MAIN RESULTS AND DEVELOPMENT LINES OF HYDRO-AEROMECHANICS OF DRILLING PROCESSES

Intensive investigation of forms and laws of fluid flow in wells began in 1901 when in the United States application of the mechanical rotary drilling with washing, the so-called rotary drilling, was found on Spindletop field in Texas state. In 1911, for the first time in Russia's Suruchan region several wells were bored by rotary method with washing of well bottom by mud solution. After nationalization of the oil industry, the rotary boring began to develop quickly.

With steady increase in well depth and complexity of mine geological conditions, widespread use of jet drilling bit and downhole motors resulted in the washing and plugging back in hydro-aeromechanical well-bed system becoming more costly and power intensive. Since under real hydro-aeromechanical system it is understood that the whole set of well elements and uncovered beds connected with each other in a unified technological set have a complex structure, it is necessary to build a mathematical model of this system. The model was developed in two directions: the description of main hydro-aeromechanical properties of separate elements and the structure of the system as a whole.

Investigation of basic element properties is aimed at finding correlations between pressure, flow rate, and time through relations of theoretical

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hydro-aeromechanics and applied hydraulics. Let us point out the most significant results of hydro-aeromechanics in drilling.

Rheological equations formulated for viscous fluids by Newton in 1685 (Krilow, 1936), for viscous-plastic media by Shvedoff in 1889 (Reiner, 1960) and Bingham in 1916 (Bingham, 1922), and for pseudoplastic media by Ostwald in 1924 (Reiner, 1960) are of profound importance in solving problems of drilling hydro-aeromechanics. With the help of these equations, formulas were obtained for pressure distribution in stationary laminar flow of viscous (Poiseuille, 1840, 1841; Stokes, 1845, 1850, 1901), viscous-plastic (Buckingham, 1921), and pseudoplastic (Rabinowitch, 1929; Mooney, 1931) fluids in circular pipes. Solutions have also been obtained for flows in concentric circular channels of viscous (Lamb, 1945), viscous-plastic (Volarovich and Gutkin, 1946), and pseudoplastic (Fredrickson and Bird, 1958) fluids.

On the basis of Bukingham and Volarovich and Gutkin formulas for the flow of viscous-plastic fluids in circular and concentric circular pipes, Grodde (1960) applied convenient graphic method to calculate pressure drop.

Schelkachev (1931) considered laminar stationary flow of viscous fluid in eccentric circular channel and obtained formula for pressure distribution. McLean et al. (1967) gave a general scheme for approximate calculation of pressure distribution in laminar flow of rheologic stationary fluid in concentric circular channel with cross section replaced by conventional sections of concentric channels with independent flows.

The stability of laminar flows of viscous fluid in circular pipes was experimentally investigated by Reynolds during 1876–1883 (Reynolds, 1883). He established transition criterion from laminar to turbulent flow. Hedström (1952) characterized the loss of viscous-plastic fluid laminar flow stability by Reynolds and Saint Venant numbers.

On the basis of boundary layer theory developed by Prandtl during 1904–1925 (Prandtl and Tietjens, 1929, 1931) for turbulent flow of viscous fluid in pipes with smooth and rough walls, Altshul (Altshul and Kiselev, 1975) obtained dependences for hydraulic resistance factors.

In developing the theory of multistage turbine, Shumilov (1943) gave formula for pressure drop in turbo-drill. To derive the pressure change in local resistances of circulation system, Herrick (1932) used the equivalent length method. Shumilov (1943) applied Borda–Karno formula for locks and Torricelli formula for drill bit orifice when determining pressure drop. Laminar flow of viscous fluid around a sphere was considered by Stokes (1845). Experimental investigations of flows around rigid spherical particles in a wide range of Reynolds numbers were generalized in the form of Rayleigh curve. Shischenko and Baklanov (1933) investigated conditions of stability and flow of mud solution around particles. Targ (1951) found pressure distribution in laminar stationary flow of viscous fluid in an axially symmetric circular channel, one of the wall of which moves with constant velocity. Gukasov (1976) considered laminar flow of viscous-plastic fluid in concentric circular channel with movable internal wall.

Basic hydrodynamic equations for multiphase fluids using empirical relations for concentrations and hydraulic resistance factor were derived by Teletov (1958). On this basis were obtained pressure distributions in pipes and circular channels in well washing by aerated fluid or gas blowdown.

A fundamental contribution to solving the problem of nonstationary flows in hydraulic systems with regard to compressibility of fluids and elasticity of walls was made by Zhukowski (1899–1921), who developed the theory of one-dimensional nonstationary flow of viscous fluid to solve many problems (Zhukowski, 1948).

In connection with problems of oil- and gas-field development in works of Pavlowski (1922), Leibenson (1934), Schelkachev (1990), Charniy (1963), Muskat (1963), and many others, the flow of reservoir fluid in porous medium has been extensively studied to solve problems with opening up of productive buildup and problems with drilling.

Along with the investigation of hydro-aeromechanic properties of system elements, methods to investigate well-bed system as a whole have also been developed. In doing so, there have been established correlations between elements of the system needed to simultaneously solve all equations characterizing separate elements. For example, Herrick (1932) had considered a problem on feed and pressure of drilling pump for circulation of washing fluid and Shazov (1938) devised a scheme of procedure in choosing number and parameters of cementing aggregates for one-step well plugging. Mirzadjanzadeh and his collaborators (Mirzadjanzadeh, 1959) developed a method for analyzing hydro-aerodynamic processes with the help of stochastic and adaptive training models.

Shischenko and Baklanov (1933) were first to systematically outline a number of washing fluid hydraulic problems. Many aspects of hydroaeromechanics of drilling processes were considered in monographs (Gukasov, 1976; Gukasov and Kochnev, 1991; Goins and Sheffield, 1983; Esman, 1982; Mezshlumov, 1976; Mezshlumov and Makurin, 1967; Mirzadjanzadeh, 1959; Mirzadjanzadeh and Entov, 1985; Shischenko et al., 1976; Macovei, 1982; and others), handbooks (Mittelman, 1963; Filatov, 1973; Gabolde and Nguyen, 1991; and others) and the periodic literature.

At present, there has been a tendency to develop systems approach to drilling hydro-aeromechanics chiefly in building well-bed system models both simplified and more complex ones demanding application of various mathematical methods with regard to designing, building, and operation of wells.