Application of Pneumatic Desilting Technology in Zhentou Dam-I Hydropower Station

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Abstract: There are about 200 thousand cubic meters of silt in the tail water section of the first grade hydropower station of Zhentou Dam-I in The Dadu River. A large amount of the silt raises the downstream water level, which seriously influences the tail water form, flood discharge capacity and power generation efficiency of the power station. So there is an urgent demand for silting. There are great technical difficulties in clearing up the silt because of the large proportion of large size pebbles in the silt, the high flow velocity of the river channel and the large variation range of water level in the tail water section, which belongs to the non-navigable area. Thus, the traditional methods like the dredgers are hard to apply. Moreover, the similar engineering cases have not been found in China. Through the productive test, this paper explores the effect of pneumatic silting on the dredging of the mountain areas with large amount of pebbles in The Dadu River, and studies the control index of the output power of the pneumatic silting machine and the production effect of the pneumatic silting system under the different water depth. It provides a new idea for solving the above problems and provides efficient and economical measures for similar projects. The results show that the pneumatic silting machine can achieve efficient silting under this condition. The main factors affecting the effect of silting are water depth, gas supply pressure and gas supply, among which the depth of water has the greatest impact on the efficiency of silting, which indicates that deep water conditions are more conducive to the use of pneumatic silting technology.

1. Introduction

At present, thousands of large and medium-sized hydropower stations and reservoirs have been built in China. With the increase of operation years, some hydropower stations and reservoirs have serious siltation of reservoirs and tail water, which affects the power generation efficiency of power stations and the operation safety of reservoirs.

In October 1989, Gongzui Hydropower Station in Leshan City, Sichuan Province, measured that the siltation elevation of the right bank beach surface has reached 520.0m, and the section 391.5m-585.0m away from the dam has occupied about 1 / 2 of the reservoir surface width[1].The Qingtongxia reservoir of the Yellow River has been silted up rapidly due to its impoundment and operation in the early stage of its construction. Although the operation mode has been changed in the later stage, the reservoir area is still silting up slowly, and only 5% of the reservoir capacity has been left by 2003[2]. By October 2010, the peak of the Delta in the main stream of Xiaolangdi Reservoir of the Yellow River was pushed to the hh12 section 18.75km away from the dam, and the sedimentation volume in the reservoir area reached 2.823 billion m^3[3].

Underwater desilting is a common maintenance measure of river and lake function in the world. There are some researches and corresponding achievements on river and lake desilting technology at home and abroad. In 1964, about 3.7 billion m3 of sediment was deposited in Aswan reservoir. The underwater multistage pump was used for desilting, and high-pressure pump was used on board. The high-pressure water was transported to the nozzle at the end of the dredging boom by venturi effect, and then dredged, and the sediment was transported to the shore in the form of mud through a special pipe[4]. Huanghua port is located on the silt silty coast with large amount of annual silting. It is a port that needs to be maintained and dredged all the year round. The small trailing suction dredger is used for dredging the berth. The final dredging effect is remarkable, and the efficient dredging with economy, convenience and no interference is realized[5].

Zhentou Dam-I Hydropower Station on the main stream of The Dadu River is the first stage of two-stage dam type development of Zhentou Dam-I in the middle reaches of The Dadu River, with an installed capacity of 720MW, an average annual power generation of 3.29 billion kw·h, and a total reservoir capacity of 46.9 million m^3. The main task of the development is to generate electricity and take into account the downstream production and domestic water. The downstream tailwater channel of the hydropower station is 1.1km long, and the sedimentation volume is about 200000m3. A large amount of sediment raises the downstream water level, affects the river flow pattern, flood discharge capacity and power station benefits, so there is an urgent need for desilting. These deposits have a wide range of gradations, including not only sand and pebbles with grain size less than 60mm, but also boulders with grain size of more than 200mm (as shown in Figure 2). Moreover, the water level changes greatly and the flow velocity is high. In the dry season, the river velocity ranges from 2.77m/s to 3.50m/s, which is a non navigable area, so the conventional desilting scheme is difficult to implement.

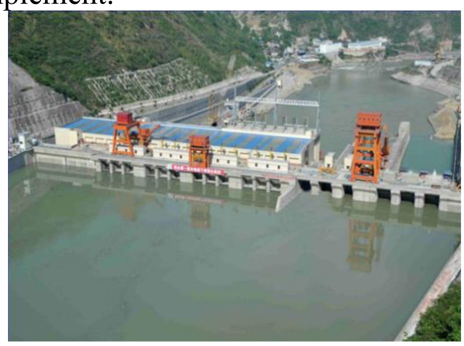


Figure 1: Power station of Zhentou-I Dam.

Figure 2: Sediment form of tailwater channel.

Table 1: Characteristics of dredging equipments in China.

No.	Comparison content	Mechanical dredger			Hydraulic dredger		
		Chain bucket type	Grab type	Bucket type	Cutter suction type	Trailing suction type	Suction type
1	Digging soil type	Silt, clay and soft rock	Gravel, clay	Soft clay, sand, gravel, pebble, etc	All kinds of clay, cutter strength enough to dig rock	Clay and loose sand	Non cohesive soil
2	construction effect of shallow water	preferably	preferably	preferably	preferably	commonly	preferably
3	Positioning method	Anchor positioning, cable moving ship	Steel pile, anchor positioning, cable moving ship	Positioning pile positioning, cable moving ship	Positioning and moving of positioning piles and anchor cables	Digging while walking	Anchor positioning, cable moving ship
4	Flatness of trench bottom	fine	commonly	commonly	preferably	Slightly worse	Poor
5	Construction efficiency	High energy consumption	efficient	high	efficient	efficient	efficient
6	Loading and unloading methods	Mud barge loading	Mud barge loading	Mud barge loading	Suction pipe loading, discharge pipe or barge unloading	Trailing suction pipe + mud tank + sludge discharge pipe	Discharge pipe or barge loading and unloading

At present, the dredging equipment at home and abroad is generally divided into two categories according to the working principle: mechanical dredger and hydraulic dredger. Their characteristics are shown in Table 1.

As a new technology, pneumatic desilting technology has the advantages of good adaptability, high efficiency, good dredging effect and low cost, so it is urgent to study whether it can be applied to the dredging of large-size sediment in The Dadu River.

Based on the experimental study of pneumatic desilting in the tailrace section of Zhentou-I Dam Hydropower Station on The Dadu River, this paper explores the application of pneumatic desilting technology under the conditions of non navigable, high velocity, large particle size riverbed, different water depth, different gas supply pressure and different gas supply quantity.

2. Principle and Equipment of Field Test

2.1.Principle

Pneumatic desilting technology consists of five parts: air floating deep water material collection device, conveying pipeline, gas supply regulating equipment, surface operation platform and auxiliary equipment. The principle of desilting is as follows: the compressed air is output to the riser as the output power of the lifting system, and the special structure of the pneumatic lift pump makes the compressed air enter the vertical riser. The local vacuum generated at this moment causes the pressure outside the pipe to be greater than the pressure inside the pipe; the compressed air itself has energy, which impacts the water after entering the lifting pipe, resulting in a large number of bubbles and bubbles It floats up in the tube and collides with each other to form large bubbles. When its volume increases to a certain extent, it breaks into small bubbles. Under this circulation state, the liquid is affected by the local vacuum formed by the bubble and high-pressure gas, and reaches the top of the riser and is discharged.

2.2.Equipment

SSYA 1000 desilting machine is mainly used in this dredging test. See Figure 3 for equipment structure, FIG. 4 for desilting system and table 2 for main equipment and parameters of pneumatic system. The diameter of the suction port of the desilting pipe is 1000mm; the outlet flow Q of the desilting machine refers to the discharge volume of the outlet water in unit time, which is the product of the flow velocity V at the outlet of the desilting machine and S; the water depth h refers to the water depth at the suction port of the desilting machine; the gas supply pressure P is the gas pressure in the accumulator upstream of the desilting machine, which is the maximum pressure that can be reached before the high pressure gas is released to the dredging pipeline The air supply quantity Qa is the air intake volume per unit time at the air inlet of the air compressor.

Table 2: Parameter table of main equipment for pneumatic dredging technology.

<table>
<tr><th>No.</th><th>Name</th><th>Model and specification</th><th>Quantity</th><th>Remarks</th></tr>
<tr><td>1</td><td>Assembled working platform</td><td>27.0m×9.0m×1.5m</td><td>1</td><td rowspan="4">Platform system</td></tr>
<tr><td>2</td><td>Mooring System</td><td>windlass
8t×250m×φ24mm×2+5t×250m×φ24mm×4</td><td>1</td></tr>
<tr><td>3</td><td>Lifting system</td><td>Lifting boom 30t×15m×1 5t×250m×φ24mm×2</td><td>1</td></tr>
<tr><td>4</td><td>dynamic system</td><td>Diesel generator 150KW×1</td><td>1</td></tr>
<tr><td>5</td><td>Pneumatic deep water desilting machine</td><td>SSYA1000-B</td><td>1</td><td rowspan="3">Dredging system</td></tr>
<tr><td>6</td><td>Steel telescopic sleeve</td><td>DN1000</td><td>1</td></tr>
<tr><td>7</td><td>Air compressor</td><td>XAVS900CD</td><td>9</td></tr>
<tr><td>8</td><td>Steel sludge discharge pipe</td><td>DN1020×12000</td><td>4</td><td>Slag tapping system</td></tr>
<tr><td>9</td><td>echo Sounder</td><td>HD-310</td><td>1</td><td rowspan="2"></td></tr>
<tr><td>10</td><td>Propeller type current meter</td><td>LS-20B</td><td>1</td></tr>
</table>

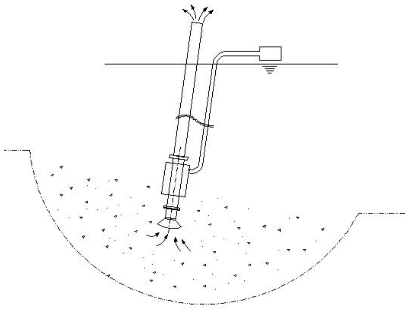


Figure 3: The structure figure of pneumatic silting equipments.

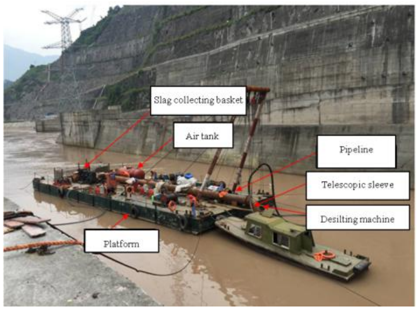


Figure 4: Pneumatic dredging system.

2.3.Method

The desilting test points are arranged at the downstream side of the longitudinal dam 0+485.0. During the test, the tail water flow of the hydropower station varies from 300 to 1600m^3/s, and the corresponding tail water level fluctuates in the range of 593.00-596.00 m. the water depth in the test is 11.0 m and 15.0 m, the flow rate at the test point is 0.666-1.725 m/s, the horizontal row spacing is 23.0 m, and the lift is 1.0 m. by changing the gas supply pressure P (0.6 MPa, 0.7 MPa, 0.8 MPa, 0.9 MPa, 1.0 MPa, 1.1 MPa) and the gas supply volume (175 m^3/min,200 m^3/min, 225 m^3/ min), the test results show that the flow rate is higher than that of the former The discharge Q of SSYA1000 desilting machine is studied.

In the implementation stage, the test contents are as follows:

(1) The flow velocity, water depth and sediment thickness were measured;

(2) Test the anchor cable system and positioning pile and other stable measures, optimize the fixed scheme of the offshore operation platform, and locate the pneumatic slag conveying system to the designated test dredging point;

(3) Connected to the horizontal slag conveying system, through controlling the pneumatic output power of the desilting machine (recording the pressure and displacement of high-pressure gas), and monitoring the flow velocity at the mouth of the desilting machine in real-time through the flow velocimeter to observe the dredging effect;

(4) The outlet flow of the dredger under different water depth and air supply pressure is compared and analyzed.

3. Test Results and Analysis

3.1.Influence of Gas Supply Pressure on Outlet Flow

(1) H=11m

The test results are shown in Table 3.

Table 3: The relationship between gas supply pressure and outlet flow of dredger.

No.	H(m)	P(MPa)	Q_a(m³/min)	Q(m³/h)	△Q(m³/h)	No.	H(m)	P(MPa)	Q_a(m³/min)	Q(m³/h)	△Q(m³/h)
1	11	0.6	175	4681	—	7	11	0.8	200	5318	846
2		0.7		4929	248	8		0.9		5311	-7
3		0.8		5481	552	9		0.6	225	4746	—
4		0.9		4962	-519	10		0.7		4785	39
5		0.6	200	4749	—	11		0.8		5438	653
6		0.7		4472	-277	12		0.9		5351	-87

It can be seen from Figure 5 (1) that Q increases first and then decreases with the increase of P, and reaches the peak value (5481m^3/h, 5318m^3/h, 5438m^3/h) with the increase of P. when P=0.6MPa, q is the lowest value (4681m^3/h, 4749m^3/h, 4746m^3/h), and the range △q is 1128m^3/h, 846m^3/h and 887m^3/h respectively.

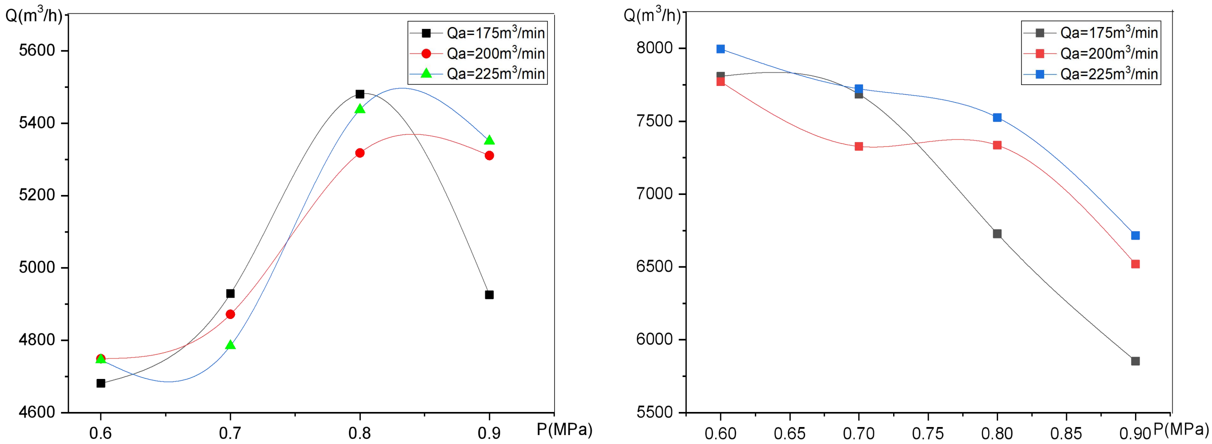
Under the condition of Qa=175m^3/min（200m^3/min、225m^3/min）, when P increases from P (0.6MPa) to P (Q_{max}), Q increases by 5% for every 0.1MPa of gas supply pressure; when P increases from P (Q_{max}) to P (0.9MPa), Q decreases by 10% (5%, 7%) for every 0.1MPa increase.

It shows that the outlet flow of the dredger increases with the increase of air supply pressure at this water level. When the outlet flow reaches the peak value, the value decreases with the increase of gas supply pressure. Under the condition of different gas supply rate, the outlet flow of the desilting machine changes greatly with the change of gas supply pressure, and under the same gas supply pressure, the outlet flow does not increase with the increase of gas supply volume. In order to achieve efficient dredging, it is necessary to find the optimal value by combining the gas supply pressure and gas supply quantity.

(2) H=15m

Table 4: The relationship between gas supply pressure and outlet flow of dredger.

No.	H(m)	P(MPa)	Q_a(m³/min)	Q(m³/h)	△Q(m³/h)	No.	H(m)	P(MPa)	Q_a(m³/min)	Q(m³/h)	△Q(m³/h)
1	15	0.6	175	7809	—	7	15	0.8	200	7336	8
2		0.7		7686	-123	8		0.9		6519	-817
3		0.8		6728	-958	9		0.6	225	7996	—
4		0.9		5854	-874	10		0.7		7723	-273
5		0.6	200	7772	—	11		0.8		7526	-197
6		0.7		7328	-444	12		0.9		6716	-810



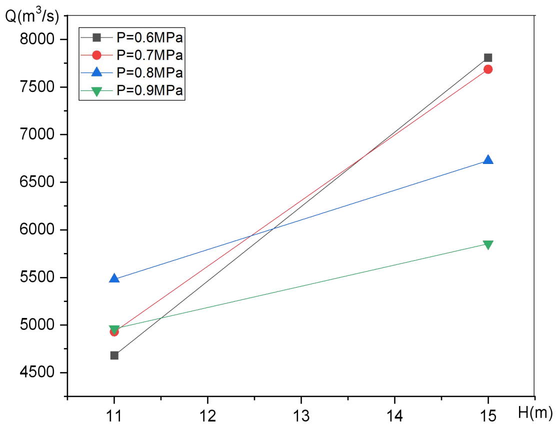
(1) H=11m (2) H=15m

Figure 5: The relationship diagram between gas supply pressure and s outlet flow of dredger.

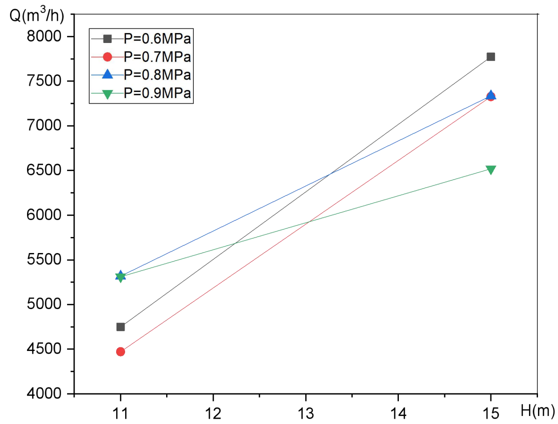
According to Figure 5 (2), when Q_a is 175m^3 / min, 200m^3 / min and 225m^3 / min respectively, Q decreases with the increase of P. when p = 0.6MPa, q is the highest value (7809m^3/h, 7772m^3/h, 7996m^3/h); when p = 0.9mpa, Q is the minimum value, and the range △Q is 1128 m^3/h, 846m^3/h and 887m^3/h, respectively.

Under the condition of Q_a =175m^3 / min (200m^3/min, 225m^3/min), when P increases from P (Qmax) to P (0.8MPa), the dispersion of the decrease difference is large. When P increases from 0.8MPa to 0.9mpa, Q decreases most, about 11.6%. Therefore, under the condition of the same gas supply at this water level, the increase of gas supply pressure leads to the decrease of the outlet flow of the dredger; when the gas supply pressure is constant, the outlet flow of the dredger increases with the increase of the gas supply.

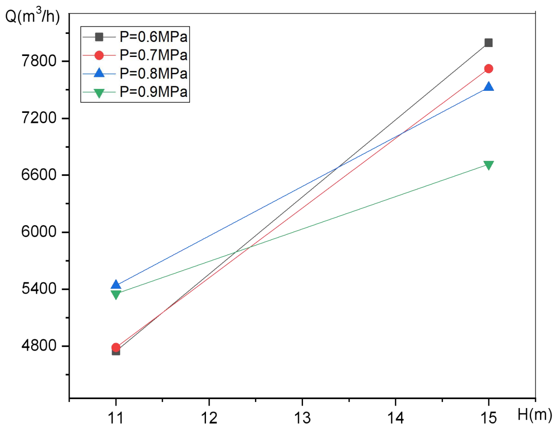
3.2.Influence of Water Depth on Outlet Discharge



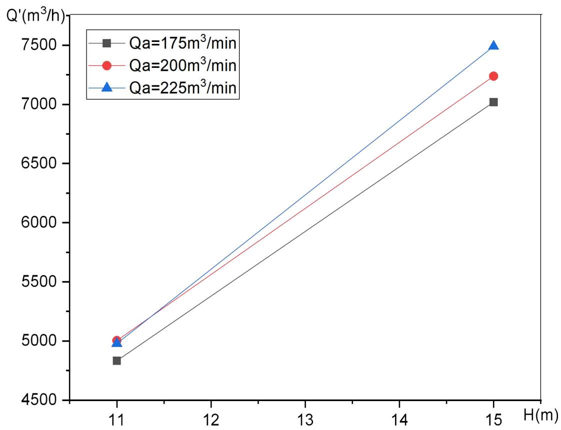
(1)Q_a=175m3/min



(2)Q_a=200m3/min



(3)Q_a=225m3/min



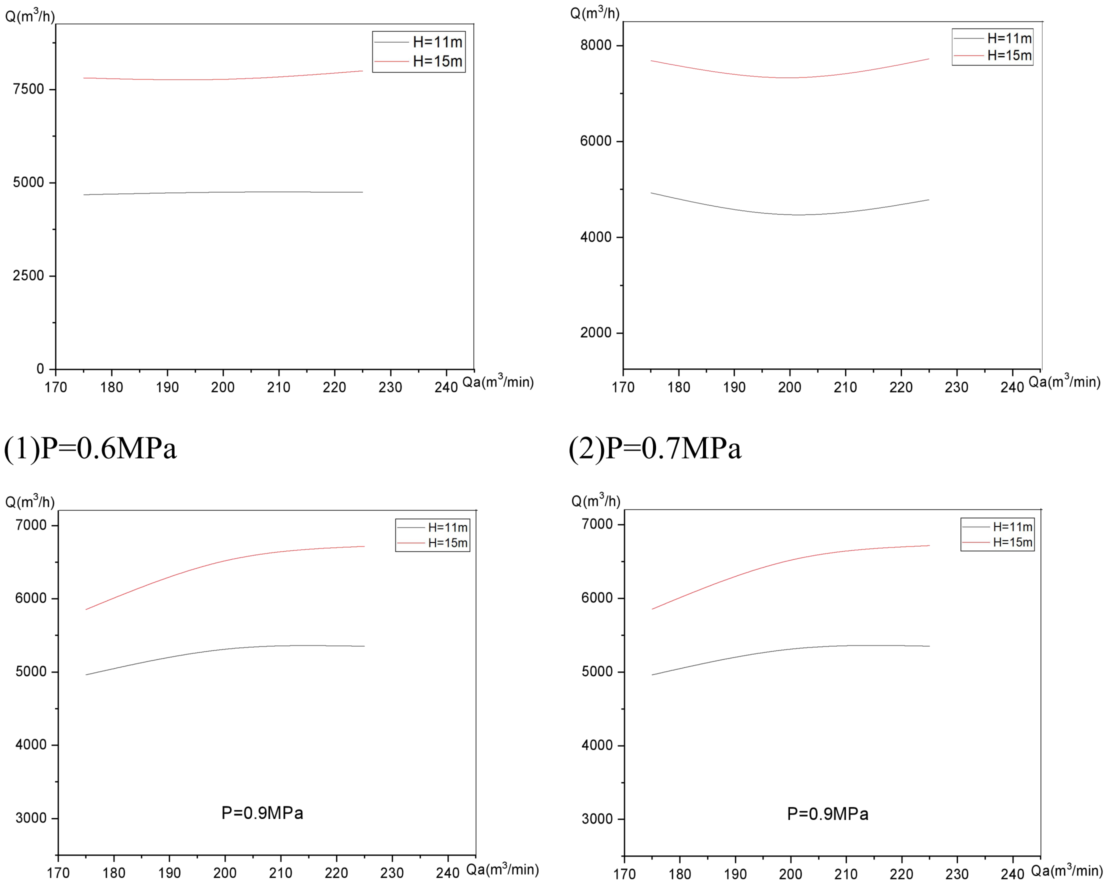
(4)The relationship between Q 'and H

Figure 6: The relationship diagram of water depth and outlet flow of dredger (average flow rate Q').

It can be seen from Figure 6 (1), (2) and (3) that when Qa is constant, Q increases with the increase of H, and its growth rate decreases with the increase of P. When P= 0.6MPa, the growth rate of Q is the largest (66.8%, 63.7, 67.5%), while the growth rate of Q is the smallest (18.0%, 22.7%, 25.5%) when p = 0.9Mpa.

According to Figure 6 (4), Q' increases with the increase of H. under the condition of Qa=225m^3/min, Q' has the highest growth rate, and Q' is the highest at H=15 m (7490 m^3/h). The results show that the outlet flow and average flow of the dredger are positively correlated with the water depth under the condition of constant gas supply and gas supply pressure, and when the water depth reaches a certain degree, the outlet flow of the dredger increases with the decrease of the gas supply pressure.

3.3.Influence of Gas Supply on Outlet Flow



(1)P=0.6MPa (2)P=0.7MPa

(3)P=0.8MPa (4)P=0.9MPa

Figure. 7 The relationship diagram of gas supply and outlet flow of dredger.

It can be seen from Figure 7 that when h is constant, the growth rate of Q with Q_a varies with P value. When h = 11m, under the conditions of P = 0.6MPa and P = 0.9Mpa, Q increases slowly with the increase of Q_a; under the conditions of P = 0.7MPa and P = 0.8MPa, Q first d ecreases and then increases with the increase of Qa; when H = 15m, under the conditions of P = 0.6MPa and P = 0.7MPa, Q decreases first and then increases; when P = 0.8MPa and P = 0.9MPa, Q increases with the increase of Q_a. Therefore, when the water depth reaches a certain degree, the outlet flow of the dredger increases with the increase of gas supply.

3.4.Significant Impact Analysis

In this experiment, H, P, Q_a are used as independent variables and Q as dependent variables. Multiple linear regression method is used to analyze the significance of the three independent variables to determine whether the three independent variables have a significant impact on Q, and which of the independent variables with significant influence has the greatest impact on energy efficiency.

Let x_i be an independent variable and Y a random variable related to x_i :

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + \ldots + b_mx_m + \epsilon \quad , \tag{1}$$

Among them, b_1, b_2, b_3, …, bm is undetermined coefficient, ϵ is random error, and $\epsilon \sim N(0,\sigma^2)$. For an arbitrary set of values x_{1t}, x_{2t}, x_{3t}, ..., x_{mt} , Accordingly, the random variable *Yt* is obtained

$$Y_t = b_0 + b_1 x_{1t} + b_2 x_{2t} + \ldots + b_m x_{mt} + \epsilon_t \quad , \qquad (2)$$

Where t is 1, 2, …, n。 $\epsilon_1, \epsilon_2, \ldots, \epsilon_n$ is independent of each other and obeys normal distribution $N(0,\sigma^2)$.

For the independent variable x_1, x_2, …, x_m and n sets of observations of random variable Y, we make the function

$$Q(b_0,b_1,\ldots,b_m) = \sum_{t=1}^{n} [y_t - (b_0 + b_1 x_{1t} + b_2 x_{2t} + \ldots + b_m x_{mt})]^2, \qquad (3)$$

Obtain the minimum value $\widehat{b_0}$, $\widehat{b_1}$, …, $\widehat{b_m}$ is the coefficient b_0, b_1, …, b_mThe least square estimation of M.

If the matrix *X, Y, B* is

$$X = \begin{bmatrix} 1 & x_{11} & \cdots & x_{1m} \\ 1 & x_{21} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & x_{nl} & \cdots & x_{nm} \end{bmatrix} \quad , \qquad (4)$$

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} \quad , \qquad (5)$$

$$B = \begin{bmatrix} b_0 \\ b_1 \\ \vdots \\ b_m \end{bmatrix} \quad , \qquad (6)$$

Then the normal equations can be written as

$$X^T X B = X^T Y \quad , \qquad (7)$$

If $X^T X$ is invertible, then the normal equation n has a unique solution

$$B = \begin{bmatrix} \widehat{b_0} \\ \widehat{b_1} \\ \vdots \\ \widehat{b_m} \end{bmatrix} = (X^T X)^{-1} X^T Y \quad , \qquad (8)$$

Thus, *Y* is about x_1, x_2, …, x_n, The multiple linear regression equation is

$$\hat{y} = \widehat{b_0} + \widehat{b_1} x_1 + \widehat{b_2} x_2 + \ldots + \widehat{b_m} x_m \quad , \qquad (9)$$

$$\bar{y} = \sum_{t=1}^{n} y_t \quad , \qquad (10)$$

$$\bar{x} = \frac{1}{n}\sum_{t=1}^{n} x_{it} \quad , \qquad (11)$$

$$\hat{Y_t} = \widehat{b_0} + \widehat{b_1}x_{1t} + \widehat{b_2}x_{2t} + \dots + \widehat{b_m}x_{mt} \quad , \qquad (12)$$

$$S_t = l_{YY} = \sum_{t=1}^{n} (Y_t - \bar{Y})^2 \quad , \qquad (13)$$

$$S_h = \sum_{t=1}^{n} \left(\hat{Y_t} - \bar{Y}\right)^2 \quad , \qquad (14)$$

St is the sum of squares of deviation, Sh is the sum of regression squares, where t is 1,2,3 ，n。

$$R^2 = {}^{S_h}/_{S_t} \quad , \qquad (15)$$

$$VIF = (1 - R^2) - 1 \quad , \qquad (16)$$

VIF is the variance expansion factor. The criterion for judging multicollinearity is 10 under normal circumstances. If it is more than 10, it indicates that there is collinearity. The larger the value, the greater the collinearity.

In this experiment, the independent variable is H、P、Q_a, and the dependent variable is Q, so the value of t is 3. The significance test is carried out, and the nonstandard coefficient, standardized coefficient, t, Sig and collinearity statistics are calculated. The statistical analysis of aerodynamic dredging parameters is shown in Table 5.

Table 5: Statistical analysis table of pneumatic dredging parameters.

Model	Coefficient of non standardization		Standard coefficient	t	Sig	Collinear statistics	
	B	Standard error				Tolerance	VIF
（constant）	-1997.506	1380.667		-0.867	0.396		
depth of water	557.771	51.550	0.913	10.820	0.000	1.000	1.000
Pressure of air supply	-1523.296	932.318	-0.139	-1.634	0.118	0.978	1.022
Supply of Gas	6.179	5.492	0.096	1.125	0.274	0.978	1.022

It can be seen from table 5 that the *VIF* (variance expansion factor) of the three independent variables are less than 10, so the three variables h, P and Q_a can have an impact on Q, and the standard coefficient can objectively reflect the influence degree of the independent variable on the dependent variable. The greater the absolute value, the greater the influence of the independent variable on the dependent variable. Therefore, the degree of influence on Q: H > P > Q_a.

4. Conclusion

(1) The results show that the pneumatic desilting machine can adapt to the operation requirements under the condition of high flow rate and large water depth in the experimental river section, and can dredge all kinds of sediment with particle size less than 1000mm, and the comprehensive production capacity is 130m3 / h. It can achieve good dredging production in non navigable, high velocity and large particle size riverbed, and solve the problems of tailrace slag piling and sedimentation in front of high dam.

(2) The change of the outlet flow of the dredger with the supply pressure is related to the water depth. When the water depth is small, the outlet flow of the dredger increases first and then decreases with the increase of the air supply pressure. When the water depth reaches a certain degree, the outlet flow of the dredger decreases with the increase of the air supply pressure.

(3) There is a positive correlation between the outlet discharge of the dredger and the water depth. The test results show that the outlet flow and average discharge of the dredger increase with the increase of water depth. When the water depth reaches a certain level, the outlet flow of the dredger increases with the decrease of gas supply pressure.

(4) The change of the outlet flow of the dredger with the gas supply is affected by the water depth. When the water depth reaches a certain level, the outlet flow of the dredger increases with the increase of air supply.

(5) Water depth, gas supply pressure and gas supply rate have significant effects on the outlet flow of the dredger. The deep water condition is more conducive to the development of pneumatic dredging technology.

Acknowledgments

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