Transportation of river sediments in cylindrical pipeline

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Abstract. This article deals with the hydraulic transport of river sediments in a cylindrical pipeline. To describe the nature of hydraulic phenomena, experiments were provided for single-phase and two-phase flows in field and laboratory condition. According to the results of the experiments, the main hydraulic parameters of the proposed jet device for hydro transportation of river sediments were determined. Based on the processing of the available data, as well as the data of specially commissioned experiments, the dependencies of flow rates, speed, jet constraining and resistance when the pulp flow from the jet apparatus has expired on the Reynolds number, are valid for certain limits of Reynolds number change. As a result of special experiments, the dependences of local resistance coefficients on the Reynolds number for some practically important cases (when the net flow and pulp from the jet apparatus pipeline have elapsed), valid within certain limits of change of Reynolds numbers, are established. The design parameters of the jet apparatus for the purification of water bodies from river sediments are substantiated, the design formulas for determining the hydraulic parameters of the proposed jet apparatus are proposed. A calculation formula for determining the flow rate of the slurry jet apparatus is proposed. As a result of special experiments, the dependences of the coefficient of hydraulic friction on the Reynolds number for various saturations of flow with a suspension are established. The article offers a new method for determination critical velocity two-phase current, and proposed method is valued with given laboratory condition.

1. Introduction

Pipeline transportation is very important in the gas and oil industries, chemical technologies, biomechanics, irrigation, land reclamation and other sectors of the economy.

The hydro transport is characterized by the joint motion of fluid and solid particles, which in a mixture form two-phase or multi-phase flows of different physical and mechanical properties. One of the main tasks of hydro transport is the study of the carrying capacity of pipelines, where taking into account the distribution of sediment concentration over a pipeline section formed under the action of gravitational force which is great importance in describing the nature of a two-phase flow.

As is well known, heavy particles suspended in the flow affect to it, manifested in changes in hydraulic resistances, distribution of the concentration of the second phase and average flow velocities [1-4]. The regularities of the motion of solid particles in a cylindrical pipeline depend, ceteris paribus, on the average flow rate. With a gradual decrease in this speed, approaching a critical one, the weighting capacity of a stream containing a given amount of solid material decreases continuously, which leads to silting of the pipeline.

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At average speeds of movement of the slurry, the lower \( \theta_{cr} \) weighting capacity of the stream, respectively, decreases and solid particles that are in the thickness of the stream, gradually precipitate. Thus, the critical regime of hydro transportation-is the boundary regime of movement of slurry in the pipes. In this regime, the limiting dynamic equilibrium between the flow of the mixture as a whole and the continuous flow of solid particles must be fulfilled.

In constructions, for efficient exploitation and ensuring the reliability of hydraulic structures, septic tanks for various purposes, reservoirs, chambers of pumping stations, it is necessary to study the patterns of river sediment movement and, on their basis, to develop measures to control silting of hydraulic structures. For this, it is necessary to develop rational methods and technologies for cleaning these structures using pressure pipelines with different gradients. In the hydraulic calculation of pipelines of pumping and compressor stations, thermal power plants, hydraulic stations and various hydraulic and gas-air systems, in addition to friction losses, it is also necessary to take into account local pressure losses caused by various locking and regulating devices arising in places where the pipe section changes or the direction of flow [5, 6].

2. Methods

In Figure 1 given the scheme of the experimental installation for hydro transport. Transport of river sediments provided with using an jet device, which is widely used in practice [7,8].

![Figure 1. Scheme of the experimental setup. 1 - tank; 2 - supply pipe; 3 - valve; 4 - discharge pipe; 5 - holes; 6 - disk; 7 - suction pipe; 8 - drain tank; 9 - piezometer; 10 - measuring tank; 11 valve; H - flow head; h-height of suction.](image)

3. Results

As a result of special experiments, the dependences of the resistance coefficients on the Reynolds number were established for some practically important cases (when the net flow and pulp from the pipeline with of a jet apparatus), valid within certain limits of variation of Reynolds numbers.

The results of all experiments performed are summarized in a table in which, along with the values of the initial data (\( \mu, \xi, \phi \)), the calculated values of the dimensionless Reynolds and Froude criteria are also given.
Table 1. The results of experimental studies of the jet apparatus in the hydro transport of a suspended flow.

| H₀-h=H cm | h/ H | t. c | Q. cm³/s | Q₁ cm² | Q₂ cm² | Q₁ sm/s | 2gH | s | Re | Fr | μ | φ | ξ |
|-----------|------|------|----------|--------|--------|----------|------|---|----|----|----|---|---|
| 43        | 0.2  | 7    | 428.5    | 0.502  | 168.7  | 290.4    | 26.0 | 29486. | 23.8 | 0.5 | 0.5 | 1.9 |
| 6         | 0.2  | 2.3  | 432.9    | 0.502  | 170.4  | 287.0    | 26.5 | 29784. | 23.6 | 0.5 | 0.5 | 1.8 |
| 42        | 0.2  | 1.9  | 512.8    | 0.502  | 201.8  | 283.6    | 9.15 | 35283. | 22.7 | 0.7 | 0.7 | 0.9 |
| 41        | 0.2  | 5    | 500.0    | 0.502  | 196.8  | 280.1    | 24.7 | 34401. | 22.2 | 0.7 | 0.7 | 1.0 |
| 40        | 0.2  | 2    | 200.0    | 0.502  | 196.8  | 280.1    | 24.7 | 34401. | 22.2 | 0.7 | 0.7 | 1.0 |
| 39        | 0.2  | 1.8  | 540.5    | 0.502  | 212.8  | 276.6    | 24.6 | 37190. | 21.6 | 0.7 | 0.7 | 0.6 |
| 35        | 0.3  | 1.7  | 561.8    | 0.502  | 221.1  | 262.0    | 14.2 | 38652. | 19.4 | 0.8 | 0.8 | 0.4 |
| 30        | 0.2  | 2.4  | 404.8    | 0.502  | 159.3  | 280.1    | 17.1 | 27855. | 22.2 | 0.5 | 0.5 | 2.0 |
| 40        | 0.7  | 7    | 420.1    | 0.502  | 165.4  | 262.0    | 15.7 | 28908. | 19.4 | 0.6 | 0.6 | 1.5 |
| 35        | 0.3  | 2.7  | 361.0    | 0.502  | 142.1  | 242.6    | 10.1 | 24838. | 16.6 | 0.5 | 0.5 | 1.9 |
| 30        | 0.3  | 2.8  | 350.8    | 0.502  | 138.1  | 221.4    | 18.1 | 24141. | 13.8 | 0.6 | 0.6 | 1.5 |
| 25        | 0.3  | 3    | 309.6    | 0.502  | 121.8  | 198.0    | 14.5 | 21300. | 11.1 | 0.6 | 0.6 | 1.6 |
| 20        | 0.5  | 3    | 285.7    | 0.502  | 121.8  | 198.0    | 14.5 | 21300. | 11.1 | 0.6 | 0.6 | 1.6 |
| 15        | 0.6  | 3.5  | 235.8    | 0.502  | 112.4  | 171.5    | 10.0 | 19657. | 8.33 | 0.6 | 0.6 | 1.3 |
| 10        | 0.7  | 4    | 253.8    | 0.502  | 92.85  | 140.0    | 1.44 | 16226. | 5.55 | 0.6 | 0.6 | 1.2 |
| 5         | 0.6  | 5    | 153.8    | 0.502  | 60.56  | 99.04    | 0.00 | 10584. | 2.77 | 0.6 | 0.6 | 1.6 |
| 2         | 0.9  | 5    | 105.2    | 0.502  | 41.44  | 62.64    | 0.00 | 7242.3 | 1.11 | 0.6 | 0.6 | 1.2 |
| 1         | 0.9  | 6    | 79.2     | 0.502  | 31.19  | 44.29    | 0.00 | 5451.8 | 0.55 | 0.7 | 0.7 | 1.0 |

To describe the nature of hydraulic phenomena, experiments were carried out for single-phase and two-phase flows. According to the results of the experiments, the main hydraulic parameters of the proposed jet device for hydro transport of river sediments are determined.

4. Discussion

For the intermediate region of Reynolds numbers, in which inertia forces and viscosity forces simultaneously manifest themselves, by processing experimental data, as well as special experimental studies, the dependencies of local resistance coefficients for fluid flow in pipes on the viscosity of a liquid (Reynolds number) were found to be valid in a wide range Reynolds numbers, and proposed formulas. Similar dependences were also obtained to determine the coefficients of the flow rate, velocity, and compression of the jet when flowing from the outlet of the jet device during hydro transport.

As mentioned above, for solving practical problems, takes main interest the dependence of flow coefficients μ, speed — φ and resistance — ξ on the Reynolds number.

Based on the analysis of experimental data, was obtained the dependence of the discharge coefficient μ on the Reynolds number.
The calculation formula for the flow coefficient of the jet device for a two-phase flow equal to:

\[ \Delta \mu_2 = 0.58 - \frac{4.22}{4\sqrt{Re\mu}} \]  

(1)

In this case, the correlation coefficient is \( r = 0.7 \).

The flow discharge moving the pipeline of jet device is determined with using formula below:

\[ Q = Q_1 + Q_2 \]  

(2)

\( Q_1 \) - discharge of the working stream, determined when the suction pipe of the jet device is closed, where the flow is single-phase;

\( Q_2 \) - discharge of slurry in the suction pipe of the jet device.

\[ Q_2 = Q - Q_1 \]  

(3)

The final formula for the flow rate of the suction pipe of the jet apparatus is:

\[ Q_2 = \Delta\mu_2 \omega \sqrt{2gH} \]  

(4)

Thus, proposed dependence of calculation for determining the flow discharge of the hydraulic system in the suction pipe of the jet device.

On the basis of experiments, analyzed effect of relative pressure \( \frac{h}{H} \) on the transporting capacity of the jet device.

As a result of processing the experimental data, gotten the dependence of the turbidity of the flow on the relative pressure in the form of:

\[ s = A_1 \cdot \rho_2 \left( 0.75 - \frac{h}{H}\right)^{0.5} \]  

(5)

there: \( \rho_2 \) - the density of suspended particles, \( kg/m^3 \);

A1 - coefficient, determined on the basis of experimental data;

h - suction height, m;

H – pressure of flow, m;

5. Conclusion

Based on the processing of the available data, as well as the data of specially commissioned experiments, the dependencies of flow rates, speed, jet compression and resistance when the pulp flow from the jet apparatus has expired on the Reynolds number, are valid for certain limits of Reynolds number change.

- As a result of special experiments, dependencies of local resistance coefficients on the Reynolds number for some practically important cases (when the net flow and pulp from the jet apparatus pipeline have elapsed), valid within certain limits of changing Reynolds numbers, are established.
- The design parameters of the jet apparatus for the cleaning of reservoirs from river banks are substantiated.
- Anosov, proposed formulas for determining the hydraulic parameters of the proposed jet apparatus.
- A calculation formula is proposed to determine the flow rate and flow rate of the slurry of the jet apparatus.
- Based on the processing of the available data, as well as the data of specially commissioned experiments, the dependencies of the flow rates, speed and resistance of the jet apparatus on the
Reynolds number, valid within certain limits of Reynolds number $Re = (7000 \text{ - } 50,000)$, were established.

- As a result of special experiments, the dependences of the coefficient of hydraulic friction on the Reynolds number for various saturations of flow with a suspension were established.

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