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High-Pressure Coal Feeding Techniques Using Bin-Type Feeders

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Hydraulische Hochdruck-Förderverfahren für Kohle mit Bunkerzuförderung
Techniques d'alimentation du charbon sous haute pression à l'aide de systèmes d'alimentation du type à trémie
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الاساليب الفنية لتلقيم الفحم بالضغط العالي باستخدام مغذيات صفيحة النوع. بقلم دبليو. تانيوا.

Summary

Starting from a brief introduction of the high-pressure bin-type coal feeding technique, a hydrohoisting system successfully developed in China and applicable to deep shafts and to mines intending to keep a low percentage of degradation of lump coal product or to mines producing ROM with a high pyrite content, reference is made both to the practical effects achieved in the industrial field and to the experience and progress made in the experimental investigations in recent years.

Notation

A	Hoisting capacity	t/h
C_x, C_y	Factors of lateral thrust and uplift, respectively, applied to solid particles	—
D	Inner diameter of pipe	m
D_p, D_z	Outside diameter of screw and shaft diameter, respectively	m
D_t	Inner diameter of screw casing	m
d	Mean particle size	m
f	Coefficient of friction between material in water and pipe wall	—
g	Gravitational acceleration	m/s^2
G	Coal transporting intensity (weight of coal fed per unit time)	t/min
H_s	Suction head of water pump	m
H_o, H_m	Height of water column in fresh water pipe and vertical height of slurry in coal/water pipe, respectively	m
h_o, h_m	Resistance loss in fresh water pipe system and of coal/water pipe system, respectively, in terms of height of water column	m H_2O
i_o, i_m	Hydraulic gradients of fresh water and slurry, respectively, in pipeline	m
K	Degree of opening, by-pass valve (opening area of valve to total area)	—
L_o, L_m	Length of fresh water pipe and coal/water pipe, respectively	m
N	Shaft power of water pump	kW
n	Speed of helical constant-rate coal feeding unit	rpm
Q	Total flow, rate	m^3/h
Q_l	Flow rate in by-pass pipe	m^3/h
Q_k	Critical rate of flow	m^3/h
S	Pitch of the screw of the helical constant-rate coal feeding unit	m
T	Period of duty cycle	s
t_s	Time of transporting coal	s
V_a, V_b	Mean fluid velocity at pump inlet and outlet, respectively	m/s
V_j	Mechanical pushing speed of screw mechanism	m/s
V_o	Mean fluid velocity in screw chamber	m/s
V_k	Critical speed for pipe	m/s
W	Weight of feed per bin	t
ω	Settling speed of material in static	m/s
α, β	Linearity factor of ψ and V_o/V_j	—
γ_t, γ_s	Bank density and bulk density of material, respectively	t/m^3
γ_o, γ_m	Volume weight of water and slurry, respectively	t/m^3
Δ	Clearance between screw and casing	m
δ	Thickness of screw vane	m
η	Efficiency of water pump	%
θ	Pipeline inclination	degree (°)
λ_o, λ_m	Resistance factors for fresh water and slurry in pipeline, respectively	—
ξ	Dilution (weight of water to coal)	—
ψ	Factor of mechanical push	—
ψ_0	Factor of hydraulic flush	—

1. Introduction

In China, slurry pumps are mostly used for hydro-transport and hydrohoist of coal. According to practical experiences over the years, better techno-economic benefits can be obtained by employing the high-pressure bin-type coal

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feeding technique for deep shafts or shallow shafts where high pyrite ROM coal is to be hoisted as well as for mines where less degradation in mine output is required.

The major points covered in this study are:

1. Development of high-pressure coal feeding equipment which will work as an aggregate together with the pump and determination of the optimum parameters of this aggregate.
2. This feeding equipment would feed coal in such a way that coal will be fed directly into its high pressure chamber under normal pressure, instead of passing through the impeller of a centrifugal pump or the valves of a reciprocating pump. The coal is then, after being cut off from the atmosphere, fed under high pressure into the slurry hoisting pipeline from the high pressure chamber evenly, efficiently and continuously. The high-pressure coal feeding equipment developed in China operates on the principle that equi-volume replacement of coal and water takes place in the high pressure chamber.

The high-pressure coal feeding technique has the following advantages:

1. Reduction of extensive wear to equipment.
2. Less degradation of lump size.
3. Applicable to deep shafts or old mines extending shafts. When underground output is increased and conventional winding system is employed for hoisting the coal, then it would be the appropriate approach to install such a feeding unit along with the necessary pipelines, if there is no possibility to increase the winding capacity of the original installation. Up to the present moment, slurry pumps that can handle large lump sizes against a high head and with high efficiency are hardly obtainable. The installation under review offers a solution that is plausible and feasible.
4. Better flexibility for hoisting coal either mined conventionally or hydraulically.

The high-pressure coal feeding equipment developed in China is bin-type. Its high-pressure chamber is a vessel of large diameter, capable of accommodating a large volume of material and susceptible to high pressure, and can be installed slantwise. Coal is introduced into the hoist pipeline by a pure hydraulic action leading thus to a simpler construction of the unit.

The first high-pressure bin-type coal feeding unit, the FS-125, successfully developed in China in 1958, has been in normal operation for as long as fifteen years in Senbukeng Coal Mine of Fushun Mining Administration indicating that it is a new technical approach for deep shaft hoisting. It is superior to conventional winding systems in terms of simplicity, low capital cost, short lead-time and low operating cost. In comparison with a slurry pump system, in spite of higher capital cost, it is still viable techno-economically by virtue of its low operating cost. Significant progress is experienced in the study of this technique in recent years, in line with the rapid development of the China coal industry.

Up to the present, the H. P. bin-type feeding units now in operation include type FS-125 and type Beilongfeng as installed in mines of the Fushun Mining Administration. Units that will be put into service soon include the HLG-165 to be used in the Huafeng Mine of the Xinwen Mining Administration and YLG-165 to be used in Yangzhuang Coal Mine of the Feicheng Mining Administration. The technical features are shown in Table 1.

2. High-Pressure Bin-Type Coal Feeding Equipment

The early design of bin-type coal feeding equipment, the type FS-125, is shown in Fig. 1 A. This unit, measuring 1 m I/D for its high-pressure chamber and 32 m in length, is a structure of pieces of sectionalized welded steel plates. The sections are brought underground and butt-welded to form a single unit which will be installed at an inclination of 45 ° and

Table 1:

	FS-125	**Bei Longfeng**	**HLG-165**	**YLG-165**
Pipe arrangement	U-shaped	U-shaped	U or L-shaped	U or L-shaped
Material to be lifted	ROM coal	ROM coal	ROM coal	ROM coal
Grain size, mm	0—120	0—120	0—50(1)	0—50(1)
Lifting height, m	392—557	540	600	212
Lifting capacity, t/h	100—120	144	165(2)	165(2)
Discharge pipe, mm	∅ 326x11	∅ 300	∅ 273x10	∅ 273x10
Discharge pipe length, m	1870	1375	2110	1880
Flow-rate inside the pipe, m/s	2.48	2.48	2.58	2.58
Coal/water ratio (by weight)	1:6	1:5.5	1:2	1:1.8
Operating pressure, kg/cm^2	48—64	63	90	46
Inner diameter of the bin, m	∅ 1.0	∅ 1.0	∅ 1.4	∅ 1.4
Length of the bin, m	32	30	12	12
Bin volume, m^3	25	25	17	17
Bin inclination, degree °	45	58	90	90
Duty cycle, min	17	15	11	11

Note: (1) Grain size of 0—50 mm is requested by the coal preparation plant.
(2) The hoisting capacity of 165 t/h is the designed capacity.

operate under a working pressure of 64 kg/cm². The two bins work alternately and are semi-automatically controlled, giving an hourly lifting capacity of 120 t. That the unit is simple in structure and feeding of coal is solely hydraulic, reduces mechanical wear and eliminates the need of high pressure sealings. Practical use reveals that the unit works perfectly well under high pressure however, with minimal maintenance.

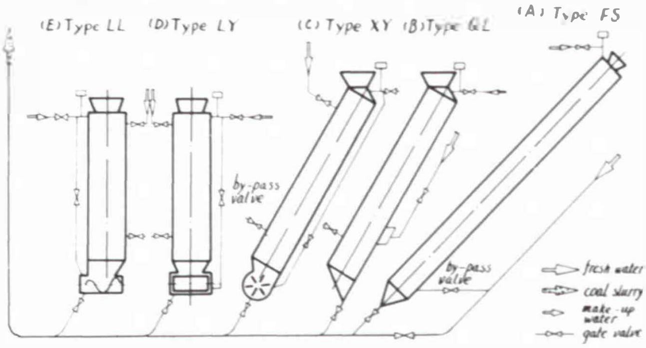

Fig. 1: Schematic diagram of various types of bin-type coal feeding equipment

It does have shortcomings, however, such as unevenness of feeding, leading to large fluctuations in slurry resistance, greater length of bin, etc. With a view to making the unit compatible to mines where high hoisting capacity is desirable, a pilot system to the scale of 1:6 was set up in the laboratory in the early 1970s. Extensive studies were carried out in respect to the dependence of transporting intensity on inclination of the bin, the effects of the variation in length of the feeding section and the shape and size of short feeding pipe on the efficiency of transporting the coal, and effect of matching of the space angle between the two flushing pipes on the feed concentration. Thereby a number of structural parameters such as the reasonable bin inclination, the appropriate length of the feed pipe, the matching of the space angle between the two flushing pipes, and the proper shape and length of the short feeding pipe were identified, which, in turn, doubled the transporting intensity (the quantity of coal in weight fed from the H.P. chamber into the slurry pipe per unit time), brought up the slurry concentration to 3 times the original and reduced the length of the bin by two thirds of the original. On another pilot system, in the scale of 1:2, intermediate tests were made, whereby accuracy of design as well as reasonableness and reliability of the structure were all verified.

This modified unit, type QL, as shown in Fig. 1B, has already been scaled up and applied to a rock bin with a capacity of 50 tons each.

There are two approaches for improving the evenness of feeding. One is to develop a set of automatic regulators for efficiently controlling the feed concentration in such a way that the coal valve will be adjusted automatically responding to the variation in concentration. The second approach is the introduction of a mechanical measuring device which will ensure fixed-amount feeding.

Experimental investigations have been carried out on the latter. On the basis of the experience obtained with the operation of measuring devices employed in hydraulic mines, the constant-rate feeding device was installed in the bottom of the bin. Tests have been made on the 1:6 model system where the devices were fitted beneath bin-type coal feeders types XY (Fig. 1C), LY (Fig. 1D) and LL (Fig. 1E). The results of the tests are as follows:

1. A great improvement was achieved in terms of evenness of feeding with those with mechanical device over those without, type QL, as shown in Fig. 2. Given the same transporting intensity, the feed concentration (expressed in terms of pressure gradient) vs. time for type XY is much more flat than that of type QL.

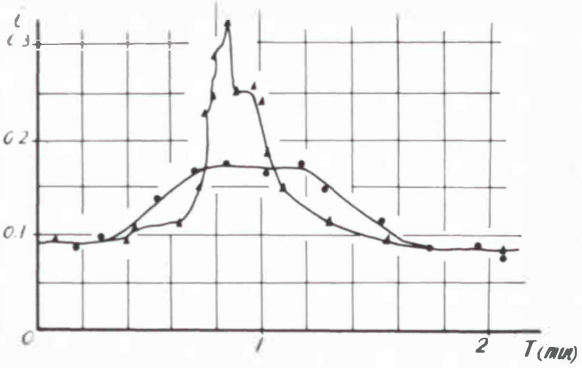

Fig. 2: Transporting concentration (expressed as hydraulic gradient *i*) versus time *T*

2. The adjusting range for regulating the coal transporting intensity is much wider compared to that of type QL. The coal transporting intensity will be higher than that of type QL provided appropriate parameters are selected, as shown in Fig. 3.

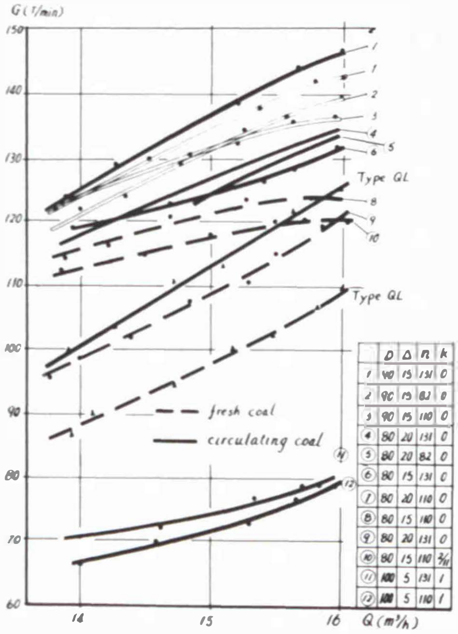

Fig. 3: Test curves of coal transporting intensity for Type XY and Type GL

3. As shown in Fig. 4, types XY, LY and LL behave similarly as far as evenness and intensity are concerned.

Type LL coal feeding equipment has already been applied to the HLG-165 bin-type coal feeding unit of Huafeng Coal Mine in Xinwen Mining Administration. Its bins are 1.4 m in inner diameter and 12 m in length, installed at an angle of 90 ° and operate at a pressure of 90 kg/cm². The two bins operate alternately under automatic control. The design capacity of this unit is 165 t/h. Preliminary coal hoisting tests have been carried out and the equipment will soon be commissioned.

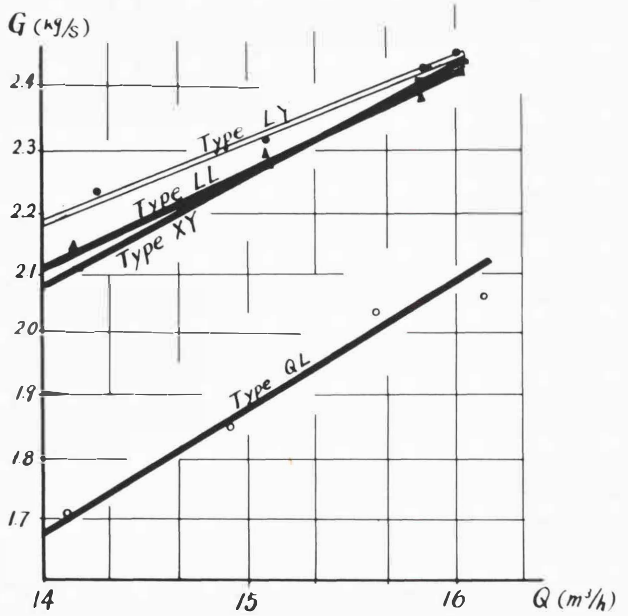

Fig. 4: Comparison of the coal transporting effects of various types of coal feeding equipment

Such coal feeding equipment has been used in YLG-165 bin-type coal feeding unit of Yangzhuang Coal Mine in Feicheng Mining Administration with a design capacity of 165 t/h.

Bin-type feeding units are installed vertically and feeding of coal is the result of a combination of mechanical and hydraulic actions. It is large in capacity and feeds coal at even concentration. It can be installed in underground rooms that can be excavated easily. It can achieve high concentration transport of coal mined either conventionally or in the form of slurry. In addition, the control system is rather centralised.

3. Coal Feeding Parameters

With structural parameters well defined, the productivity of the unit mainly depends on its duty cycle. With two bins operating alternately, the duty cycle depends on the time of transporting coal which, in turn, depends on the transporting intensity, i.e.,

$$t_s = 60 \frac{W}{T} \text{ (s)} \qquad (1)$$

The key parameter is thus the transporting intensity G.

When the bin-type feeding equipment with fixed rate feeding device is in operation, the parameters that could be regulated include the total flow Q, opening of by-pass valve K, and the speed of the feeding device n, or $Q = f(Q.n.K)$.

Attempts have been made with the 1:2 model system to study the general regularity associated with its operation and the results achieved are as follows:

1. Transporting intensity varies with the total flow-rate, $G = f_1(Q)$, as shown in Fig. 5. Coal transporting intensity increases with the increase of total flow.

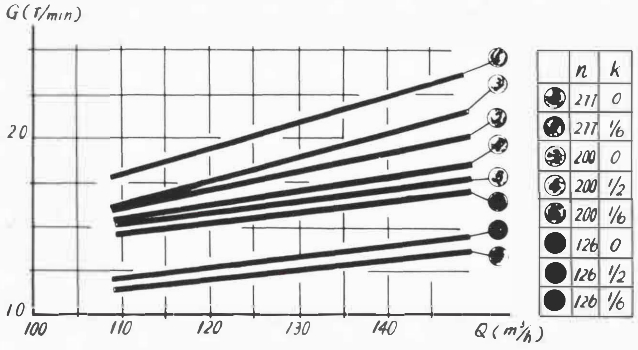

Fig. 5: Coal transporting intensity versus total flow-rate

2. Transporting intensity is a function of speed of the screw, $G = f_2(n)$, and varies as shown in Fig. 6. Intensity does not increase with screw speed infinitely, but finitely. In other words, there is a certain limit, beyond which intensity decreases instead of increasing.

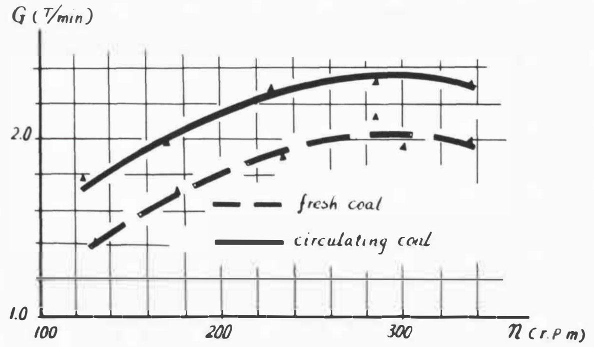

Fig. 6: Coal transporting intensity versus speed of the helix

3. Intensity varies with the opening of the by-pass valve in a pattern as shown in Fig. 7, namely, $G = f_3(K)$. When the by-pass valve is fully closed ($K = 0$), intensity attains a maximum. Then it reduces rapidly with the increase in valve opening, until it reaches a minimum when $K = 2/3$ or so of full opening.

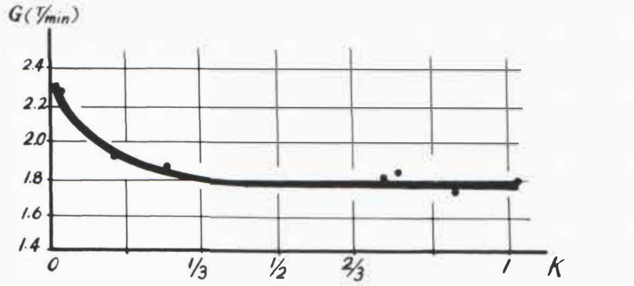

Fig. 7: Coal transporting intensity versus the opening degree of the bypass value

The above mentioned three groups of curves are of certain significance in practical operation and further experimental investigations have been carried out on the basis of the theoretical analysis.

Based on the analysis made on the coal feeding mechanism of the helical feeder, the coal transporting intensity can be expressed by the following equation:

$$G = \psi \frac{\pi}{4} (D_p^2 - D_z^2)(S - \delta) n \cdot \gamma_s +$$

$$+ \psi_o 60 \times \frac{\pi}{4} (D_t^2 - D_p^2) V_o \gamma_s \qquad (2)$$

The above equation consists of two terms:

The first one shows the mechanical pushing action and the hydraulic conveyance of coal by the screw in water. In the case where the bin construction and the material is certain, the non-dimensional coefficient represents the mechanical pushing action coefficient which is related according to the following formulae to the mean velocity of water flow in the helical constant-rate coal feeding unit V_o and the mechanical conveyance velocity of the screw V_r

$$V_o = \frac{Q - Q_e}{\frac{\pi}{4} (D_t^2 - D_z^2)\, 3600} \qquad (3)$$

$$V_j = (S - \delta) n / 60 \qquad (4)$$

The relationship of the above can be represented by the non-dimensional equation

$$\psi = \psi (V_o / V_j). \qquad (5)$$

The latter shows the water flow in the spacing between the screw and the casing which flushes and conveys coal hydraulically. In our experience, the mean velocity of water flow in the spacing of the screw casing may be considered equal to that in the screw passage. The non-dimensional coefficient ψ_o is called hydraulic flushing coefficient. It is a constant in the case where the bin construction and the material is certain.

The latter can be ignored in the case where the spacing between the screw and the casing is very small, namely, $D_t - D_p \approx 0$, and thus

$$G = \psi \frac{\pi}{4} (D_p^2 - D_z^2)(S - \delta) n \cdot \gamma_s \qquad (6)$$

From a large quantity of test data, it is known that there is a linear relationship between the mechanical pushing action coefficient ψ and V_o/V_j, i.e.,

$$\psi = \alpha \frac{V_o}{V_j} + \beta \qquad (7)$$

1. $\psi \approx 1$ in the case of $V_o/V_j = 1$, namely, when the mean velocity of water flow in the screw chamber is equal to that of the mechanical push, the coal transporting capacity of the screw in water then will be equivalent to that of the conventional screw conveyor.
2. $\psi < 1$ in the case of $V_o/V_j < 1$, namely, when the mean velocity of water flow in the screw chamber is lower than that of the mechanical pushing action; the coal transporting capacity of the screw in water will then be lower than that of the conventional screw conveyor.
3. $\psi > 1$ in the case of $V_o/V_j > 1$, namely, in the case where the mean velocity of water flow is higher than that of the mechanical pushing action, the coal transporting capacity of the screw in water will be higher than that of the conventional screw conveyor, and furthermore, the higher V_o/V_j, the higher the coal transporting capacity will be.

In the case of no water flushing action, i.e., $V_o = 0$ and $\psi = \beta$, the coal transporting capacity per minute will be

$$G = \beta \frac{\pi}{4} (D_p^2 - D_z^2)(S - \delta) n \cdot \gamma_s \qquad (8)$$

In the case of the screw remaining at stand still, i.e., $V_j = 0$ and $n = 0$, but with water flushing, then the above equation for G, after substituting in the equation for ψ as given previously, becomes

$$G = (\alpha \frac{V_o}{V_j} + \beta) \frac{\pi}{4} (D_p^2 - D_z^2)(S - \delta) n \gamma_s +$$

$$(9)$$

$$+ \psi_o \frac{\pi}{4} 60 (D_t^2 - D_p^2) V_o \gamma_s$$

Substituting the expression for V_j into above equation results in

$$G = \alpha 15 \pi (D_p^2 - D_z^2) V_o \gamma_s + \psi_o 15 \pi (D_t^2 - D_p^2) V_o \gamma_s \qquad (10)$$

Since all are in a water flushing state, $\psi_o = \alpha$ is to be considered, and the complete equation will be expressed as follows:

$$G = \left(\alpha \frac{V_o}{V_j} + \beta\right) \frac{\pi}{4} (D_p^2 - D_z^2)(S - \delta) n \gamma_s +$$

$$(11)$$

$$+ \alpha 15 \pi (D_t^2 - D_p^2) V_o \gamma_s$$

The values of α and β differ with various run-of-mine coals tested.

The coal transporting intensities of the helical constant-rate coal feeding unit for both HLG-165 and YLG-165 bin-type coal feeding units are obtained on the basis of the above equations in combination with the corresponding test data.

4. Determination of the Parameters of the Pipeline Hydrohoist

Various terms of hydraulic parameters of the coal slurry flowing in the pipeline should be correctly selected so as to achieve a better efficiency in operation in the pipeline hydrohoist system. In practical engineering, it will be simpler to find out the parameters diagrammatically.

The seven groups of curves (Fig. 8) for identifying the various terms of hydraulic parameters are determined diagrammatically in such a way:

1. Mean fluid velocity versus flow-rate.

In determining the pipe diameter D in accordance with the size of material hoisted and the capacity, the value of V can be gained from the following equation, and curve V — Q can be obtained.

$$V = \frac{Q}{900\ \pi\ D^2} \tag{12}$$

2. Critical fluid velocity versus pipe diameter.

There exist many equations in the literature on the calculation of the critical fluid velocity. Based on experience, the following equation is normally used in China for hydraulic filling operations:

$$V_k = \sqrt[3]{\frac{\gamma_m - \gamma_o}{\gamma_m} \cdot \frac{g D}{\lambda_o}} \tag{13}$$

hence curve V_k — D can be obtained.

The rational operating range of flow rate for a certain critical flow rate is $V_k < V < 1.5\ V_k$ and the corresponding rational range of flow rate is $Q_k < Q < 1.5\ Q_k$.

$Q = Q_k$ is represented by line a in the figure and $Q = 1.5\ Q_k$ by line b.

3. Flow rate versus dilution.

   Since

$$Q = \frac{A}{\gamma_o} \left(\xi + \frac{\gamma_o}{\gamma_T}\right) \tag{14}$$

curve Q — ξ can be obtained. We know from tests that the minimum dilution will be down to $\xi \leq 1$. $\xi = 1$ in the figure is represented by line c; and the range of rational parameters is above line c and within the area confined by a and b.

4. Fresh water resistance curve i_o — V.
5. Coal slurry resistance curve i_m — V.

   Here, the equation usually used in hydraulic filling operations remains applicable:

$$i_m = i_o + \frac{\gamma_m - \gamma_o}{\gamma_m} \left(\frac{\omega}{Q} + \frac{f \cos_\theta + \sin_\theta}{1 + f \frac{C_y}{C_x}} \right) \tag{15}$$

$$i_m = i_o + \frac{\gamma_m - \gamma_o}{\gamma_m} \left(\frac{900\ \pi\ D^2 \omega}{Q} + \frac{f \cos_\theta + \sin_\theta}{1 + f \frac{C_y}{C_x}} \right) \tag{16}$$

6. Pipeline curve:

$$H_G = H_s + H_o + \frac{\gamma_m}{\gamma_o} H_m + h_o + h_m + \frac{V_b^2 - V_a^2}{2 g} \tag{17}$$

$$= H_s + H_o + \frac{\gamma_m}{\gamma_o} H_m + i_o L_o + i_m L_m + \frac{V_b^2 - V_a^2}{2 g} \tag{17a}$$

   According to this equation, curve H_G — Q can be obtained.

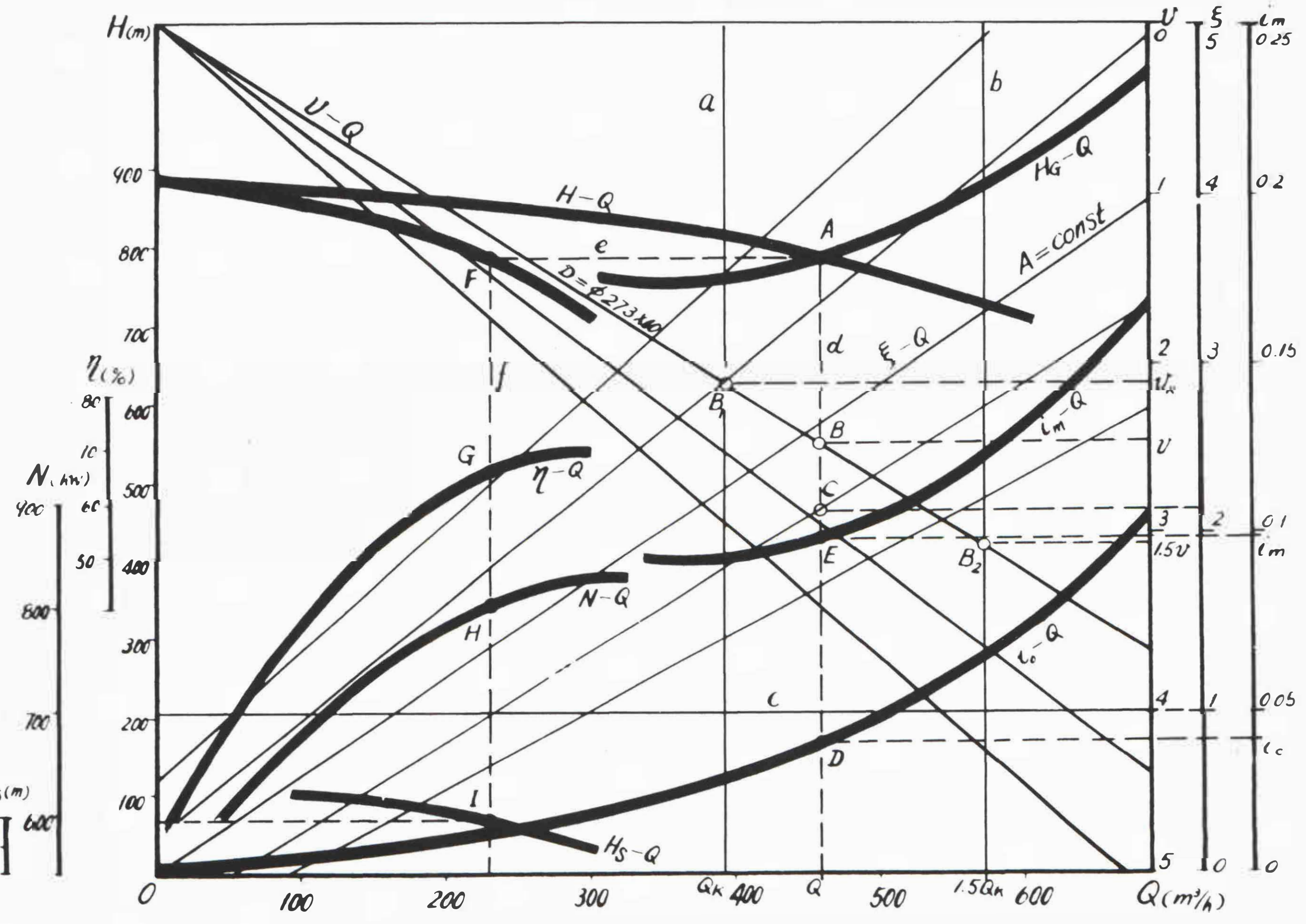

Fig. 8: Performance curves for the coal feeding unit in the hydrohoist system

7. Main water pump curves: $H - Q$; $N - Q$; $\eta - Q$; $H_s - Q$.

The two pumps operate in parallel as shown in the figure.

The abscissa of point A represents the flow Q of the main pump, whereas the ordinate stands for head H.

A perpendicular line leading from point A crosscuts the straight line $V - Q$ at point B. The abscissa of point B represents the mean velocity V.

The straight line d and the straight line which represents a certain dilution ξ of the abscissa intersect with each other at point C. In the $\xi - Q$ straight line group, the value A of the line passing through point C is thus taken as the hoisting capacity.

The straight line d intersects the curve $i_o - Q$ considered as fresh water drag curve i_o.

The straight line d represents the curve $i_m - Q$ at point E. The abscissa of point E is considered as slurry resistance loss i_m.

Various terms of parameters of the hydrohoist system for each point of the state of operation being thus determined, we are now able to select the optimum value as a solid basis of hoisting. We determine the operation parameters of the pipeline hydrohoist system for HLG-165 high-pressure bin-type coal feeding unit in Huafeng Coal Mine on the basis of the above method (Table 2).

Table 2:

Known conditions	Optimum operation parameters
$D_o = 0.253$ m	$Q = 467$ m³/h
$L_o = 250$ m	$V = 2.58$ m/s
$H_o = 0$ m	$V_k = 2.15$ m/s
$\lambda_o = 0.0162$	$i_o = 0.0212$ m/m
$D_m = 0.253$ m	$i_m = 0.0928$ m/m
$L_m = 2110$ m	$A = 160$ t/h
$H_m = 594$ m	$H = 870$ m
$\theta = 16°$	$N = 814 \times 2$ kW
$\lambda_m = 0.0162$	$\eta = 69.2\%$
$\gamma_T = 1.5$ t/m³	$H_s = 4$ m
$\gamma_m = 1.125$ t/m³	

5. Conclusions

Conveying and lifting coal through pipeline with the help of the H.P. bin-type feeding system is a technique that is quite promising. Its good performance is well established in research and practice over the past two decades or more.

The fact that instead of feeding coal through pump impellers of pump valves as is conventional, coal is admitted under normal pressure and then fed into pipelines under high pressure, makes this aggregate comprising the feeding unit and pump set a system competent for use in deep shafts or shallow shafts where less degradation in lump size is desirable and/or high pyritic coal is to be handled, enabling conveying and lifting coal hydraulically.

Laboratory research reveals that the introduction of an additional mechanical fixed-amount feeder underneath the bin-type feeding unit is an effective technical approach to improving the performance of the unit.

Problems in connection with the treatment of replacement of water do exist with this kind of feeding unit. But this is the result of the working principle which has a dual nature inherent in it and can probably be solved by taking some technical measures.

Further work is warranted in respect of an efficiency analysis of the unit, improving the arrangement layout, and research relating to the segregation in the pipelines, the theory pertaining to two-phase flow with uneven large grains, and the analogy of the model installation to the real installation.