined by an experimental approach, was found in the form of a mathematical model of a logarithmic function

$$Q_1^e = b_0 + b_1 \ln x_1 + b_2 \ln x_2 \quad (1)$$

where Q_1^e – efficiency of a pilot plant without high-pressure air feed, kg/m; b_0, b_1, b_2 – coefficients of an approximate model under orthogonality and symmetry conditions; having made calculations, it has been determined that b_0 = -27.49; b_1= 5.2; b_2 = 2.77; coded factors according to the area of a hopper discharge hole: x_1 - S_c×10^{-4}, m²; frequency of screw rotation: x_2 – n, rev/m.

According to the results of the conducted multi-factor experiment, the general view of the regression equation of the dependence of the pilot plant efficiency Q_1^e without high-pressure air feed on the hopper discharge hole area S_c and the screw rotation frequency n in actual values is the following:

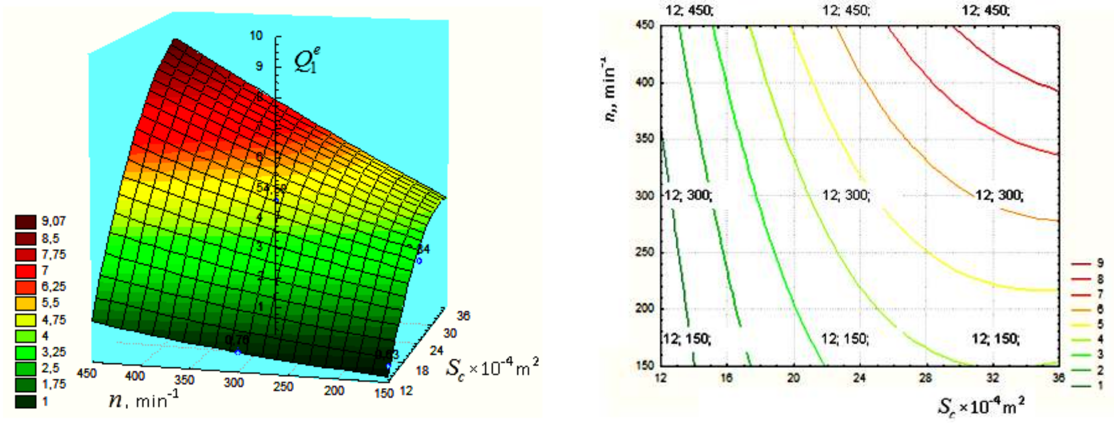
$$Q_1^e = -27.49 + 5.2\ln(S_c) + 2.77\ln(n) \tag{2}$$

During the performance of the experiments, the factorial field was determined by the following parameter range: 12 ≤ S_c ≤ 35 (10^{-4} m²); 150 ≤ n ≤ 450 (rev/m).

The obtained regression equation (2) can be used for determining the efficiency of a pilot plant Q_1^e without high-pressure air feed according to the area of a hopper discharge hole S_c and the frequency of screw rotation n.

Based on the regression dependences, a response surface with its two-dimensional section of the change in the efficiency of a pilot plant without high-pressure air feed as a functional $Q_1^e = f(S_c, n)$ was constructed, which is represented in Fig. 2.

The pattern of Q_1^e change shows that within the limits of factor variation, the efficiency changes from 0.75 to 9.0 (kg/m). Here, the pattern of Q_1^e changes depending on each separate factor is different: the rate of Q_1^e gain depending on the change in the hopper discharge hole area S_c is much bigger that the rate of efficiency gain depending on screw rotation frequency n and is within the limits of 0.5…2.5 kg/m and 3.5…7.0 kg/m respectively. Thus, the S_c influence on the plant efficiency is much bigger than the one of screw rotation frequency n.



a b

Fig. 2. - Response surface (a) and its two-dimensional section (b) of the change in pilot plant efficiency depending on the hopper discharge hole area S_c and the screw rotation frequency n

The determination of the lower value of air feed operating pressure P, at which the beginning of material acceleration (its rolling off) at the discharge end of a flight can be observed, was carried out by means of implementing searching experiments, which were conducted at constant minimum values of the factors S_c = 12·10^{-4} m² and n = 150 rev/m.

In order to conduct comparative studies with high pressure air feed P at the take-off shaft of a screw feeder, nozzles of various configurations were made (Fig. 3). When determining maximum distance of free material movement from a nozzle, investigations were conducted at the constant frequency of feeder rotation n = 450 rev/m and air feed pressure 0.8·10^6 N/m².

The necessity of conducting searching experiments was based on the fact that a pilot plant is a scaled model, the dimensional specifications of which significantly differ from those of a full-scale pneumatic screw conveyor. The beginning of accelerated material movement was visually observed with the help of screening and comparing high-speed shooting (Fig. 4) at the initial value of P = 0.05·10^6 N/m² and the following level of operating pressure variation ΔP = 0.02·10^6 N/m².

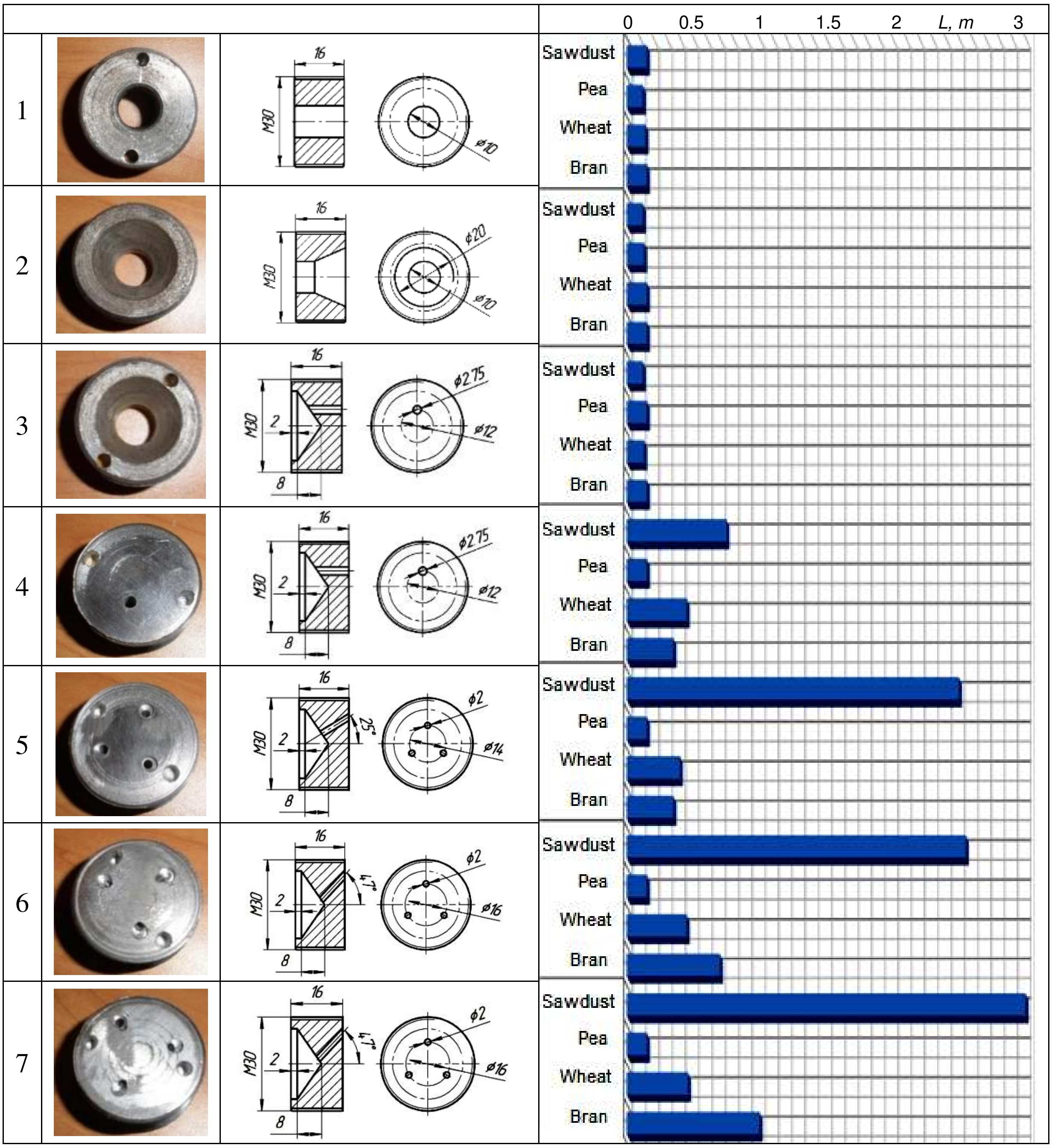


Fig. 3 - The distance of loose material transportation depending on the form and the geometrical parameters of a pneumatic screw conveyor nozzle:

1, 2, 3 – with a central opening of various conicity (diameter D = 10 mm); 4, – with a non-central opening (diameter D = 2.75 mm); 5, 6, 7 – with three openings located at various angles to the axis

Fig. 4 - **General view of high-speed shooting of material movement acceleration process**

RESULTS

The results of the experimental investigations on the change in pneumatic screw conveyor efficiency depending on the initial values of high pressure air feed *P* are represented by a graphic chart (Fig. 5).

It has been determined that the change of the operating pressure *P* within the limits of $(0.05…0.2)·10^6$ N/m^2 has almost no influence on the pneumatic screw conveyor efficiency and material movement acceleration is observed at $P_{min} \approx 0.2·10^6$ N/m^2.

Experimental investigations of the pilot plant efficiency at high pressure air feed were conducted based on the implementation of a multi-factor experiment (three-factor experiment at the levels of variation).

The procedure of planning and conducting experiments and the processing of the obtained experimental data is similar to the previous one, except for the fact that together with engaging the drive of the screw, a compressor unit was simultaneously turned on as well, having the preset necessary value of the operating air pressure *P* entering the collector.

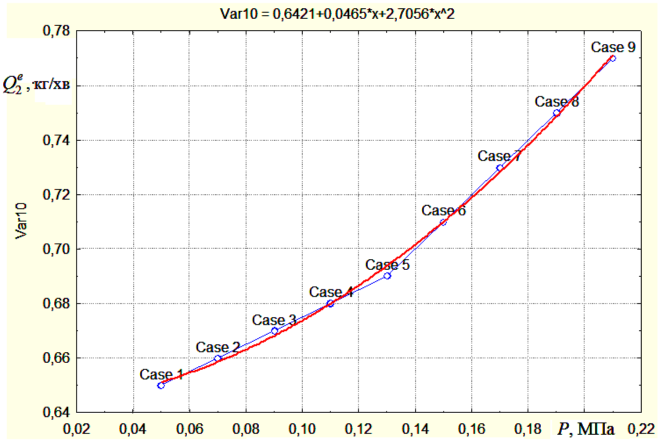


Fig. 5 - Dependence of efficiency as a functional on air pressure *P* = (0.5…0.21)·10^6 N/m^2

The general view of the regression equation, which describes the dependence of pilot plant efficiency Q_1^e at high pressure air feed on the area of a discharge hopper hole S_c, the frequency of screw rotation *n* and operating pressure *P* based on the results of the conducted multi-factor experiment in actual values is the following:

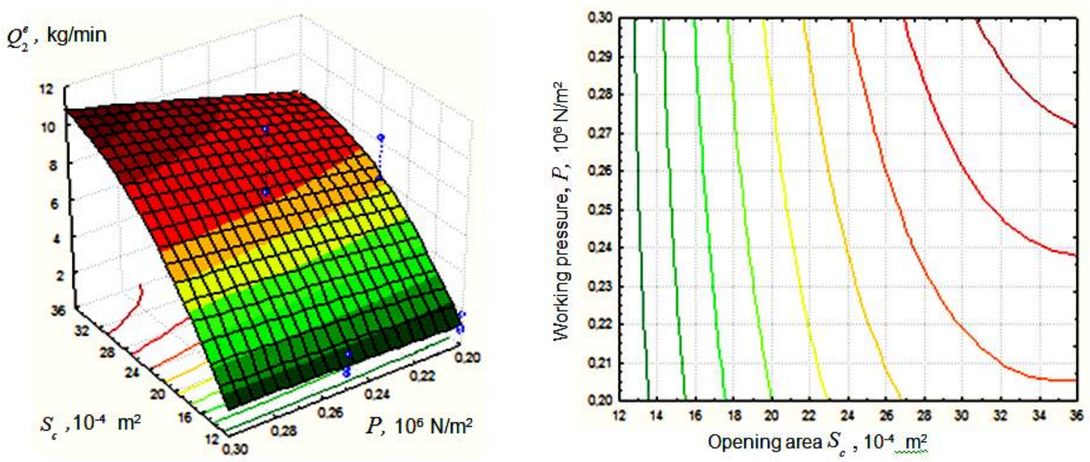
$$Q_2^e = -25.23 + 7.34\ln(S_c) + 2.26\ln(n) + 2.97\ln(P). \quad (3)$$

During the performance of the experiments, the factorial field was determined by the following parameter range: $12 \le S_c \le 35$ (10^{-4} m^2); $150 \le n \le 450$ (rev/m); $0,2 \le P \le 0,5$ (10^6 N/m^2).

Based on the regression equation (3), a response surface with its two-dimensional section of the change in the pilot plant efficiency Q_2^e at high-pressure air feed as a functional $Q_2^e = f(S_c, P)$ and $Q_2^e = f(n, P)$ at constant values of the relevant third factor, that is to say at $x_2 = n = \text{const}$, $x_1 = S_c = \text{const}$ was constructed. Graphical dependences of functional $Q_2^e = f(S_c, P)$ and $Q_2^e = f(n, P)$ are represented in Fig. 6 and Fig. 7.

It has been determined that efficiency Q_2^e increases with the increase of operative factors and is within the limits of 2…11 kg/s depending on their change. The frequency of screw rotation *n* and the area of a hopper discharge hole *S* have the most significant influence on the pattern of efficiency Q_2^e change, namely, a significant increase of Q_2^e is observed at the increase of the relevant factor value $S_c \ge 24·10^{-4}$ m^2, $n \ge 300$ rev/m. In addition, it has been determined that depending on the change of operating air pressure *P* within the limits of factor change $0.2 \le P \le 0.3$ (10^6 N/m^2), the efficiency of a pneumatic screw conveyor increases rectilinear to the increase of *P*, here, the gain is about 1.1 kg/m.

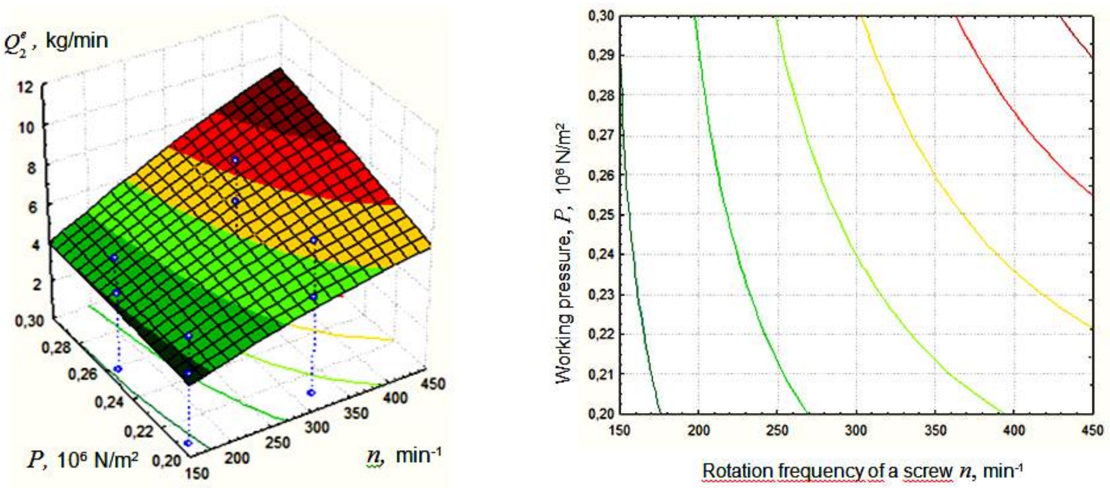
The disadvantage of such additional feeding is that air streams, which are coming out of pneumatic system nozzles and directed into a transportation flow, are placed at a high angle. Such arrangement of nozzles is inconsistent with the direction of material movement in a flexible pipe.



a *b*

Fig. 6 - A response surface (a) and its two-dimensional section (b) of the pneumatic screw conveyor efficiency as a functional $Q_n = f(S_c, P)$ at n = 300 rev/m

The construction arrangement and the general view of a new technical performance of the pneumatic screw conveyor are represented in Fig. 8. It consists of carriage *1* and 2, where there is a drive *3*, a frame *4* with a hopper *5*, a screw feeder *6*, a pneumatic system *7* and a pneumatic valve *8* arranged. A conveyor pipeline consists of series-connected sections *9* of length *l*, here, each section contains an elastic casing *10*, which, on its right side, is fixed on a coupling cylinder bushing *11* with the help of a ring *12* that is regulated by bolt *13* tightening.



a *b*

Fig. 7 - Response surface (a) and its two-dimensional section (b) of the pneumatic screw conveyor efficiency as a functional $Q_n = f(n, P)$ at S_c = 24· m^2

In the central part of a cylindrical bushing *11* there are openings *14* inclined in the direction of material transportation, which are arranged in a circle and are caught by a *П*-shaped bushing *15*, on the outer diameter of which there are connectors *16* arranged at an angle in the direction of material transportation and to which there are air supply hoses *17* attached. On the left side of an elastic casing on air supply hoses there are inlet connectors *18* arranged, which are connected to the common pneumatic system of the conveyor, here, the length of air supply hoses of every next section are twice bigger than those of the previous one and the hoses of the section are displaced in circular direction and fixed along the section length *9* by a clamp *19*.

While in operation, the material comes through a hopper *5* into a conveyor body *4* on a screw feeder *6*. When there is overload caused by the accumulation of a certain amount of loose material in the processing chamber of the conveyor body *4*, a screw feeder is displaced axially in the direction opposite to material transportation. Here, air comes along hoses *17* through holes *14* into the section *9* and dilutes the accumulated material.

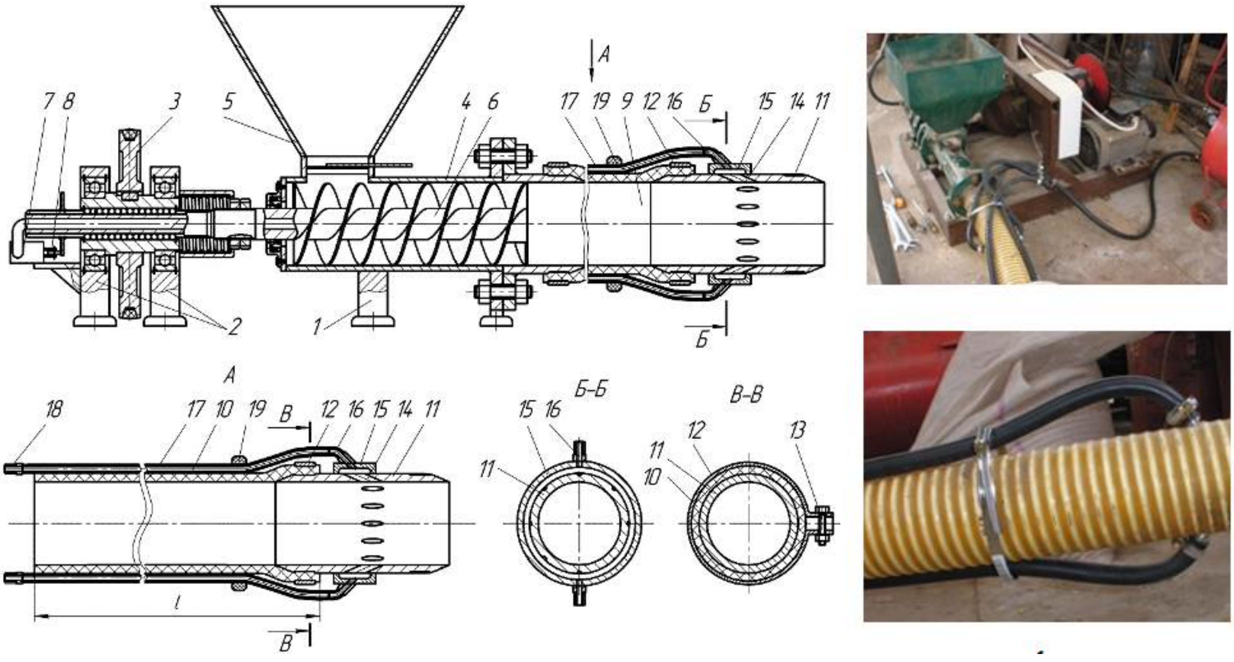


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Fig. 8 - Construction arrangement (a) and general view (b) of the pneumatic screw conveyor with feeding hoses connected to a flexible casing

CONCLUSIONS

The paper presents the developed design of a pneumatic screw conveyor and investigation procedure for determining the dependence of pneumatic screw conveyor efficiency on the change in the form and the geometrical parameters of a nozzle, the area of hopper hole, the frequency of screw feeder rotation and the value of operating air pressure in a technological lane.

Response surfaces and their two-dimensional sections have been constructed and their analysis shows that the efficiency Q_n of a pneumatic screw conveyor increases with the increase of the operating factors and is within the limits of 2…11 kg/s.

The frequency of screw rotation n and the area of a hopper discharge hole S_c have the most significant influence on the pattern of efficiency Q_n change, namely, there is significant increase of Q_n with the increase of the relevant factors value $S_c \geq 24\ 10^{-4}$ m^2 and $n \geq 300$ rev/m.

Based on the results of the conducted investigations, a pneumatic screw conveyor with additional feeding of material flow by means of air streams has been developed and made.

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