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RESEARCH OF INFLUENCE OF THE MAIN PARAMETERS ON THE CAPABILITY OF THE PNEUMATIC CHAMBER PUMP WITH MULTIJET AERATION UNIT

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Abstract:

It is necessary to improve the process of cement fluidization in the aspiration area of cement-air ambient in the transmission pipeline for increasing the efficiency of pneumatic conveying of cement using pneumatic chamber pumps with top unloading; a new design of multijet aeration unit has been suggested for this purpose. A large number of geometrical and technological parameters, which have been identified in the research process, influence the process of absorption of cement-air mixture.

As a result of full-scale experiments a regression equation of momentary efficiency of elevation of the discharge pipe, extreme pressure in the pump chamber and the elevation of the aeration unit position relative to the chamber bottom was obtained. It was found that the pneumatic conveying is advisable at a lower pressure; this would entail an increase of concentration and a decrease of the rate of cement-air mixture.

However this may create congestions, impairing the movement of material through the pipeline. Therefore pneumatic conveying of cement using pneumatic chamber pumps with the top discharging is advisable with an auxiliary feed of air into transmission pipeline, which will increase the efficiency of the pneumatic system.

Keywords: pneumatic conveying, pneumatic chamber pump, fluidizing efficiency, discharge time, air pressure, multijet aeration unit, circuital field, bending angle of jets, jets rotation angle, discharge pipe, conveyed materials, pore channels, chamber bottom.

Introduction

Pneumatic chamber pump is a cylindrical tank with spherical upper and conical lower bottoms. Conveyed material is inserted through a hole in the upper bottom, tight-closed with a special shutter [1, 2, 4]. After loading the material and sealing the tank compressed air is delivered to the tank. Loosened with compressed air the aerated mass enters the transmission pipeline under the influence of pressure differences and mixes with the air coming from the jets and aeration units; it moves through this pipeline to the destination [7-11].

A proportional flow of material to the fluidization area, smooth leakage of cement-air mixture to the entrance of the discharge pipe with minimum arching and channeling, flow friction and cement remaining residue in the pump chamber after the discharge should be organized in the pump chamber to organize effective pneumatic conveying of cement, that can be achieved by arranging the maximum thickness of the fluidized bed [5].

Basic indicators of batch action pneumatic chamber pump are efficiency dependent on the discharge time of the chamber, as well as air flow, the value of which is influenced by the pressure in the chamber, so it is advisable to choose them as indicators of response functions in the study of the influence of the major geometric and technological parameters of pneumatic chamber pump on the cement transportation process.

Main part

A laboratory setup was developed and produced to study the main aspects of the pneumatic chamber pump work. It allows assessing the impact of the factors that characterize the cement pneumatic conveying process with the use of pneumatic chamber pumps.

Due to the large variety of pumps for the conveyance of cement, their principle of operation, operating conditions one-hour efficiency is one of the main technical and economic indicators which depends on the number of cycles per hour (loading and unloading). In this regard, it is difficult to compare the efficiency of the pump, so it is advisable to use momentary efficiency for the preparatory comparing of the pumps.

The following factors influence the pneumatic chamber pump efficiency in this case:

Gy (τr) = f (P, hrt, D, ψ, ha, nc, D0, γ1, γ2, hr, nr, Vk, Dk, Hk, kz) (1)

where τr - discharge time;

P - absolute pressure in the pump chamber atm $P=P_n+P_g$;

Pn - normal pressure of 1 atm .;

P_g - extreme (gage) pressure atm .;

h_{rt} - the elevation of the discharge pipe from the bottom of the chamber, m;

D - the diameter of the discharge pipe, m;

ψ - expansion angle of confuser (checker filling at the end of the discharge pipe), ^{o};

h_a - the elevation of the aeration unit from the chamber bottom, m;

n_c - number of jets of the aeration unit;

D_0 - diameter of aeration unit jets m;

γ_1 - bending angle of jet;

γ_2 - the angle of rotation of the jet about itself, ^{o};

h_r - pitch between rows of jets, m;

n_r - number of rows of jets;

V_k - volume of the pump chamber, m^3;

D_k - pump chamber diameter, m;

H_k - the height of the pump chamber, m;

k_z - chamber loading factor .

Analysis of pneumatic chamber pump structures [6, 8], with the upper discharge showed that the most appropriate to use the ratio of the height of the chamber to its diameter (H_k/D_k) equal to 1.3-1.7, the diameter of the discharge pipe is connected to pump chamber diameter with the following characteristic curve D ≈0,1 D_k, so these ratios were applied in the design of the laboratory setup (H_k=0,7 м, D_k=0,4 м, D=0,04м, ψ=90°).

Preliminary evaluation tests to determine the rational confuser expansion angle ψ disclosure, which dimension influences the amount of the remaining cement in the pump chamber after completion of discharge, were carried out. It should also be noted that the expansion angle affects the intensity of the involvement of the material into the discharge pipe. Confusers with expansion angle of 50°, 70°, and 90 ° were made.

The experiments found that when the expansion angle is more than 90° the charging material hover on the aisles of the confuser, and when the expansion angle is 50° suction process takes place with the same intensity that without confuser, so it is advisable to apply confusers with an expansion angle of 80°-90°.

Multijet aeration units of various designs (with straight jets, with the jets having a bending and rotation angles and others) were used in the experimental studies. To create a fluidized bed with a circuital field in confuser zone an aeration unit with jets, which ends have a bending angle γ_1=60° about its vertical axis and jets rotational angle γ_2=25° relative to the radius drawn through the jet axis from the center of the aeration unit, was manufactured.

The bending angle γ_1 can vary from 50 ° to 70° depending on the size of the pump chamber, the number and the pitch of turns. It is obvious that the greater the pump chamber size, the pitch and the number of turns are, the less should be the bending angle of the jets. It is advisable to change the rotation angle of jets γ_2 within 15 ° -30°, since if the rotation angle is 30º air currents intersect and interfere with one another without forming a circuital field, which should promote to involve the material into discharge pipe.

If an angle is less than 15º, air currents separation will occur and the particles located by the chamber wall in a collision with the chamber will sink to the bottom, increasing the discharge time. Under the influence of air currents emerging from the jets of the aeration unit a circuital field in the chamber bottom closer to the center is created. It has a better effect on the material and prevents the formation of end-to-end channels, which allows increasing the homogeneousness of cement dispersion in fluid bed.

Due to the action of downward and tangential components of the jet velocity stagnant areas and pore channels are removed; it significantly influences the consumption of compressed air. At that the created fluidization zone is larger than with the use of direct jets, and it relieves the process of involving of cement-air mixture into the discharge pipe, and hence reduces the time of the pump chamber discharge. Under certain conditions, for example, cement aggregation, its pour density increases, that's why when applying air from jets so-called porous or end-to-end channels appear; with the help of which the air passes through the cement, without mixing with it or creating fluidized bed [12].

Multijet aeration unit with the jets, having bending and rotation angles creates a circuital field on the bottom of the pump chamber, converging to the entrance of the discharge pipe; it prevents the formation of end-to-end channels in the material layer. As a result of the flow out of currents of air from the jets the air intensively mixes with cement and roiling of cement occurs.[3].

It is known [11] that the material chamber loading factor depends on its structure and mechanical and physical properties of the material; it varies from $k_z = 0,75$ to $k_z = 0,85$; for top unloading pumps $k_z = 0,75$ is generally used.

Based on the above-stated, the main factors are the following:

1. Geometric (the elevation of the discharge pipe from the chamber bottom h_{rt} = 20-90 mm, the elevation of the aeration unit from the chamber bottom, h_a = 40-70 mm).

2. Technological (the absolute pressure in the pump chamber,

$$P = P_n + P_g = 1+ (0.8\text{-}1.5) \text{ atm.}).$$

This choice can be explained by the fact that in the range of variation of extreme pressure P_g = 0.8-1.5 atm. at the bottom of the laboratory setup in preliminary tests the smallest remaining residue of the discharged cement is observed. The reason for this is that the diameter of the discharge pipe D is connected with such parameters as the elevation of the discharge pipe from the chamber bottom h_{rt} and the elevation of the aeration unit from the chamber bottom h_a, as following:

$$h_{rt}=(0{,}5\text{-}2)\ D;\ h_a=(1\text{-}1{,}7)\ D. \qquad (2)$$

During the implementation and processing of the experimental results the following regression equation was obtained

$G_y = f\ (P_g;\ h_{rt};\ h_a)$, which shows the change in momentary efficiency as a function of the main factors.

The regression equation of momentary efficiency G_y in coded form looks like this:

$$G_y = 6{,}6+1{,}4x_1-0{,}8x_2-0{,}4x_3-0{,}56x_1x_2-0{,}4x_1x_3+0{,}2x_2x_3+0{,}34x_1^2-1{,}6x_2^2-0{,}8x_3^2. \qquad (3)$$

Analyzing the regression equation the relevance of factors was determined (Fig. 1). The greatest impact on the efficiency has the factor x_1 (extreme pressure P_g = 54%), and the sign "+" indicates that if it increases the response function increases also. The negative sign for the coefficients of x_2 and x_3 factors indicates that while their increasing the productivity will decrease. The significance of the factors x_2 and x_3 are equal to 31% and 15%, which is less than the effect of factor x_1 in 1.7 and 3.6 times respectively.

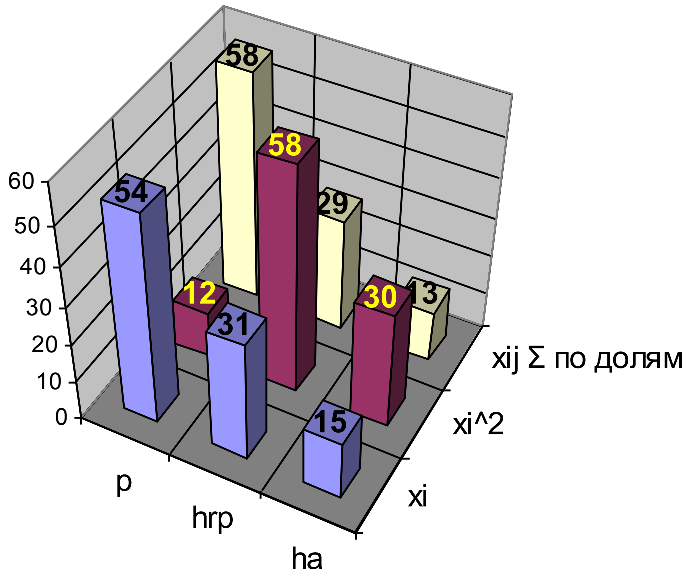


Figure 1. The significance of the main factors for the momentary efficiency

🟦 xi - x_1 (P_g) = 54%; x_2 (h_{rt}) = 31% ; x_3 (h_a) = 15% ;

🟪 xi^2 - x_1 (P_g) = 12%; x_2 (h_{rt}) = 58% ; x_3 (h_a) = 30% ;

🟨 xij Σ по долям - x_1 (P_g) = 58%; x_2 (h_{rt}) = 29% ; x_3 (h_a) = 13%

As the significance of the factor x_3 is relatively small, to simplify the analysis of influence of the factors on efficiency we accept the elevation of the aeration unit location from the chamber bottom equal to basic value (zero) level of variation (h_a = 55 mm).

The regression equation in decoded form looks like this:

$$G_y = -65{,}8 + 3P + 0{,}5h_{rt} + 1{,}2h_a -$$

$$-0{,}12Ph_{rt} - 0{,}21Ph_a + 0{,}001\, h_{rt}h_a + 7{,}71P^2 - 0{,}004h_{rt}^2 - 0{,}01h_a^2. \qquad (4)$$

Dimensional shapes showing the dependence of the efficiency of the main factors variance for fixed values G_y = 8,3; 7,3; 6,3 kg / s were constructed; (Fig. 2).

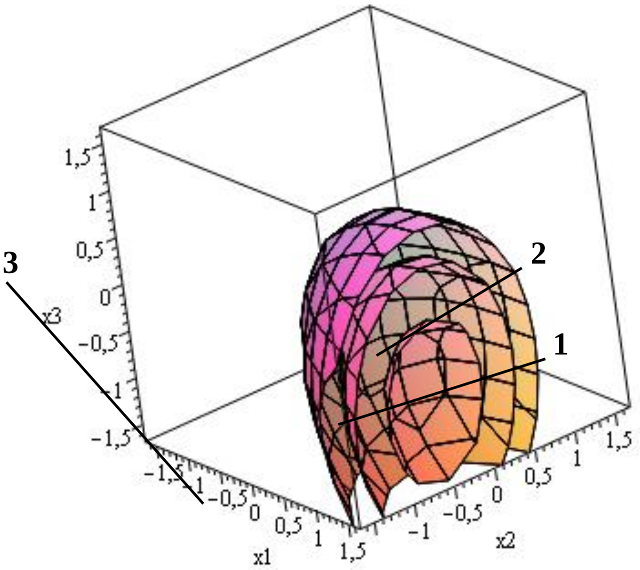
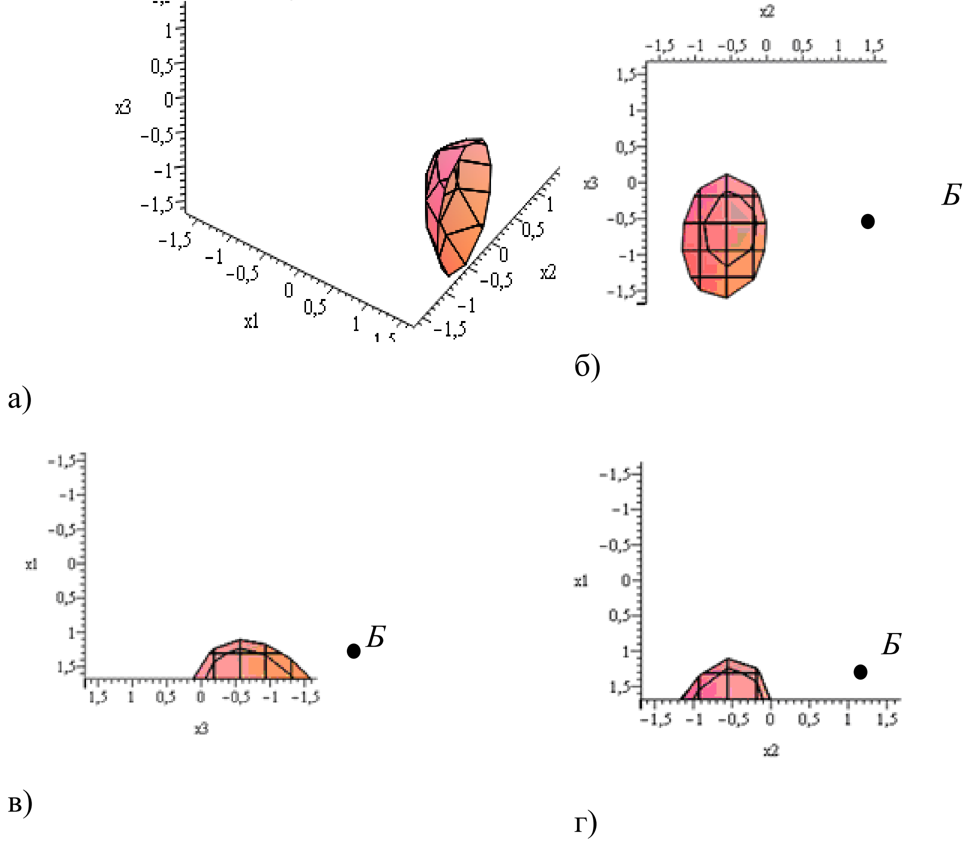


Figure 2. Graphic structures showing the fixed values of efficiency depending on the main factors:1 – G_y = 8,3 kg / s; 2 – G_y = 7,3 kg / s; 3 – G_y = 6,3 kg / s

Figure 3 shows a surface on which an arbitrary point indicates at what values of factors the highest momentary efficiency can be achieved G_y = 8,3 kg / s, namely in the combination of excess pressures, discharge pipe elevation from the chamber bottom and the aeration unit in the intervals 1,36-1,5 atm., 28-55 mm and 40-58 mm respectively.

Geometrical parameters are adjusted structurally, since it is inherent in the design and manufacture of a laboratory setup and an extreme pressure has an effect on the air flow and consequently on energy usage in the transportation process, it can be assumed that it is advisable to use the values of the factors in the point B (Fig. 3), selecting the minimum pressure: P_g = 1.36 atm, $h_{rt} \approx 45$ mm, $h_a \approx 50$ mm..

The surface, which reflects the maximum efficiency, is of an increasingly-decreasing kind. Decreasing of the function is due to the influence of the interaction term of paired members x_1x_2 and x_1x_3 (Fig. 4), which coefficients are negative and of the influence proportion of the value of the coefficient x_1 (58%) (the most significant); that is 32% more than the total influence of shares x_2 (18%) and x_3 (8%), and the coefficient of the combined influence of the pair member x2x3 interaction effect is positive and has 16% of influence.



а) б)

в) г)

Figure 3. Graphic structures, showing the maximum fixed efficiency amount G_y = 8.3 kg / s of the main factors: a) 3-dimensional image, b) projection on the axis x_1,

c) projection on the x_2-axis, g) projection on the axis x_3

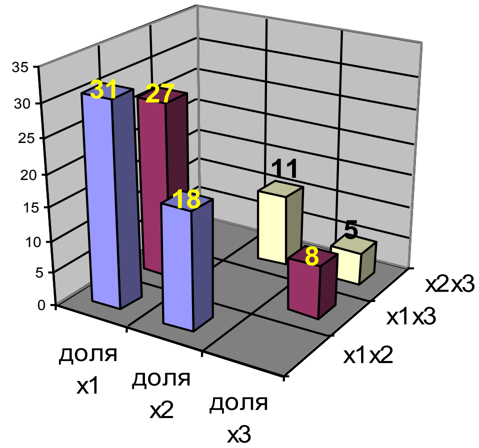


Figure 4. The significance of the impact of each of the paired members interaction effects for the momentary efficiency:

▨ x1x2 ■ x1x3 ☐ x2x3

Let’s consider the momentary efficiency dependence on changes in excessive pressure and elevation of the discharge pipe from the chamber bottom over the entire range of their variation when the values of aeration unit elevation is fixed h_a=40, 46, 55, 64, 70 mm.(Fig. 5). Graphic chart analysis showed that they are of the increasingly-decreasing kind.

The highest momentary efficiency for each value of h_a can be achieved in the following case:

-at h_a = 40 mm and pressure P_g = 1.25-1.5 atm, G_y = 5,8-8 kg / s at h_{rt} = 34 mm. G_y = 6-7,5 kg / s at h_{rt} = 55 mm (Figure 5a.);

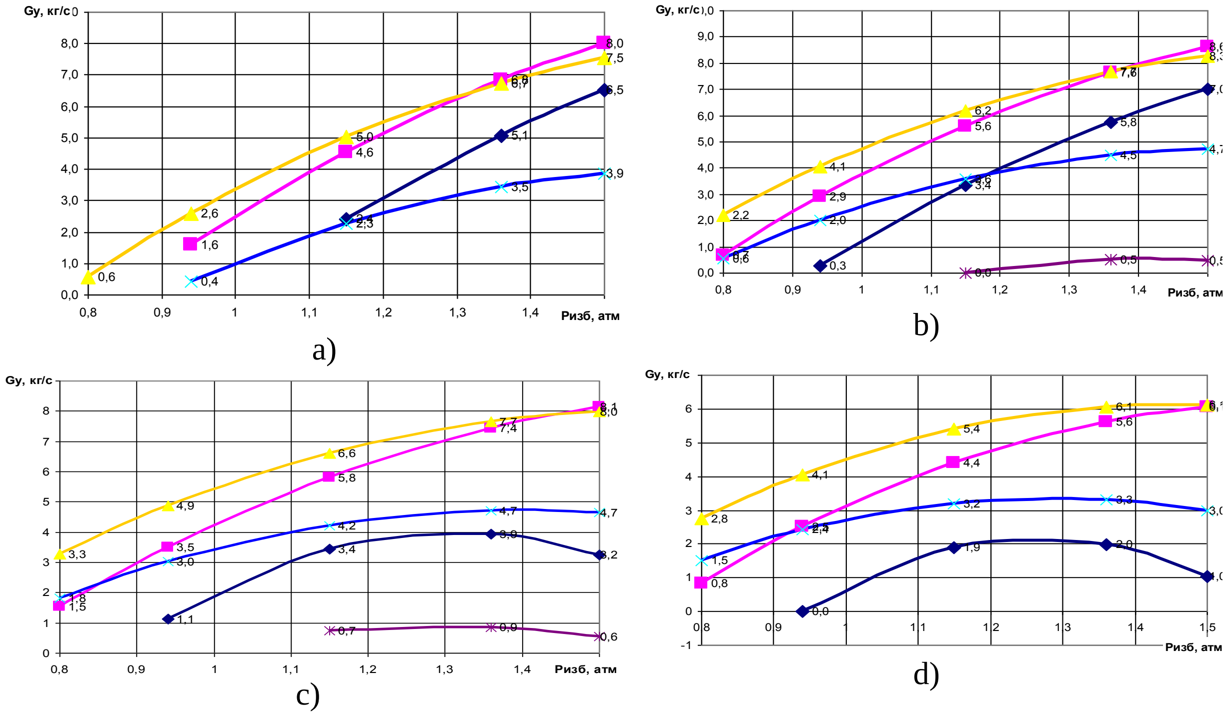
- at h_a = 46 mm and a pressure P_g = 1.25-1.5 atm, Gy = 6,5-8,6 kg / s at hrt = 34 mm. Gy = 7-8,3 kg / s at hrt = 55 mm (fig 5 b).

- at ha = 55 mm and pressure P_g = 1.25-1.5 atm, Gy = 6,6-8,1 kg / s at hrt = 34 mm. Gy = 7,2-8 kg / s at hrt = 55 mm (fig 5 in.);

- at ha = 64 mm and pressure P_g = 1.25-1.5 atm, Gy = 5-6,1 kg / s at hrt = 34 mm. Gy = 5,8-6,1 kg / s at hrt = 55 mm (fig 5 g.);

- at ha = 70 mm and pressure P_g = 1.25-1.5 atm, Gy = 3,1-3,7 kg / s at hrt = 34 mm. Gy = 3,9 kg / s at hrt = 55 mm (Figure 5, d.); at P= 1.36 atm., Gy = 4,1 kg / s.

Thus, the greatest momentary efficiency can be achieved under varying of pressure P_g in the interval of 1.25-1.5 atm. and the following design values: the elevation of the aeration unit from the chamber bottom h_a = 46 mm and h_a = 55 mm, the elevation of the discharge pipe from the chamber bottom hrt = 34 mm - Gy = 6,5-8,6 kg / s and Gy = 6,6-8,1 kg / s; at hrt = 55 mm - Gy = 7-8,3 kg / s and Gy = 7,2-8 kg / s (Figure 5, b, c.), respectively. That is to a greater extent depends on the elevation of the discharge pipe h_{rt}, but aeration unit is located above the discharge pipe at 12 mm and 15 mm, respectively.



a)

b)

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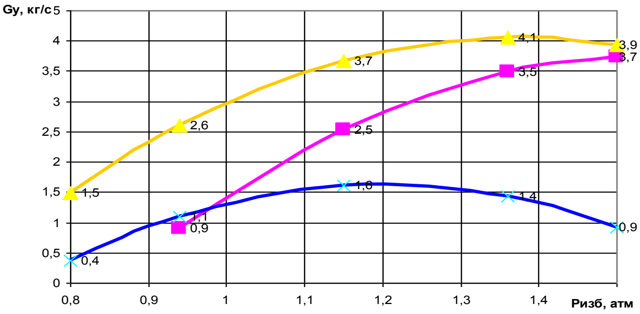


e)

Figure 5. Dependence of the momentary efficiency on changing of extreme pressure and elevation of the discharge pipe by varying the elevation of the aeration unit from the camera bottom h_a

Graphic charts analysis (Fig. 5) of dependence of momentary efficiency on changing of extreme pressure P_g and elevation of the aeration unit h_a location by varying the elevation of the discharge pipe from chamber bottom h_{rt}=20, 34, 55, 76, 90 showed that they are not linear and they are of the ascending kind. The greatest productivity for each h_{rt} can be obtained in the following cases (Table 2.):

- at h_{rt} = 20 mm and pressure P_g =0,8-1,5 atm., G_y=5,3-6,7 kg/s at h_a = 46 mm; G_y=5,1-6,2 kg/s at h_a = 55 mm; G_y=4,6-6,2 kg/s at h_a = 40 mm (рис. 5, a);

- at h_{rt} = 34 mm and pressure P_g =0,8-1,5 atm., G_y=7,2-8,4 kg/s at h_a = 46 mm.; G_y=7,2-8,0 kg/s at h_a = 55 mm; G_y=5,4-6,0 kg/s at h_a = 40 mm (fig. 5, b);

- at h_{rt} = 55 mm and pressure P_g =0,8-1,5 atm., G_y=7,4-8,1 kg/s at h_a = 46 mm; G_y=7,5-7,9 kg/s at h_a = 55 mm; G_y=6,5-7,4 kg/s at h_a = 40 mm (fig. 5, c);

- at h_{rt} = 76 mm and pressure P_g =0,8-1,5 atm., G_y=4,4-4,7 kg/s at h_a = 46 mm; G_y=4,7 kg/s at h_a = 55 mm; G_y=3,3-38 kg/s at h_a = 40 mm (fig. 5, d);

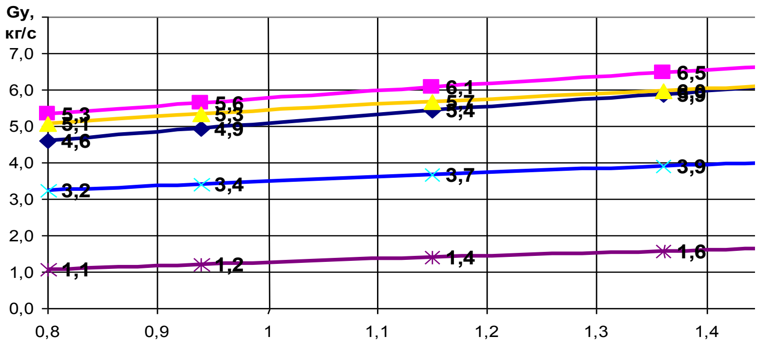
- at h_{rt} = 90 mm and pressure P_g =0,8-1,5 atm., G_y=0,5 kg/s at G_y=0,9-0,7 kg/s at h_a = 55 mm (fig. 5, e).

Table 1.

The highest efficiency of the extreme pressure changes (P_g = 0.8-1.5 atm.), elevation of the aeration unit (h_a = 40-55 mm) and the elevation of the discharge pipe (h_{rt} = 20-55 mm)

h_{rt}	h_a	G_y for $P_{g\ min}$ = 0,8 atm.	G_y for $P_{g\ max}$ = 1,5 atm.
34	40	5,4	6,0
	46	7,2	8,4
	55	7,2	8,0
55	40	6,5	7,4
	46	7,4	8,1
	55	7,5	7,9

a)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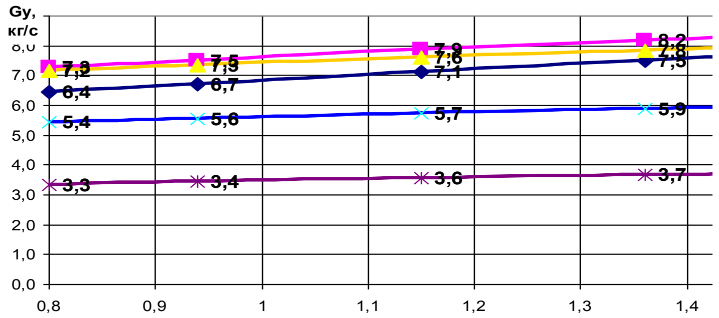
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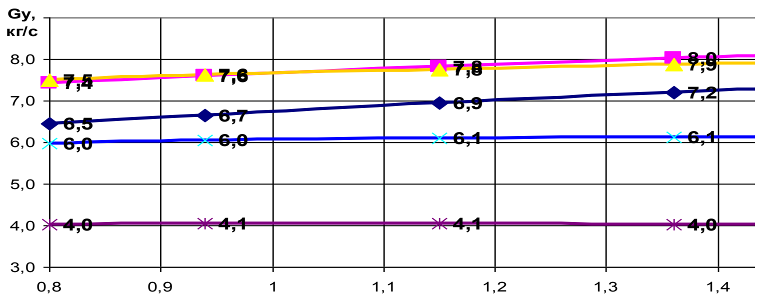
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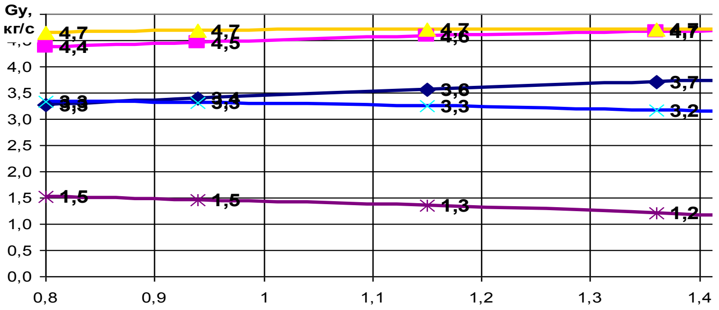
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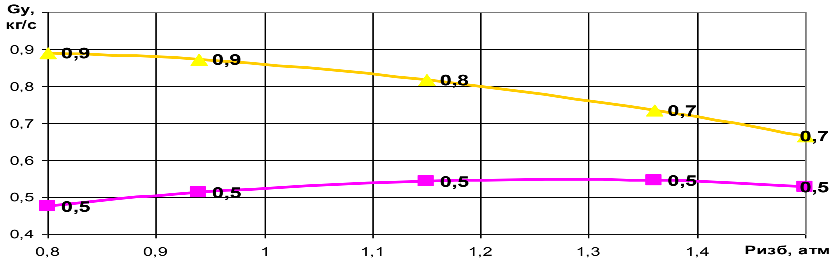
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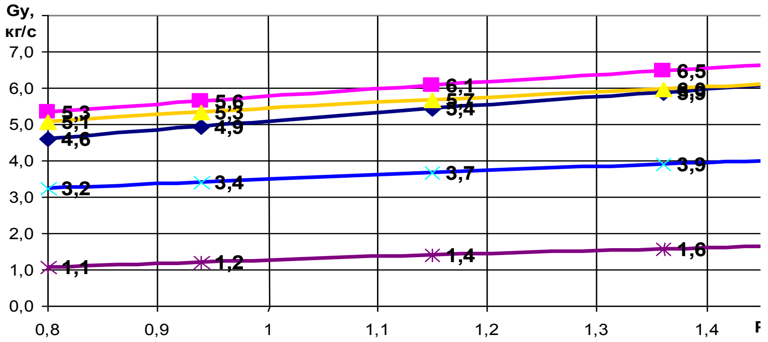
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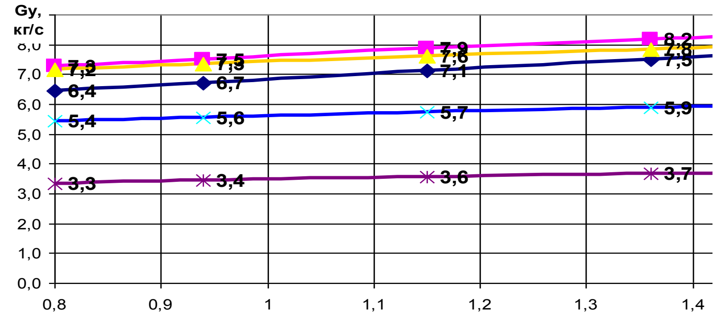
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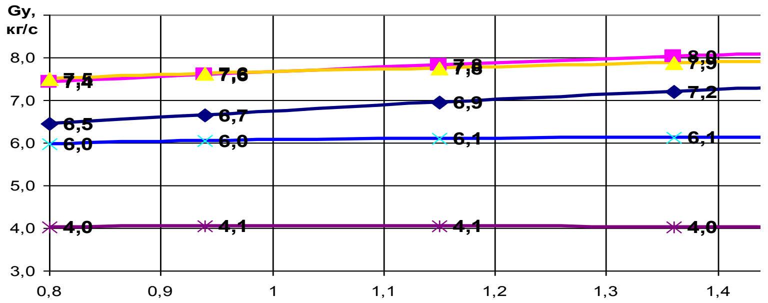
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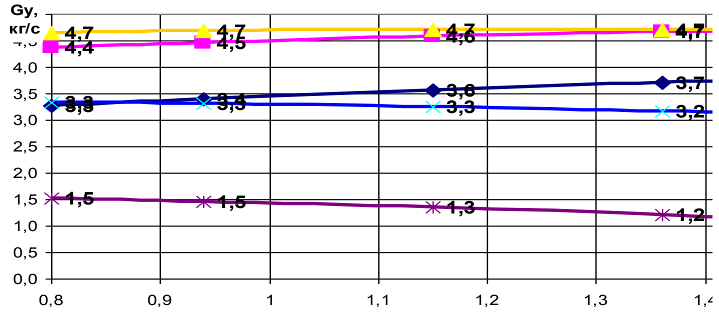
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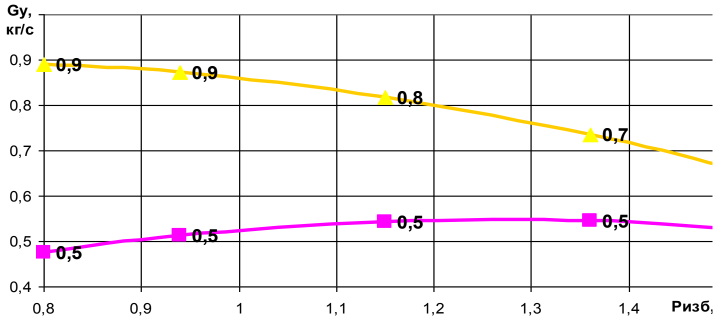
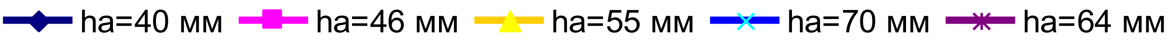

Gy, кг/с
0,4
0,5
0,6
0,7
0,8
0,9
0,8
0,9
1
1,1
1,2
1,3
1,4
Ризб,
0,9
0,9
0,8
0,7
0,5
0,5
0,5
0,5

Figure 6. Dependence of the momentary efficiency on the changing of the discharge pipe elevation from the chamber bottom h_{rt}: a– h_{rt} = 20 mm; b– h_{rt} = 34 mm; c – h_{rt} = 55 mm; d – h_{rt} = 76 mm; e– h_{rt} = 90 mm



Conclusion

Analysis of the results of experimental studies of dependence of the momentary efficiency on varying the elevation of the discharge pipe, extreme pressure and the elevation of the aeration unit from the chamber bottom showed that at the elevation of the discharge pipe from the chamber bottom hrt = 20-34 mm and for the elevation of the aeration unit values from the chamber bottom ha = 40 mm and ha = 46-55 mm at the minimum P_g = 0.8 atm. The efficiency is equal to Gy = 5,4 kg / s and Gy = 7,2 kg / s, respectively.

Also, when the maximum value P_g = 1.5 atm. The efficiency is the highest Gy = 8,4 kg / s at hrt = 34 mm, ha = 46 mm and at hrt = 55 mm, ha = 55 mm P_g = 0.8 atm. Gy = 7,5 kg / s. It should be noted that if the pressure increases almost in 2 times the efficiency will increase in about 1.2 times and 1.1 times, respectively.

Summary

Analyzing the process of fluidization and the pump chamber discharge, it can be concluded that in terms of saving of compressed air consumption it is advisable to use pneumatic conveying at a lower pressure; it would entail an increase in concentration and a decrease in the rate of cement-air mixture, which will have a beneficial effect on the fluidization process in the in zone of cement involvement into the transmission pipeline. However, this may create congestion impairing movement of material through the pipeline.

Therefore pneumatic conveying of cement using pneumatic chamber pumps with the top discharge is advisable to carry out with auxiliary feed of air into transmission pipeline, which will increase the efficiency of the pneumatic transporters.

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