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POSSIBILITIES OF OPTIMUM SELECTION OF VALUE OF PARAMETERS OF SCRAPER PIPE CONVEYOR

SUMMARY

Still growing requirements connected with environmental protection, work safety, but also many advantages of scraper pipe conveyors caused that they find more and more wide applications in transport of fine grained, bulk, dusty materials and pulp in chemical, ceramic, aluminium industry, cement mills, electric plants and steelworks. Those conveyors have: simple construction and maintenance, small dimensions in crosswise section, easy configuration of routes, transport materials at high temperatures (even at 700 ^oC). Those conveyors have also disadvantages; their great resistances of movement (friction) causing significant friction wear of parts, which is essential problem in exploitation. Parameters connected with conveyor construction, route configuration and transported materials properties have essential influence on those resistances.

In the paper had been indicated possibilities of selection of such scraper pipe conveyor basic parameters like internal pipe diameter, distance between scrapers and speed, at which resistances of movement or needed drive power are minimal. It has essential meaning for rational designing and exploitation of scraper pipe conveyors.

***Keywords**: scraper pipe conveyor, resistances of movement*

MOŻLIWOŚCI OPTYMALNEGO DOBORU WARTOŚCI WYBRANYCH PARAMETRÓW PRZENOŚNIKA ZGRZEBŁOWEGO RUROWEGO

Rosnące wymagania związane z ochroną środowiska, bezpieczeństwem i higieną pracy, a także liczne zalety przenośników zgrzebłowych rurowych sprawiły, że znajdują one coraz szersze zastosowanie w transporcie materiałów drobno uziarnionych, sypkich, pylistych i pulpy, między innymi w zakładach przemysłu chemicznego, ceramicznego, aluminiowego oraz w cementowniach, elektrowniach, koksowniach i hutach. Charakteryzują się one prostą budową i obsługą, małymi wymiarami w przekroju poprzecznym, możliwością łatwego konfigurowania tras oraz transportowania materiałów, także o podwyższonych temperaturach (do 700 ^oC). Przenośniki te obok wielu zalet mają też wady: ich duże opory ruchu (tarcia) powodują znaczne zużycie ścierne elementów, które jest istotnym problemem eksploatacji tych przenośników. Na te opory istotny wpływ mają parametry związane z konstrukcją przenośnika, konfiguracją jego trasy oraz własnościami transportowanych materiałów.

W pracy wskazano na możliwości takiego doboru wartości podstawowych parametrów przenośnika zgrzebłowego rurowego t.j. średnicy wewnętrznej rurowej rynny, odstępu między zgrzebłami oraz prędkości ruchu, przy których minimalizuje się opory ruchu lub moc potrzebną do jego napędu. Ma to istotne znaczenie dla racjonalnego projektowania oraz eksploatacji przenośników zgrzebłowych rurowych.

***Słowa kluczowe**: przenośniki zgrzebłowe rurowe, oporu ruchu*

1. INTRODUCTION

Transport in many industry plants is a very important technological part, which have essential influence not only on technical and economical results, but also on safety (including ecological safety) and working hygiene. Due to still growing requirements connected with environmental protection for transport of fine grained, bulk, powder and dusty materials especially harmful for environment, more and more frequently scraper pipe conveyors are used (Furmanik 2009; Kasza 2008; Katterfeld and Williams 2008a, b; Krause *et al*. 1999, SCHRAGE, www.ferind.com.pl)). They allow in automated and hermetic way receive dusts, dosing and transporting and also moving different kinds of bulk materials in technological and reloading processes in many branches of industry (Fig. 1). Those conveyors are very often better than different kinds of conveyors (for example screw, belt or bucket conveyors), due to their simple construction and operation, small dimensions, and also possibility to ensure dust-, water- and even gas-tightness, what often have an important meaning for technological and particularly ecological reasons.

In differ from the traditional scarper conveyors, with open chute, scarper pipe conveyors, with closed chute profile, have got much more great resistances of movement and caused by it friction wear of pipes and scrapers, which is basic problem in exploitation (Antoniak 1990).

Rational designing of those conveyors needs such selection of their basic constructional parameters (like internal pipe diameter, distance between scrapers and speed), at which resistances of movement (or drive power) will be possibly minimal, and friction wear of parts will also be reduced.

In the paper had been indicated possibilities of selection of such scraper pipe conveyor basic parameters, at which resistances of movement or needed drive power are minimal.

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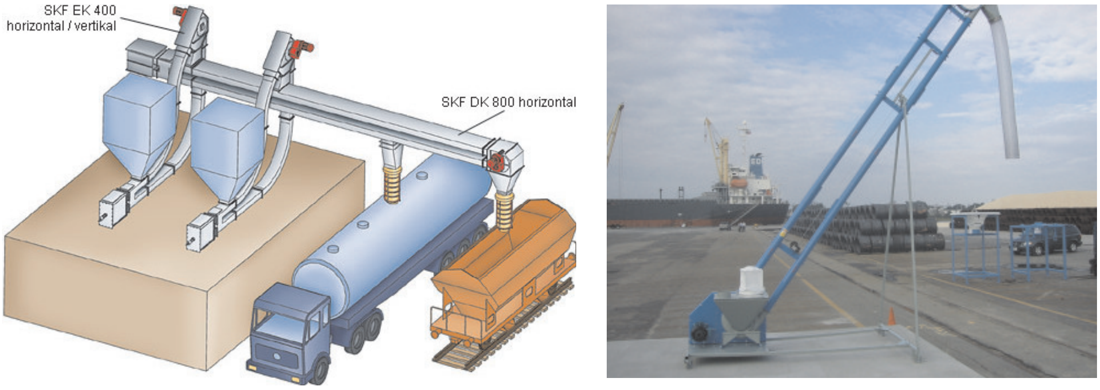

Fig. 1. Example of application of scraper pipe conveyors for loading vehicles and railway carriages (Krause *et al*. 1999)

2. RESISTANCES OF MOVEMENT AND DRIVE POWER OF STRAIGHT CONVEYOR

On total resistance of movement W_0 of scraper pipe conveyor (Fig. 2) consists transported material resistances of movement and pull rod with scrapers resistances of movement (Furmanik 2009):

– resistance of loaded part:

$$W_l = L \cdot [\frac{\pi(D^2 - d^2)}{4}\gamma_m(\mu\cos\alpha + \sin\alpha)\cdot \cdot e^{\frac{4\mu kD}{D^2-d^2}h\cdot \mathrm{sgn}(\alpha-\alpha_{grp})} + q(\mu_l\cos\alpha+\sin\alpha)] \quad (1)$$

where a_{grp} – boundary pipe inclination angle at which resistances are equal to zero,

– resistance of empty part:

$$W_{pr} = qL(\mu_l\cos\alpha - \sin\alpha) \quad (2)$$

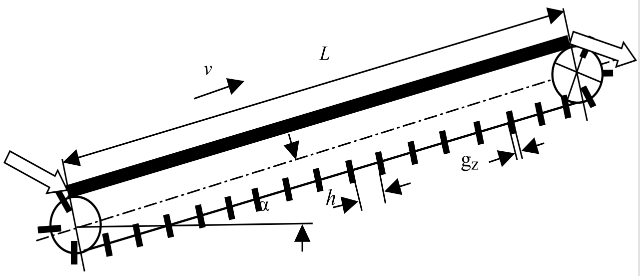

Fig. 2. Scraper pipe conveyor scheme

Conveyor's total resistance of movement for $a > a_{grp}$ will be:

$$W_0 = W_l + W_p = = L[\frac{\pi D^2}{4}\cdot(1-\delta^2)\cdot\gamma_m\cdot(\mu\cos\alpha+\sin\alpha)\cdot \cdot\exp\left(\frac{4\mu\cdot k\cdot h}{D(1-\delta^2)}\right) + 2q\cdot\mu_l\cdot\cos\alpha] \quad (3)$$

where:

- D – pipe internal diameter, [m],
- L – conveyor length, [m],
- h – distance between scrapers, [m],
- k – active pressure coefficient,
- α – angle of pipe inclination against the level, [°],
- μ – material against pipe friction coefficient,
- μ_l – scrapers against pipe friction coefficient,
- γ_m – bulk density, [N/m³],
- q – pull rod with scrapers unit weight, [N/m].

Conveyor resistance of movement compared to its length unit:

$$w_j = \frac{W_0}{L} = \frac{\pi D^2}{4}\cdot(1-\delta^2)\cdot\gamma_m\cdot(\mu\cos\alpha+\sin\alpha)\cdot \cdot\exp\left(\frac{4\mu\cdot k\cdot h}{D(1-\delta^2)}\right) + 2q\cdot\mu_z\cdot\cos\alpha\left[\frac{\mathrm{N}}{\mathrm{m}}\right] \quad (4)$$

where:

$\delta = \frac{d}{D}$,

d – pull rod diameter.

Efficiencies of two conveyors with index 1 and 2, and parameters h_1, D_1 and scrapers velocity v_1 and h_2, D_2 and v_2, will be the same, when:

$$\left(\frac{D_1}{D_2}\right)^2 = \frac{v_2}{v_1} \text{ and } \frac{v_2}{v_1} = \frac{h_2}{h_1} \text{ thus } \left(\frac{D_1}{D_2}\right)^2 = \frac{h_2}{h_1} \quad (5)$$

Inserting coefficient c as:

$$c = \frac{D_1}{D_2} \quad (6)$$

we got:

$$D_2 = \frac{D_1}{c} \quad (7)$$

and according to dependence (5) we will get:

$$h_2 = c^2\cdot h_1 \text{ and } v_2 = c^2\cdot v_1 \quad (8)$$

and ratio of unit resistances of conveyors 1 and 2 will be:

$$\frac{w_{j2}}{w_{j1}} = k_W(c) = \frac{\frac{\pi D_2^2}{4}\left(1-\delta^2\right)\cdot\gamma_m\cdot(\mu\cdot\cos\alpha+\sin\alpha)\cdot\exp\left(\frac{4\mu\cdot k\cdot h_2}{D_2(1-\delta^2)}\right)+2q_2\cdot\mu_z\cdot\cos\alpha}{\frac{\pi D_1^2}{4}\left(1-\delta^2\right)\cdot\gamma_m\cdot(\mu\cdot\cos\alpha+\sin\alpha)\cdot\exp\left(\frac{4\mu\cdot k\cdot h_1}{D_1(1-\delta^2)}\right)+2q_1\cdot\mu_z\cdot\cos\alpha} \tag{9}$$

Unit weight of pull rod with scrapers is:

$$q = q_l + q_z \tag{10}$$

where:
q_l – pull rod unit weight (chain or steel rope), [N/m],
q_z – scrapers unit weight, [N/m].

Unit weights of pull rod and scrapers depends on values of parameters h and D and correspondingly are equal [2]:

$$q_l = \frac{\pi\cdot d^2\cdot\gamma_l}{4} = \frac{\pi\cdot D^2\cdot\delta^2\cdot\gamma_l}{4}\left[\frac{\mathrm{N}}{\mathrm{m}}\right] \tag{11}$$

$$q_z = \frac{D^2}{h+g_z}\cdot\frac{\pi\cdot g_z\cdot\gamma_z}{4} \cong \frac{\pi\cdot g_z\cdot D^2\cdot\gamma_z}{4\cdot h} = \frac{\pi\cdot\delta_z\cdot D^3\cdot\gamma_z}{4h}\left[\frac{\mathrm{N}}{\mathrm{m}}\right] \tag{12}$$

where:

$$\delta_z = \frac{g_z}{D} \tag{13}$$

g_z – scraper thickness, [m],
γ_l – rope specific gravity (rope type 35(W)×7; γ_l = 55000 [N/m^3]), [N/m^3],
γ_z – scraper specific gravity (for cast iron γ_z = 72 000 [N/m^3]), [N/m^3].

After including of above relations in dependence (9) it is given:

$$k_W(c) = \frac{\frac{\pi D_1^2}{4\cdot c^2}\left(1-\delta^2\right)\cdot\gamma_m(\mu\cdot\cos\alpha+\sin\alpha)\cdot\exp\left(\frac{4\mu\cdot k\cdot h_1\cdot c^3}{D_1\left(1-\delta^2\right)}\right)+2\left(\frac{\pi\cdot\delta^2\cdot D_1^2\cdot\gamma_l}{4\cdot c^2}+\frac{\pi\cdot\delta_z\cdot D_1^3\cdot\gamma_z}{4h_1\cdot c^5}\right)\cdot\mu_z\cos\alpha}{\frac{\pi D_1^2}{4}\left(1-\delta^2\right)\cdot\gamma_m(\mu\cdot\cos\alpha+\sin\alpha)\cdot\exp\left(\frac{4\mu\cdot k\cdot h_1}{D_1\left(1-\delta^2\right)}\right)+2\left(\frac{\pi\cdot\delta^2\cdot D_1^2\cdot\gamma_l}{4}+\frac{\pi\cdot\delta_z\cdot D_1^3\cdot\gamma_z}{4h_1}\right)\cdot\mu_z\cos\alpha} \tag{14}$$

Based on the assumption that friction coefficients μ and μ_z do not depend on pull rod velocity v (they are constant), finding of conveyor parameters in which resistances of movement are minimal is reduced to obtaining parameters D_2 and h_2, or their ratio $\frac{D_2}{h_2}$. Inserting ratio:

$$x_1 = \frac{D_1}{h_1} \tag{15}$$

to dependence (14) it is given:

$$k_W(c) = \frac{\frac{\pi}{4\cdot c^2}\left(1-\delta^2\right)\cdot\gamma_m\cdot(\mu\cdot\cos\alpha+\sin\alpha)\cdot\exp\left(\frac{4\mu\cdot k\cdot c^3}{x_1\left(1-\delta^2\right)}\right)+2\left(\frac{\pi\cdot\delta^2\cdot\gamma_l}{4\cdot c^2}+\frac{\pi\cdot\delta_z\cdot\gamma_z}{4c^5}x_1\right)\cdot\mu_z\cdot\cos\alpha}{\frac{\pi}{4}\left(1-\delta^2\right)\cdot\gamma_m\cdot(\mu\cdot\cos\alpha+\sin\alpha)\cdot\exp\left(\frac{4\mu\cdot k}{x_1\left(1-\delta^2\right)}\right)+2\left(\frac{\pi\cdot\delta^2\cdot\gamma_l}{4}+\frac{\pi\cdot\delta_z\cdot\gamma_z}{4}x_1\right)\cdot\mu_z\cdot\cos\alpha} \tag{16}$$

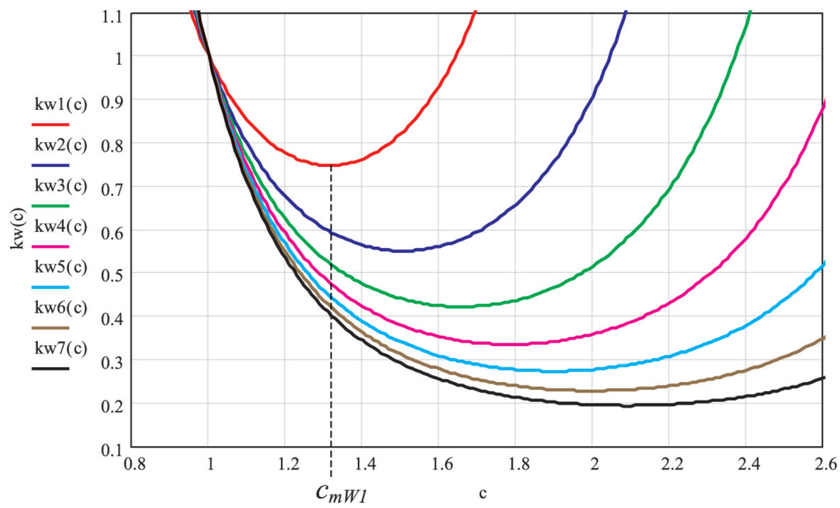

Fig. 3. Graphs of dependence $k_W(c)$ at: x_1 = 0.5; 0.75; 1.0; 1.25; 1.5; 1.75; 2.0, $\alpha = 0^o$, γ_m = 7357.5 [N/m^3]; μ = 0.563; μ_z = 0.3; k = 0.085 (dry coal) (Kasza 2008)

Obtained dependence (16) has non dimensional form and depends on parameters characterizing kind and properties of friction pair: transported material – pipe (γ_m, μ, k) and pull rod with scrapers – pipe (μ_z), and also on angle α of pipe inclination against the level and parameters δ and δ_z. Dependence (16) allows to obtain value of parameter $c = c_{mW,}$ in which values of ratio $k_W(c)$ are minimal (Fig. 3) – therefore minimal conveyor resistances of movement, not only for D_1 and h_1, but also for their set defined as a constant ratio D_1/h_1. Value of parameter $c = c_{mW}$ one should obtain from equation:

$$\frac{d}{dc} k_W(c) = 0 \tag{17}$$

From dependence (17), it is hard to analytical obtain value of parameter c_{mW} in general form, but numerical obtaining is possible.

On Figure 3 one presented for example graphs $k_W(c)$ for dry coal, at different values of parameter x_1 (Kasza 2008).

For ratio $x_1 = \frac{D_1}{h_1}$, from graph $k_W(c)$ one can obtain value of parameter $c = c_{mW}$ (Fig. 3), at which conveyor unit resistances of movement w_{j2} are minimal.

Then using dependences (5) and (15) we obtain:

$$x_2 = \frac{D_2}{h_2} = \frac{D_1}{c_{mW}} \cdot \frac{1}{c_{mW}^2 \cdot h_1} = \frac{D_1}{c_{mW}^3 \cdot h_1} = \frac{x_1}{c_{mW}^3} \tag{18}$$

and values of conveyor parameters:

$$D_2 = \frac{D_1}{c_{mW}};\ h_2 = c_{mW}{}^2 \cdot h_1 \text{ and } v_2 = c_{mW}{}^2 \cdot v_1 = c_{mW}{}^2 \cdot \frac{h_1}{1} \tag{19}$$

at which conveyor resistances of movement are minimal.

According to presented method one obtain, for given kind of transported material, the same ratio x_2 independently of values D_1 and h_1, therefore of their ratio $\frac{D_1}{h_1} = x_1$. On Figure 4 one presented graphs of parameter x_2 dependence on parameter x_1 for different kinds of transported materials, which were included in laboratory tests (Kasza 2008), at $\alpha = 0^o$.

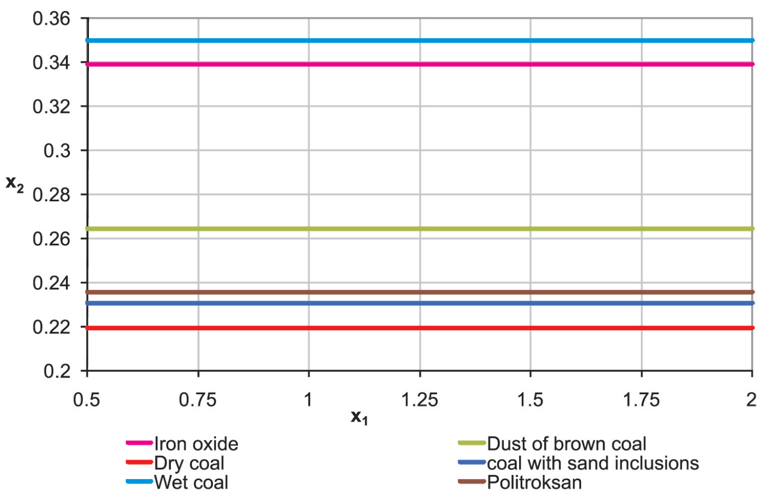

Fig. 4. Graphs of dependence of parameter x_2 from parameter x_1 for different kinds of transported materials at $\alpha = 0^o$ (Kasza 2008)

As presented on Figure 3, for given kind of transported material, independently of values x_1, one obtain only one, constant value of parameter x_2. Obtained ratio $x_2 = D_2/h_2$ for specific kind of material (for iron oxide $x_2 = 0.339$) one can obtain according to dependence (19) values of h and D parameters and velocity v, at which conveyor resistances of movement are minimal. It is significant for designing and exploitation practice of scraper pipe conveyors, because wear and durability of conveyor elements depend on resistances of friction.

On account of quite small lengths, efficiencies and speed of scraper pipe conveyors, their drive powers are not too big, but it is very interesting, if there is possibility to obtain such values of D and h parameters, at which drive power is minimal? Searching answer for that question, following analysis were carried out.

Corresponding to unit resistances w_j unit power is given:

$$N_j = w_j \cdot v \tag{20}$$

Based on the assumption that:

$$v_1 = \frac{h_1}{1};\quad v_2 = \frac{h_2}{1} \tag{21}$$

and including dependence (8) one obtain:

$$k_N(c) = \frac{N_{j2}}{N_{j1}} = \frac{w_{j2}\cdot v_2}{w_{j1}\cdot v_1} = \frac{w_{j2}\cdot h_2}{w_{j1}\cdot h_1} = k_w c^2 \tag{22}$$

Minimal power one obtain from equation:

$$\frac{d}{dc} k_N(c) = 0 \tag{23}$$

Dependence (23) allows to obtain values of $c = c_{mN}$ parameters, at which one obtain minima values of ratio $k_N(c)$ – therefore minima driver power, not only for D_1 i h_1, but also for their set defined as a constant ratio D_1/h_1. Analytical obtaining of value of parameter c_{mN} from dependence (23) is very difficult, but it is very easy to obtain it numerically (Fig. 5).

Initial values of parameters D_1 i h_1 are taken from given volumetric efficiency:

$$Q_v = \frac{\pi D_1^2}{4}\cdot h_1\cdot v_1 = \frac{\pi D_1^2}{4}\cdot h_1\cdot\frac{h_1}{1} = \frac{\pi D_1^2}{4}\cdot\frac{h_1^2}{1} \tag{24}$$

Using dependences (14) and (22) one should prepare graphs of dependence $k_N(c)$, and then obtain $c = c_{mN}$. Example calculations for data as on Figure 3 were carried out below, and their results are on Figure 4, it is important that unit resistances of movement w_j are in [N/m], angle α in [^{o}], and unit power N_j in [W/m].

As it is shown on Figures 3 and 5 obtained graphs are similar, but valuable different. From Figure 4 one can obtain for given ratio $x_1 = D_1/h_1$ value of parameter $c = c_{mN}$, at which conveyor unit power is minimal.

Following analogical for obtained value of parameter $c = c_{mN}$ one calculate values $D_2 = D_1/c_{mN}$, $h_2 = c_{mN}^2 \cdot h_1$ and conveyor speed $v_2 = h_2/1$, at which one can obtain conveyor minimal resistances of movement. For accepted changeability range of parameter $x_1 = 0.5–2.0$ at $\alpha = 0^o$ on the base on obtained graphs from figures 3 and 5 one obtain constant ratio $c_{mN}/c_{mW} \cong 0,7$.

Presented above method of obtaining values of parameters D_2, h_2 and v_2 of scraper pipe conveyors allows on minimization of their resistance of movement (and reduce wear of parts), or needed drive power, what gives measurable technical and economical benefits and is essential in rational designing and exploitation of scraper pipe conveyors.

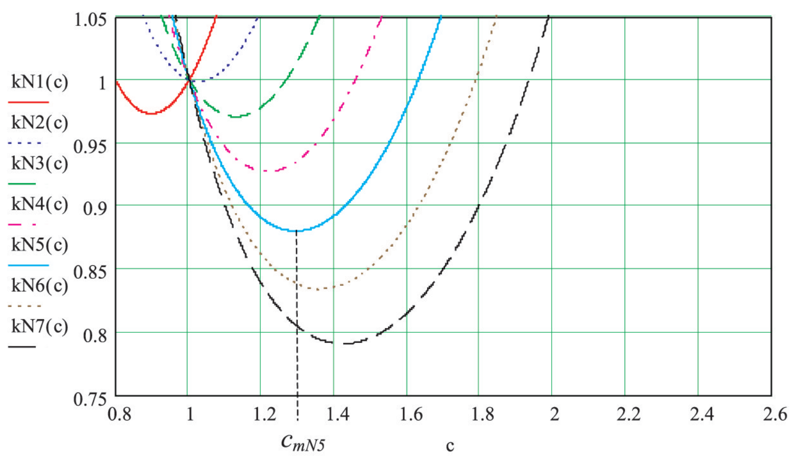

Fig. 5. Graphs of dependence $k_N(c, x_1)$ at: $x_1 = 0.5; 0.75; 1.0; 1.25; 1.5; 1.75; 2.0$, $\alpha = 0^o$, $\gamma_m = 7357.5$ [N/m^3]; $\mu = 0.563$; $\mu_z = 0.3$; $k = 0.085$ (dry coal)

3. CONCLUSIONS

Scraper pipe conveyors allows to mechanize and automatize transport processes of bulk, dust materials and even pulp. Due to their many advantages they have many applications in different branches of industry, especially there where are high requirements regarding to environmental protection and work safety. They create new possibilities of solving technical transporting problems, which in general economical, exploitation and ecological balance, could be more favorable than other transport devices. Significant disadvantage of those conveyors – great resistances of movement (and friction) – and caused by them wear of parts could be reduced by proper selection of values of scraper pipe conveyor basic parameters such as: internal pipe diameter, distance between scrapers and speed, at which resistances of movement or needed drive power are minimal. In the paper had been presented method of obtaining those parameters which are essential in rational designing and exploitation of scraper pipe conveyors.

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