RESEARCH, DESIGN, NUMERICAL ANALYSES, AND OPERATING EXPERIENCE

PROCESSES AND EQUIPMENT OF CHEMICAL AND OIL-AND-GAS TECHNOLOGIES

INFLUENCE OF OIL INJECTION METHODS ON HYDRODYNAMICS IN ELECTRIC DEHYDRATORS OF ELECTRIC DESALTING PLANTS

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Numerical methods were used to analyze the hydrodynamics of flows in horizontal electric dehydrators as a function of the position of the nozzles for introducing the original oil into the apparatus. Based on the calculation results, an option of existing 2EG160-2 electric dehydrator updating by replacing its slotted nozzles with cylindrical ones in combination with low-volume single- or multi-stage mixers is proposed. This will prevent formation of counterflows of the original oil in the apparatus and ensure effective oil flow movement throughout the apparatus space.

Keywords: electric oil desalting, electric dehydrator, hydrodynamics, computer simulation, numerical calculation, velocity field, nozzles.

Breaking water-oil emulsion in a settler is a classic example of hydromechanical process of separation of a heterogeneous or a multi-phase system by the force of gravity.

The Main Methods of Intensification of this Process Are:

– organization of the disperse-phase (water drops) movement in the apparatus (division of the working space by horizontal settling shelves to reduce the drops settling height, fabrication of the shelves using hydrophilic materials to increase the forces of adhesion of the drops to the surface of the shelves, and installation of the shelves with a slope for draining of the accumulated water from them);

– organization of the dispersed medium (oil) movement in the apparatus (division of the working space of the apparatus by vertical partitions to increase the oil path length in the apparatus and/or to separate the volume of the settled water from the oil) [1, 2].

Water-oil emulsion breaking processes in an electric dehydrator of an electric desalting plant is much more complex than in a settler because desalting and dehydration of water-oil emulsion take place under conditions of merging of drops of the original stratal water and fresh water under the action of the forces of electric field.

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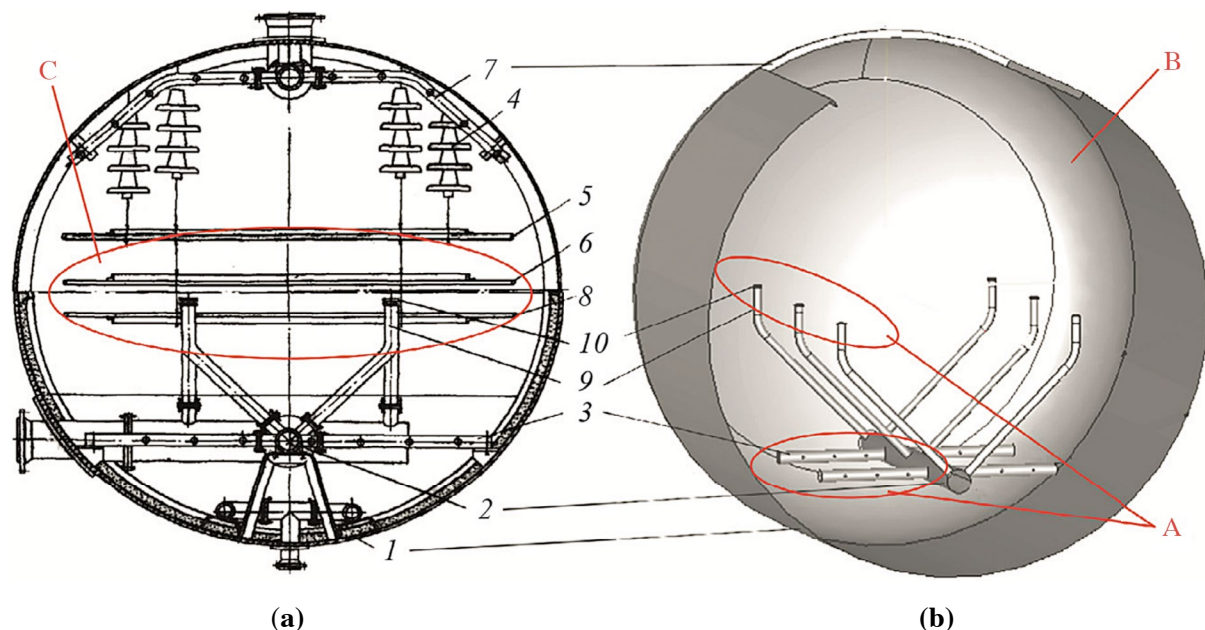[2] Penza State Technological University, Penza, Russia.

Fig. 1. Schematic diagram of a 2EG160-2 horizontal three-electrode electric dehydrator (with crude oil injection jointly into the zone between the bottom and middle electrodes and into the settled water layer): (a) — cross section; (b) — boundary surfaces of three-dimensional solid model; *1* — housing; *2* — longitudinal crude supply manifold; *3* — outlet; *4* — suspension insulator; *5, 6* — electrodes; *7* — dehydrated oil collector; *8* — additional bottom electrode; *9* — vertical pipe; *10* — slotted nozzle.

Crude oil is desalted due to dilution of stratal water drops as they merge with drops of washing fresh water. Enlargement of drops facilitates settling of drops and, consequently, accelerates separation of the water-oil emulsion into layers. Even though some amount of less saline water remains in the oil, the degree of mineralization of the oil, in general, decreases, i.e., it is desalted.

To increase closeness and collision of the drops in industrial electric dehydrators of the 2EG160, 2EG160-2, 2EG160-3, and 2EG200-2R types, the electrodes are made in the form of horizontal grids with large cells for free movement (settling) of the water drops in vertical direction.

Processes of formation and breaking of water-oil emulsions during desalting and dehydration are greatly affected by hydrodynamic factors, particularly the velocity field in the electric dehydrators. Formation of ascending fluid flows in the electric dehydrator causes entrainment of fine stratal water droplets from the apparatus, which adversely affects desalting efficiency. Therefore, the goal of this work was to investigate the hydrodynamics of electric dehydrators by changing the method of crude oil injection into the apparatus for enhancing the efficiency of oil desalting.

The location of the zone of crude oil injection into electric dehydrator depends on the apparatus design: crude oil is injected into vertical and spherical electric dehydrators between the electrodes, into horizontal electric dehydrators 2EG160, under the electrodes, into 2EG160–3, between the bottom and middle electrodes, and into 2EG160-2, between the bottom and middle and under the electrodes.

In zone A of the electric dehydrator (Fig. 1), two processes, namely, dispersion and merger of drops, occur simultaneously in the immediate vicinity of the crude oil injecting nozzle. The crude oil, together with the washing water drops and the demulsifying agent, is turbulently mixed with the main volume of the oil in the electric dehydrator.

The degree of flow turbulence in the apparatus is set taking account of occurrence of collisions of the dispersed washing water drops and their merger with stratal water drops. If the fresh water is not dispersed

adequately in the initial water-oil emulsion, large drops of washing water are formed and they settle without mixing with the stratal water drops, due to which the oil desalting process effectiveness decreases significantly. In the calculations, in general, it is taken that in zone A stratal and washing water drops mix and stratal water is diluted with washing water to salt concentration specified by GOST 9965–76 or GOST 31378–2009.

The largest water drops from the freshly formed emulsion settle in zone B (Fig. 1).

Fine water droplets collide and merge in zone C under the action of an electric field. The water drops enlarged in zone C fall into zone B. In zones B and C, it is necessary to provide laminar flow movement conditions for contact of large water drops (settling down) with fine water droplets from the rising crude oil flow because merger of these drops is essential for enhancing efficiency of the oil desalting process.

Thus, the oil desalting process parameters are determined with due regard for the maximum intensification of the processes of collision, merger (enlargement), and settling of water drops.

The velocity field of the fluid in an electric dehydrator depends on its design, dimensions and layout of the nozzles, and, consequently, on the rate of oil injection through the nozzles into the apparatus. It is essential that the linear oil movement speed (from the bottom up) in an electric dehydrator was at least twice less than the calculated water drops settling (from the top down) speed. The type and intensity of oil circulation in the apparatus, which greatly affects the stratal and washing water drops merger process, depend on the direction of oil ejection from the nozzles as well as on the layout of the nozzles in the electric dehydrator.

The rate of free settling of fine droplets in a static fluid (at Re numbers below 1) is calculated by the Hadamard equation:

$$w_{\text{set.max}} = \frac{gd^2(\rho_w - \rho_o)(\mu_o + \mu_w)}{6\mu_o \cdot (2\mu_o + 3\mu_w)}.$$

For the standard 2EG160-2 electric dehydrator, water drops settling speed in a static fluid based on Hadamard equation will be $w_{\text{set.max}} = 0.0033$ m/sec under the following conditions: dynamic viscosity of oil $\mu_o = 0.8$ MPa·sec and of water $\mu_w = 0.2$ MPa·sec; density of oil $\rho_o = 900$ kg/m^3 and of washing water $\rho_w = 1000$ kg/m^3; diameter of least settled water drops $d = 2 \cdot 10^{-4}$; gravitational acceleration $g = 9.81$ m/sec^2. Here, the Re number will be

$$\text{Re} = w_{\text{set.max}}d\rho_o/\mu_o = 0.66,$$

i.e., for such conditions use of Hadamard equation is correct.

The 2EG160-2 electric dehydrator is rated for 1.8 MPa operating pressure, for a diameter $D = 3.4$ m, a cylindrical part length $L = 16.0$ m, and horizontal cross-sectional area along the dehydrator axis $S = DL = 54.4$ m^2. In electric dehydrators of such a design, the crude oil flow rate will be $V_{c.o} = 240–480$ m^3/h. At crude oil flow rate $V_{c.o} = 240$ m^3/h the average velocity of oil ascent through the interelectrode space (for the entire apparatus section) will be $u_{\text{act}} = V_{c.o}/S = 0.0012$ m/sec, which agrees with the literature data (0.0012–0.0030 m/sec [10]). For stratal water drop diameter $d = 2 \cdot 10^{-4}$, the condition $u_{\text{act}} < 2w_{\text{set.max}}$ is met.

For analysis of oil desalting processes in an electric dehydrator it is essential to take account of the fact that the area of horizontal cross-section of the apparatus passing through the central axis of the apparatus is roughly 30% larger than the cross-sectional area of the apparatus at the height of installation of the horizontal outlets of the oil injection manifold and, therefore, the average oil rising speed (after the oil is fed into the apparatus through the manifold outlet) diminishes as the oil rises up to the axis of the electric dehydrator.

As a result, as the oil moves in the apparatus from the bottom up, the water drops settling conditions in the oil initially improve and then (in the region above the apparatus axis) worsen due to increase of oil flow velocity.

Let us determine the oil flow direction and velocity in all zones of the 2EG160-2 electric dehydrator (at volume crude oil flow rate of 240 m^3/h) taking account of the method of oil injection into the apparatus.

The oil enters the electric dehydrator (with the cylindrical section length $L = 16$ m) through two longitudinal manifolds (each of 8 m length and 150 mm diameter) and is then distributed in the apparatus through horizontal and inclined outlets at two levels: 2/3 of the oil is fed under the surface of the water settled in the bottom section of the apparatus (through the horizontal outlets) and 1/3 of the oil is fed into the interelectrode space (through the inclined outlets).

Process of Oil Supply to Bottom Section of Apparatus (to Settled Water Layer)

From each manifold the oil is distributed through 16 horizontal transverse perforated outlets (diameter 76 mm). In each outlet (in the apparatus axis direction) there are 12 holes (diameter 15 mm). The volume rate of crude oil flow through each hole $V_{hole} = 0.66 V_{c.o}/(2 \cdot 32 \cdot 12) = 0.0001$ m^3/sec, the speed of oil exit from the holes $v_{hole\ bot} = 4V_{hole}/(\pi d_{hole}) = 0.65$ m/sec.

At the hole exit the oil flow disperses into drops in the settled water layer. The formed oil drops (with inclusions of fine water droplets) rise upward, pass through the *oil–water* interface and enter the interelectrode space, whereupon occurs the process of merger of the drops of stratal and fresh water. The large water drops settle down and the desalted oil is discharged from the apparatus.

The direction of oil circulation in the electric dehydration space greatly affects the electric desalting process. Oil circulation around the horizontal axis affects the process of settling of large drops. Oil circulation around the vertical axis does not affect the drop settling process significantly (at low speeds), but it affects the processes of collision and merger of drops considerably.

To optimize the hydrodynamics of the flows in the working space of the apparatuses, numerical investigation methods are used. A generalized method of calculation and investigation of electrohydrodynamic mixers and dehydrators was proposed earlier in [3–7] for optimizing the design and operation conditions of electric dehydrators.

The method in [3–7] was used to analyze the intensity of hydrodynamic processes in a horizontal electric dehydrator (by the example of a 2EG160-2 electric dehydrator) for developing new technical solutions of feed injection into the apparatus.

From the fluid velocity field in a 2EG160-2 electric dehydrator, when the crude oil is injected into the bottom section of the apparatus under the electrodes (Fig. 2), it follows that crude oil crossflows are formed at the exit from the holes of the perforated pipes in the horizontal plane of the apparatus (at the manifold level). After collision, the horizontal flows are redirected with formation of ascending and descending flows.

The descending flows reach the bottom of the apparatus and is redirected upward (back to the perforated outlet pipes), due to which a system of horizontal vortices *1* and *2* is formed in the bottom section of the apparatus (Fig. 2).

The ascending flows reach the middle of the apparatus where the fine water droplets captured by the flows move to the manifold for oil discharge from the apparatus. As a result, the top system of horizontal vortices *3* (Fig. 2) is formed, which reduces the crude oil dehydration (consequently, also desalting) efficiency.

In the flow circulation zone, the velocities vary from 2 m/sec (at the point of oil exit from the hole of the perforated outlet pipe) to ~0.05 m/sec (in the middle of the circulation zone).

Above the circulation zone, the velocity of upward movement of the flow is about 0.005 m/sec.
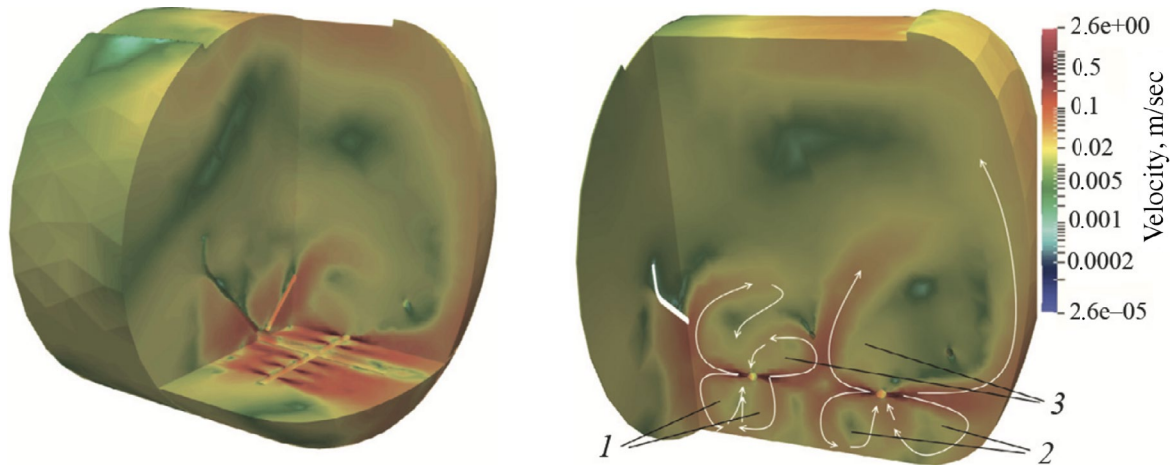
Fig. 2. Schematic diagram of velocity field in a 2EG160-2 horizontal electric dehydrator when the oil is injected into the settled water surface under the electrodes (on the right and left — two sections of the apparatus).
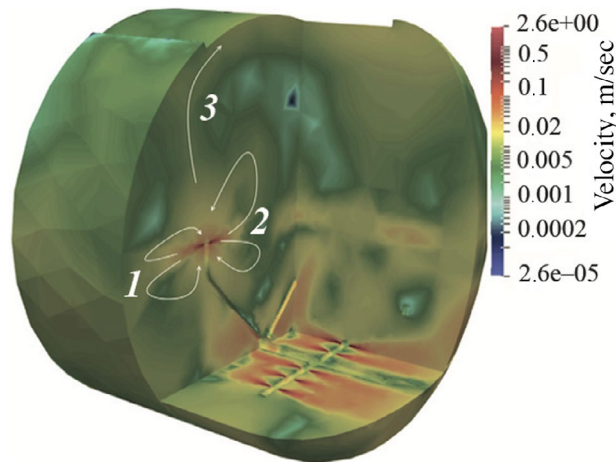

Fig. 3. Schematic diagram of velocity field in 2EG160-2 horizontal electric dehydrator in case of simultaneous oil injection between bottom and middle electrodes and under electrodes (velocity of oil exit from nozzles 1 m/sec).

Process of Oil Delivery into Interelectrode Space of Electric Dehydrator

The oil fed into the interelectrode space (1/3 of the total oil flow in the electric dehydrator) from two longitudinal horizontal manifolds is distributed in 9 inclined outlet pipes, from which it is fed into the interelectrode space through slotted nozzles with a velocity $v_{hole\_up} \approx 1$ m/sec.

From the results of numerical calculation by the method in [3–7] it was established that at 1 m/sec velocity of oil exit from the nozzles the oil circulates in the space near the nozzles. Near each nozzle two toroidal vortices are formed (Fig. 3, flows *1* and *2*), the ascending parts of which move the fine droplets upward, whereupon the efficiency of removal of saline water drops from the oil in the apparatus space decreases.

The dewatered and desalted oil is removed from the electric dehydrator (Fig. 3, flow *3*) through the "dry" oil collector *7* (Fig. 1) into the top section of the electric dehydrator. The collector is made of perforated metal sheets installed at remote corners, past which the "dry" oil removing nozzles are located.

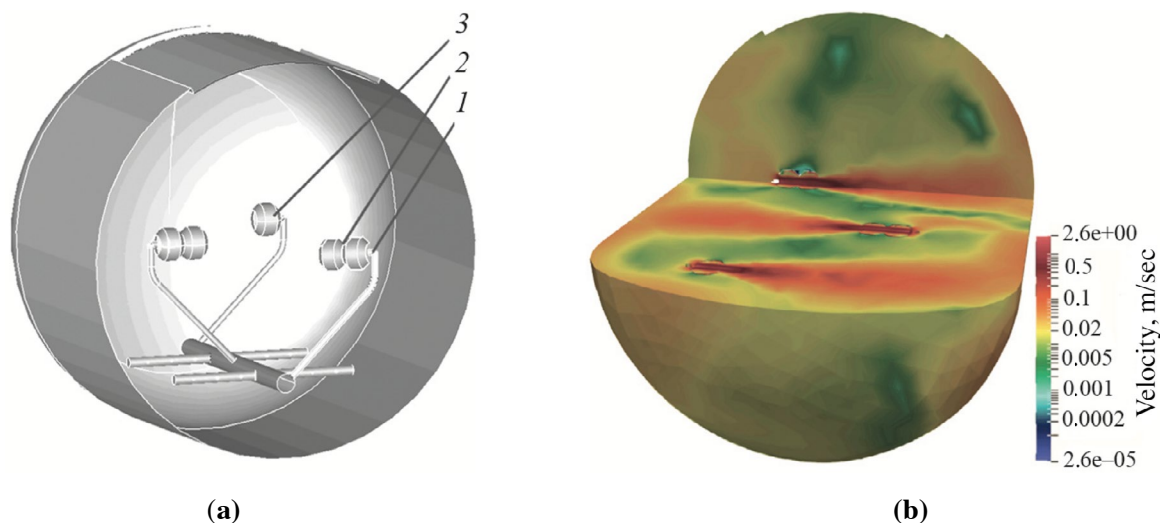**(a)**   **(b)**

Fig. 4. Updated electric dehydrator: (a) — boundary surfaces of 3D solid model of electric dehydrator with simultaneous oil injection between bottom and middle electrodes and under electrodes: *1* — horizontal cylindrical nozzles; *2* — multi-stage low-capacity mixers; *3* — single-stage low-capacity mixer; (b) — diagram of velocity field in electric dehydrator.

From the results of the performed analysis of the hydrodynamics in a 2EG160-2 electric dehydrator with due resgard for the published data [8, 9] it follows that it is necessary to prevent, as far as possible, formation in the electric dehydrator of flow structures with vortices oriented around the horizontal axis. Since it is impossible to fully prevent flow circulation in the apparatus, it is advisable to create (by judicious designing and selection of process parameters) flow structures with vortices oriented around the vertical axis. This will help prevent formation in the apparatus of zones with additional ascending flows that affect entrainment from the apparatus of fine saline stratal water droplets before their merger with the washing fresh water.

To solve this matter, it is proposed to replace the slotted nozzles by cylindrical nozzles (of equal area) directed toward each other (with a bias) taking account of the creation of a system of vertical vortices by counter flows (Fig. 4).

It is proposed to install, right past the nozzles, low-capacity single- or multi-stage mixers where the flows move under turbulent conditions, which contributes to increased probability of collision and merger of drops. Oil circulation in the apparatus will take place in this case around the vertical axes (with decrease of number and intensity of ascending oil flows in the apparatus).

Thus, based on the numerical modeling results, it is established that replacement of slotted nozzles used in 2EG160-2 horizontal electric dehydrators by horizontal cylindrical nozzles, in combination with low-capacity single- or multi-stage mixers, will ensure effective movement of oil flow in the apparatus space.

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