DEVELOPMENT OF EXPERIMENTAL METHODS TO STUDY HETEROGENIC FLOWS IN THE CONTEXT OF HYDRAULIC HOISTING DESIGN

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Abstract

In view of rapid decrease of resources of raw-material base of continental formations, problems of ore field development in the World Ocean become absolutely essential. They are connected with the progress of topical research of resource-saving methods intended to extract solid minerals.

Construction of mining marine complexes on the basis of hydraulic systems for the extracted primary material hoisting is notable for high probability of their engineering implementation. Pump hydraulic hoisting and air-lift one are considered as the potentially productive alternatives to transport polymetallic concretions despite their high power intensity. The abovementioned sets the *relevant research and development problem* to improve accuracy of experimental methods.

Subjects of the study are vertical high-speed unidirectional annular flows and disperse flows within blading sections of deep-water hydraulic hoisting.

Objective of the research is to analyze the solid material transportability with the help of vertical three-phase flow in terms of annular and disperse flow structures as applied to hydraulic hoisting modeling. The objective is in the natural line with statement of the research and development problem.

The idea is to decrease power intensity of hydraulic hoisting and to improve its efficiency owing to selection of reasonable consumable parameters while advancing both experimental calculation techniques and theoretical ones as well as implementing innovative designs.

Originality is that for the first time the experimental methods have been developed to analyze three-phase flow with an active role of solid particles using the improved experimental and technical basis.

Innovative scientific finding is in the opening of previously unknown phenomenon titled conventionally «*change of a leader*» which is a definite stage in the development of dynamics of turbulent heterogeneous flows.

Introduction

Having analyzed and generalized their thirty-year experience in the design of deep-water pump and air-lift hydraulic hoisting, the authors believe that the available analytical methods are not efficient due to significant quantitative and qualitative differences in the end results of the modeling.

The efforts applied to improve theoretical models [4] in isolation from the currently unavailable experimental capability only result in unjustified losses of time and mental labour. As for the semiempirical models [10, 11], they are far from being reliable due to the use of closing empirical dependences generated exclusively with the help of short modeling facilities. The matter is that it is impossible to simulate the majority of determinant multiphase hydrodynamical processes, implemented in the deepwater hydraulic hoisting, using the short experimental devices since deepwater air-lift hoisting involves changes in structure of heterogeneous mixture flow, hundred-fold extension of a gaseous phase within a lift pipe, pressure nonlinearity, absorption and desorption processes under the conditions of high pressure gradients, multiscale turbulent fluctuations, specific features of a boundary layer as well as phase interaction etc.

Methodology to design deepwater hydraulic hoisting has been proposed. According to the methodology, at the current stage of marine facilities, the developers should focus on the upgrading of test benches and on the improving of experimental methods. Theoretical methods should be improved in parallel. The abovementioned is the research stage paradigm. One may say allegorically that theory has to step aside for systematic experiments.

Implementation of innovative techniques is the promising tendency to improve the efficiency of hydraulic hoisting [7, 9].

Since the experiments concerning three-phase flows are in the initial stage, it is possible to talk today only of the extension of area of empiric analysis of sporadic results, and of verification of phenomenological hypotheses.

Experimental studies of annular and disperse structure

Experimental studies of vertical multiphase flow were carried out in the laboratory of hydraulics and hydraulic drive of the Rock Mechanic Department of the NTU “Dnipro Polytechnic” on the basis of the developed integrated experimental hydraulic bench (see Fig. 1). Experiments concerning projectile flow structure have been carried out earlier [1-3].

In view of the new object studies, certain units have been reconstructed and modernized which is described by certain specifications [8].

The bench design provides a possibility to simulate two- and three-phase flows, and to analyze trajectory parameters of sole solid particles as well as their groups within the blading sections of air-lift facilities. Moreover, the bench helps study the airlift behaviour when a value of relative geometric submersion of a mixer is 0.4-0.95 [5, 12]. In view of small dimensions, the experimental device can be only used to study morphology of certain structures of three-phase mixture flow within a vertical pipeline, transportation kinematics of solid particles in terms of different flow structures, and qualitative studies of metering characteristics of short airlifts.

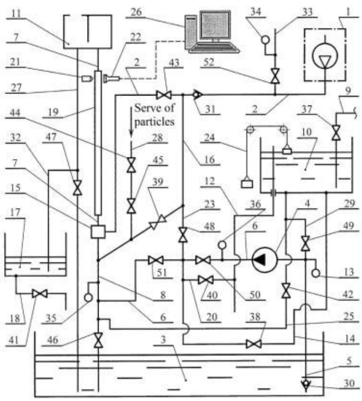

Fig. 1. Integrated experimental hydraulic bench

The authors do not set a goal to implement physical simulation of behaviour of powerful highly productive deepwater hoisting.

The research programme provided series of experiments for different groups of round particles of a monodisperse composition. Each particle group differed in diameters of the samples under study, and their densities. In this context, diameters of the particles being studied varied within the range of 0.002-0.014 mm and their densities varied within the range of 1100-1400 kg/m^3. In addition, groups of particles with similar diameters and varied densities were analyzed.

The complex experimental hydraulic bench consists of compressor unit *1* with pressure pipeline *2*; pool *3*; centrifugal pump *4* with intake pipeline *5*, and pressure pipeline *6*; lifting pipe *7* and feeding pipe *8* of airlift connected with pool *3*.

Pipeline *9* is connected with reservoir *10* through valve *37*. Air separator *11* is mounted on lifting pipe *7*. Pipeline *12* is connected with reservoir *10* and pool *3*. Intake pipeline *5* is equipped by one-way valve *30* and vacuum measuring transducer *13*. Compensatory pipeline *14* involves valve *38*; it is connected with pressure pipeline *6* and reservoir *10*. Mixer *15* is connected with pressure pipeline *2*, lifting pipe *7*, and feeding pipe *8*. Additional pipeline *16* involves valve 39; it is connected with pressure pipeline *2* and feeding pipe *8*. Metering reservoir *17* is connected with pool *3* through a casing neck *18*. Lifting pipe *7* includes an area made of transparent plastic (plastic pipe *19*). Connection pipe *20* is connected with compensatory pipeline *14* and pipeline *12*. Laser light source *21* and photoresistor *22* are fastened in the upper share on the diametrically opposed sides of pipe *19*. Connection pipe *20* includes valve *40*; casing neck *18* includes valve *41*. Bypass pipe *22* is connected with additional pipeline *16* and pressure pipeline *6*. Reservoir *10* is equipped with a float-type transducer to determine liquid level *24* connected with feeding pipe *8* through bypass pipeline *25*. Photoresistor *22* is installed in the frame, making safe from outer light; it is connected to computer system *26*. Outlet pipeline *27* is connected with air separator *11* and pool *3*. Bypass pipeline *25* includes valve *42*. Supplementary connecting pipe *28* is connected with additional pipeline *16* and atmosphere; additional connecting pipe *29* is connected with intake pipeline *5* and bypass pipeline *25*. One-way valve *31* and valve *43* are mounted within a pressure pipeline *2*; valves *44*, *45*, and *46* are mounted within supplementary connecting pipe *28* and feeding pipe *8* respectively. Outlet pipeline *27* includes valve *47*; it is connected with metering reservoir *17* through separate pipeline *32*. Separate connecting pipe *33* is connected with atmosphere, gas meter *34*, and pressure pipeline *2*; feeding pipeline *8* is connecter with manometer *35*. Valves *48* and *49* are mounted within bypass connecting pipeline *23* and supplementary connecting pipeline *29* respectively. Pressure pipeline *6* is equipped with manometer *36* and valves *50* and *51*; separate connecting pipe *33* is equipped with valve *34*. The device provides the use of valves *37-40*, *42-47*, and *49-52* of ball type.

Basic regularities of the three-phase flow and its effects

Analysis of gas-liquid flows demonstrates definite achievements as for the two-phase flow theory development [6]. However, the data are hardly used for calculation of parameters for hydraulic hoisting of solid material since the processes are complex and poorly understood. The area cannot avoid extra deep analysis of the complicated physical phenomena as well as experimental results.

Vertical flow of a three-phase mixture (i.e. liquid, gas, and solid particles) arises within the marine air-lift. Availability of a solid phase varies significantly the structure of differential equations as well as ideology of the development of mathematical models and experimental methods.

It is possible to make a final conclusion concerning one or another method while comparing analytical results with the experimental data obtained using full-scale facilities. However, it is impossible to implement such efficient devices if a wide range of empirical problems were not solved at the stage of pre-design research.

Various structures of gas-liquid flow, differing in the interaction mechanisms of the flow phases, are of diverse potentials as for solid material transportation. In terms of a bubble flow structure, and a slug one, solid particles are transferred owing to high density of the mixture; in terms of annular structure and disperse one, stable hoisting of the particles is supported by high velocities of the flow.

The following can be considered as the basic difficulties while solving the problem [8]:

– the necessity to take into consideration relative phase velocity, depending upon the size of particles, their shape, surface roughness, concentration of the solid within sludge as well as effect of the pipeline walls, while determining density of the mixture, and its transportation velocity;

– since composition of the solid particles is not homogenous in terms of their sizes, availability of a boundary layer in the neighbourhood of the pipeline walls results in the origination of a radial force factoring into size separation of the particles;

– rotation of the particles and their mutual collision as well as collision with the pipeline walls initiate distortion in the liquid flow and in the increase of turbulent fluctuations.

Such a transition from one structure to another one takes place along with the increase in volumetric flow rate of a gas phase depending upon diameter of the pipeline and its length, physical properties of the liquid and its velocity as well as upon a number of other factors. The mechanism of structure transition may be interpreted as follows. When low-flow rate gas is supplied to a vertical liquid column, gas phase is distributed in the form of separate bubbles. If the bubbles are of rather small diameter, they move like solid spheres performing upward vertical motion. However, while achieving critical size (i.e. a value depending upon the mixture pressure) the bubbles start their deformation; their motion becomes zigzagged and randomized. Along with the increase in the bubble volume, their collision and slug formation take place. While achieving higher velocities, rod-like gas places within a central share of a pipeline pushing liquid away to a periphery. In this context, the liquid layer has undulating boundary line. Liquid waves fractionize and draw into the central gas column in the form of small components. Basically, the liquid moves up owing to resistance forces arising within a boundary line. In the process of further flow acceleration, the wall liquid layer drags into a gas core; a disperse structure of the mixture flow in the form of liquid drops is formed.

The data, represented fragmentally, involve the development of experimental methods as well as modernization of architecture of facilities in the context of the development of mining methods along with adequate equipment when sufficient experience of industrial hydraulic hoisting is accumulated.

The expanded conclusions

1. The current methods of deep-water hydraulic hoisting development should rely upon synthesis of classical scientific bases of liquid and gas mechanics with the latest advances in the empirical suspension theory, and engineering knowledge of the designers.

2. The experimental bench did not demonstrate ideal annular or disperse structures of the three-phase flow; their visualization is rather fuzzy and indistinct.

Maybe, the fact is explained by extra turbulization of the flow due to the availability of solid particles within the mixture being transported; specific features of boundary lines of the phases; and a nature of phase interaction. Thus, the unified disperse-annular model should be considered from the viewpoint of the applied calculation of deep-water hydraulic hoisting. In all cases, the flow under study involves numerous liquid drops compressing the gas core at the expense of mass exchanging processes.

3. Certain experiments demonstrated stable liquid plates and spacers shutting down gas core of the three-phase flow. In the context of Griffith's experiments, formation of such spacers is connected with a slug flow implementation [ ]. Disappearance of the plates coincides with a slug mode transition to an annular one. Probably, the experimental fact may be recommended a priori as a criterion of changes in flow structures in terms of three-phase flow as well. However, changes in the mode should involve greater value of actual gas content of the flow since certain share of the consumed energy is spent for the solid material transportation.

4. Visual studies of both annular and disperse modes have helped detect previously unknown phenomenon titled preliminary as a «*change of a leader*» being typical only for vertical unidirectional high-velocity three-phase flow. The phenomenon idea is as follows: if annular flow structure is applied then transportation of the majority of solid particles within high-velocity gas core leaves behind liquid located mainly at the pipeline periphery owing to the force interaction with walls. In the context of a disperse structure of the three-phase flow, liquid drops, which joined the total flow, leave behind solid particles owing to the difference of acting gravitational forces. The abovementioned results from the gas core destruction as well as from the intensive intermixing of upward phase trajectories. It goes without saying that the phenomenon needs more scrupulous and careful verification, and systematic performance of more delicate experiments.

Moreover, it is also possible to formulate additional useful effect according to which logic one may suppose conceptually that leveling of profile of velocities of solid particles and liquid drops means indirectly changes in the flow structures.

Referens

1. **Kyrychenko, Y.O., Kyrychenko, V.E., & Evteev,V.V.**(2013). Teoriya i algoritmy rascheta snaryadnogo techeniya v erlifte. Dnepropetrovsk: Natsyonalnyi gornyi universitet [in Russian]

2. **Kyrychenko, Y.O., Goman, O.G., Kyrychenko V.Y., & Romanyukov, A.V.** (2012). Modelirovaniie dinamicheskikh protsessov v glubokovodnykh pnevmotransportnykh sistemakh. Dnepropetrovsk: Natsyonalnyi gornyi universitet [in Russian]

3. **Kyrychenko, Y.O.** (2009). Mekhanika glubokovodnykh gidrotransportnykh sistem v morskom gornom dele. Dnepropetrovsk: Natsyonalnyi gornyi universitet [in Russian]

4. **Kyrychenko, Y., Kyrychenko V., & Romanyukov, A.** (2011). *Research of dynamic processes in deep-water pumping hydrohoists lifting two-phase fluid.* Technical and Geoinformational Systems in Mining (pp. 115-124). London: CRC Press/Balkema, Taylor & Francis Group

5. **Kyrychenko, Y.O., Shvorak, V.G., Kyrychenko V.Y., & Yevteyev, V.V.** (2010). Dinamika glubokovodnykh gidropodyemov v morskom gornom dele. Dnepropetrovsk: Natsyonalnyi gornyi universitet [in Russian]

6. **Pivnyak, G.G., Kyrychenko Y.O. , Franchuk V.P**. (2008). *Problems of deep-water hydraulic lifting of solid mineral resources* . New technologies in mining 21st World mining congress (pp. 49-57). – Krakow

7. **Pivnyak, G.G., Kyrychenko, E.A. , Franchuk, V.P., Yevteyev, V.V., & Shvorak, V.G.** (2009). Sposib zapusku hlybokovodnoho erlifta (varianty) ta erliftna ustanovka dlia yikh realizatsii. UK. Patent № 91130 [in Ukrainian]

8. **Kyrychenko, Y.O., Goman, O.G., Kyrychenko V.Y., & Yevteyev, V.V.** (2014). Osnovy proiektirovaniia sistem gidrotransporta polimetallicheskikh rud Mirovogo okeana. Nikopol: FOP Feldman O.O. [in Russian]

9. **Pivnyak, G.G., Kyrychenko, E.A. , Franchuk, V.P., Yevteyev, V.V., & Shvorak, V.G.** (2009). Sposob zapuska i funktsionirovaniia morskogo erlifta i sistema dlia ego realizatsii. RF. Patent № 2346160 [in Russian]

10. **Kyrychenko, Y.O., Samusya V.I., & Kyrychenko V.E.** (2008). The technology of polymetallic concretions extraction and transporting. *Innovations in Non-Blasting Rock Destruction* (pp.169-178). − Freiberg

11. **Kyrychenko, Y., Kyrychenko V., & Taturevych A.** (2011). *Advanced method for calculation of deep-water airlifts and the special software development.* Technical and Geoinformational Systems in Mining (pp. 215-222). London: CRC Press/Balkema, Taylor & Francis Group

12. **Samusia, V.I., Yevteyev, V.V., & Kyrychenko, Y.O.** (2008). Eksperimentalnoie issledovaniie parametrov vertikalnogo dvukhkomponentnogo potoka primenitelno k erliftnomu techeniiu. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu* (12), 68-74 [in Russian]