

Analysis of the application for the magnetohydrodynamic effect in the hydrocarbon production

A V Logunov¹, V A Kopyrin, A L Portnyagin and M V Deneko

Federal State Budget Educational Institution of Higher Education «Industrial University of Tyumen», Volodarsky Street, 38, Tyumen, 625000, Russia

¹E-mail: logunovav97@mail.ru

Abstract. Nowadays the main share of oil fields is at a late stage of operation. It is characterized by high water cut of the extracted products. Salts in the formation fluid, under certain thermobaric conditions, settle on the process equipment and they cause its failure. Failure of technological equipment entails the well's downtime and high material costs. Water-soluble salts in the formation fluid are subject to electrolysis. There, the molecules of the substance are decomposed into ions. The Lorentz force acts when a magnetic field is applied to the ions. The magnetohydrodynamic effect is manifested in the formation fluid. The purpose of the article is to analyze the applicability of the magnetohydrodynamic effect for hydrocarbon production. The chemical composition of formation waters for some deposits is given. On its basis the chemical model for electrolysis of the main salts in sodium chloride and potassium chloride contained in the formation liquid is constructed. The design and operation principle of the simplest magnetohydrodynamic pump is considered. The description of the developed laboratory sample of the magnetohydrodynamic pump is given. The main conclusions are reflected in this article.

1. Introduction

Nowadays, the share of hard-to-recover hydrocarbon reserves is steadily increasing. There are reserves in oil reservoirs with low permeability, high water content, reserves with low oil saturation, as well as reserves located in small thicknesses, heavy and superheavy oil. At the present stage of development and operation on oil fields the oil companies are forced to extract a huge amount of associated water to the surface for maintaining the required volume of produced oil. In some instances the water cut of oil can reach 98 %. It reduces the profitability of its production. Another negative factor of high-water cut is the increased scaling on the technological equipment. The oil wells' operation in such conditions entails increased material costs and undersupply of products with the equipment failure.

In the oil industry the installation of submersible electric centrifugal pumps (ESP) is the most widespread during the oil wells' operation. The ESP installation is equipped at more than 65 % of the world's oil wells [1-3]. The mean time for ESP failure is 500-700 days. It can be reduced in some cases up to 30 - 90 days during operation in wells with high scaling. It is unacceptable in conditions of inaccessibility for oil production facilities due to high logistics costs during repairs.

A significant contribution to the problem solution of salt formation in oil production is made by many domestic and foreign scientists: Agalarov, D. M., Ashirov K. B., Valeev M. D., Ibragimov L. H., Ilchenko V. P., Iyushin S. F., Paguba, A. I., Khusnullin M. H., Chistovskiy A. I., Blount C. W., Davis J. E., MacDonald R. W., Philips R. C., Smith H. A., Tompson M. B., etc. In the authors' study, the detailed methods of dealing with scaling are described. The theoretical and experimental



investigation of salt precipitation in the reservoir, the method of predicting the salt formation in the extraction of oil are also proposed.

The formation fluid under conditions of high-water cut is an electrolyte according to its chemical properties. There is a dissociation of water-soluble salts into ions under the influence of the electric current. There is the magnetohydrodynamic effect under the influence of the

The magnetohydrodynamic effect was studied by: Baake E., Timofeev V. N., Boyakov S. A., Woldek A. I., Sipliviy B. N., Chojainov A. I., Vasiliev L. G., Andreeva E. G., Cowling T. G., etc.

The questions of the magnetohydrodynamic effect's research are considered in the published authors' studies. They are in the field of astrophysics, nuclear energy, marine engineering and metallurgy, general and particular cases for solving the equations of magnetic hydrodynamics. But the possibility of applying this effect in the oil industry is not considered. Therefore, it is important to analyze the applicability of the magnetohydrodynamic effect for hydrocarbon production in conditions of high-water cut and scaling.

The main source of salt is produced water, which is extracted together with oil. The process of scaling is directly related to a significant supersaturation of the water environment with soluble salts. It is happened due to the changes in the physical- chemical parameters of the oil production system (temperature, pressure, gassing, concentration of precipitating ions, etc.). The intensive salts' deposition on the electric centrifugal pump's wheels is due to the increasing in the flow temperature of the extracted liquid. It is caused by the heat output of the operating submersible motor. The dispersed dense rock-like salt precipitate is formed on the working parts and surfaces of the electric centrifugal pump. It disrupts heat exchange, leads to jamming of the electric motor, shaft and pump failures.

The mechanical wedge of the pump or ESP failure by the overheating of the submersible motor is possible in case of intensive scaling process or operation of low-capacity pumps with a minimum size of the passage channels. It also can be in case of poor-quality monitoring for operation wells. In case of failure of electric pumps installation, the cost of lifting operations and subsequent repairs can reach the cost of new installations. It is necessary to determine the possibility of the reservoir fluid production using the magnetohydrodynamic effect [4–5].

2. Materials and Methods

Let the produced formation fluid salt deposits occur with a predominance of the following salts' types: calcite - CaCO_3 , gypsum - $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, anhydrite - CaSO_4 , barite - BaSO_4 , baritocelastine – $\text{Ba}(\text{Sr})\text{SO}_4$, halite - NaCl . In the later stages of deposits development occur deposits of sulfide salts. There is iron sulfide mainly. In general, sediments of salt deposits are not monomineral. They have a complex petrographic composition, including both mineral and organic parts. It is qualified as "loss during calcination" in chemical analyses.

According to the studies, dozens and dozens of different minerals can be in the composition of salt deposits along with hydrocarbon components and corrosion products. Additional components in the deposits are the sulphates and carbonates of magnesium, hydroxides of calcium $\text{Ca}(\text{OH})_2$ and magnesium $\text{Mg}(\text{OH})_2$, iron hydroxides, oxides (quartz, jolt – FeO , maghemite – Fe_2O_3 , magnesite Fe_3O_4 , etc.), magnesian calcite that is less soluble than calcite dolomite – $\text{CaMg}(\text{CO}_3)_2$. There can be such mineral formations, as bishofit – $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, kieserite – $\text{MgSO}_4 \cdot 2\text{H}_2\text{O}$, epsomite – $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, etc.

The organic component of salt deposits are mainly aromatic hydrocarbons, asphaltenes, resins, finely dispersed bitumen, refractory paraffins and sulfur compounds. It is also noted that water-soluble organic matter occupies an insignificant place in the organic component of the scale.

An important feature of water is the property of dissolution to a certain extent of solids. For example, there are inorganic salts and their crystallization. The last one depends on the thermobaric conditions and the chemical composition of the solutions. The solubility of sulfate salts, such as barite and gypsum, decreases with the temperature and pressure decreasing. Their loss occurs, except for anhydrite (anhydrous gypsum), which falls at high temperatures. The calcite solubility increases at low temperatures in contrast to sulfate salts. The sedimentation occurs at high temperatures with a partial decrease in the partial pressure of CO_2 . The presence of carbon dioxide (CO_2) in water increases the

solubility of calcium carbonate. The presence of sodium chloride in the solution has a significant effect on the salts' solubility.

Along with thermobaric conditions, an important reason for the formation of inorganic salts precipitation is the mixing of chemically incompatible waters. It requires complex hydrochemical calculations like the solubility properties of salts. The following are the main provisions that should be taken into account in this kind of calculations due to the solution of the salt formation problem.

A solid substance under certain thermobaric conditions (at constant pressure and temperature) is dissolved in water until it reaches the limit or equilibrium concentration in the solution. That is when the same amount of substance is dissolved and precipitated at equal intervals.

Table 1 shows the solubility of petroleum-related inorganic compounds in grams of anhydrous substance per 100 g of water at 20 °C.

Table 1. Solubility of inorganic compounds in 100 g of water

Inorganic compound	Solubility per 100 g of water at 20 °C
Potassium carbonate (K ₂ CO ₃)	111.5
Sodium hydroxide (NaOH)	107.0
Calcium chloride (CaCl ₂)	74.5
Magnesium chloride (MgCl ₂)	54.3
Ammonium chloride (NH ₄ Cl)	37.4
Sodium chloride (NaCl)	35.9
Barium chloride (BaCl ₂)	35.7
Magnesium sulphate (MgSO ₄)	35.6
Potassium chloride (KCl)	34.4
Sodium carbonate (Na ₂ CO ₃)	21.6
Sodium sulphate (Na ₂ SO ₄)	19.1
Calcium sulphate (CaSO ₄)	2.0
Barium hydroxide Ba(OH) ₂	3.5
The calcium hydroxide Ca(OH) ₂	0.17
Calcium carbonate (CaCO ₃)	0.06

The chemical composition of water from wells, operated in the conditions of scaling is considered to assess the qualitative and quantitative analysis of the salts' composition in the formation fluid (Table. 2) [8].

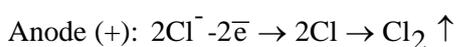
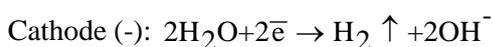
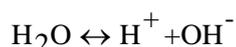
Table 2. Characterization of formation waters

Chemical composition of water, g/l							M, g/l	pH	T, °C	P, MPa
Cl ⁻	SO ₄ ²⁻	HCO ₃ ⁻	Ca ²⁺	Mg ²⁺	Na ⁺ K ⁺	Ba ²⁺				
Well 520 of the Bashkir stage on the Yarino-Kamennologskiy field										
120.6	1.13	0.117	13.95	3.24	56.66	0.0	196	6.66	20.5	13.7
Well 75 Romashkinskiy field										
172.6	0.014	0.025	24.08	4.3	76.19	0.21	277.2	6.0	38	18
Well 4910 Romashkinskiy field										
165.7	0.121	0.049	23.89	2.23	75.89	0.005	267.8	6.2		0.1
Well 1828 Romashkinskiy field										
135.4	1.045	0.165	19.92	-	65.54	0.0	222.1	6.8	25	
Well 5012 Samotlor field										
1.773	0.009	0.178	0.17	0.10	7.477	0.0	27.02	8.57	70	17.3

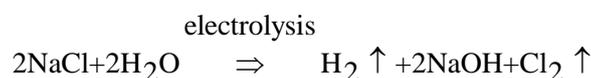
The analysis of the table shows that the main share of formation waters is occupied by chlorine anions (Cl^-), sodium cations (Na^+) and potassium (K^+). It indicates the predominance of sodium chloride (NaCl) and potassium chloride (KCl). These salts are water-soluble and they are subjected to the electrolysis process.

During electrolysis, the water-soluble salts of sodium chloride (NaCl) and potassium chloride (KCl) are broken down into chlorine anions (Cl^-), sodium cations (Na^+) and potassium (K^+), respectively. The magnetohydrodynamic effect acts on the ions of salts in the presence of a magnetic field.

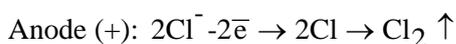
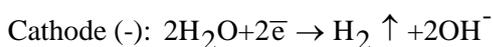
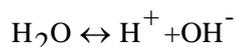
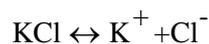
Electrolysis of sodium chloride electrolyte:



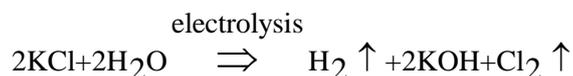
Overall equation:



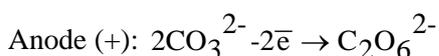
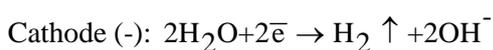
Electrolysis of potassium chloride electrolyte:



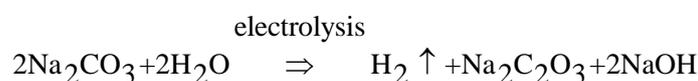
Overall equation:



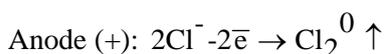
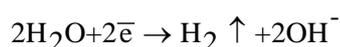
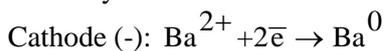
Electrolysis of sodium carbonate electrolyte (sodium carbonate):



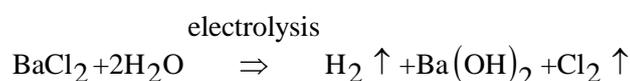
Overall equation:



Electrolysis of barium chloride electrolyte:



Overall equation:



Analysis of chemical reactions shows that gases (hydrogen and chlorine) are evolved during electrolysis in all cases. This factor produces a positive effect of the fluid lifting due to the energy of the gas mixed with it under pressure (gas lift).

We consider the operation of a simple magnetohydrodynamic pump, which includes at least two electrodes (of different polarity) and permanent magnets. In this case, the electrodes are arranged with respect to the magnets so that the magnetic induction lines are directed perpendicular to the flow of electric current between the electrodes. This arrangement provides the maximum efficiency (Fig. 1).

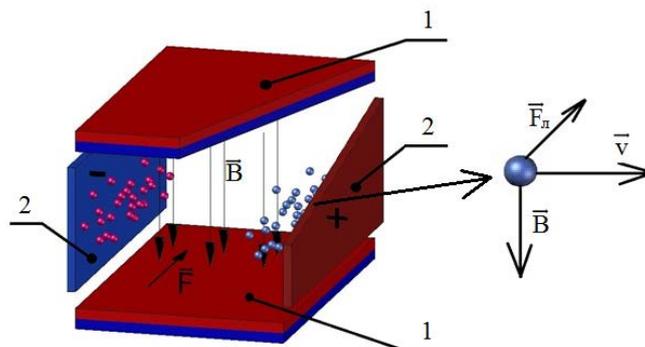


Figure 1. The simplest design of a magnetohydrodynamic pump

where 1 – permanent magnets; 2 – electrodes; \vec{F}_L – Lorentz force; \vec{B} – magnetic induction vector; \vec{v} – the velocity vector of the conductive fluid.

MHD pump works as follows. The salt dissociation into ions occurs (as an example, there is a water-soluble salt sodium chloride NaCl) when a constant voltage is applied to the electrodes in the formation fluid. The formation fluid is a solution of salts, acids, oil, etc. The negatively charged anions of chlorine (Cl) move towards a positively charged electrode (anode), and positively charged sodium cations (Na⁺) move towards a negatively charged electrode (cathode) under the influence of the electric field.

The Lorentz force affects the chlorine anions during their moving to a positively charged electrode (anode). The Lorentz force is determined by the equation:

$$\vec{F}_L = q \cdot \vec{v} \cdot \vec{B} \cdot \sin \alpha . \quad (1)$$

где q – is a charge. CL; \vec{v} – the velocity vector of the conductive fluid, m/s; \vec{B} – magnetic induction vector, T; α – is the angle between the velocity vectors and magnetic induction.

According to the rule of the left hand, the Lorentz force is directed perpendicular to the lines of the magnetic field. The magnetic field is created by permanent magnets [6]. The trajectory of chlorine anions changes under its influence. They move along the channel and capture the formation fluid.

3. Results

The laboratory sample of the magnetohydrodynamic pump for oil production is developed at the robotics center. It is created during the simplest design modernization of the magnetohydrodynamic pump and well conditions are taken into account. The laboratory sample of the magnetohydrodynamic pump consists of the body made from abs plastic (Fig. 2 and Fig. 3). Inside the body there is a liner for placing magnetic field sources. There are neodymium magnets in the amount of 8 units. The electrodes are installed in the upper and lower part of the liner. The constant voltage is applied to them. The electrodes are perpendicular to the neodymium magnets. It provides the maximum efficiency according to the equation (1). In the lower part of the body there is a channel for moving the produced formation fluid.



Figure 2. Liner (left) and body (right) of magnetohydrodynamic pump



Figure 3. Magnetohydrodynamic pump stage in assembling

4. Discussion

Analysis of formation water characteristics (Table 2) shows that the main share of the salts in the formation fluid are sodium chloride (NaCl) and potassium chloride (KCl). There are water-soluble salts and they are subjected to electrolysis.

During the analysis of the chemical model, it is found that hydrogen and chlorine are released during the electrolysis of water-soluble salts. The gases, which are released in the well create additional lift. It is a positive moment in electrolysis.

The developed laboratory sample of the magnetohydrodynamic pump allows efficient use of the well space in comparison with the design of the simplest magnetohydrodynamic pump. That can be due to the use of the ring design. Also, the use of individual stages allows us to get a flexible installation for oil production and select its parameters (pressure, performance, etc.) individually for each well.

5. Conclusions

The chemical model of the basic salts dissolved in the formation fluid and involved in the electrolysis process is considered. The analysis of the chemical model revealed the release of hydrogen and chlorine. They should create additional lift during production.

A laboratory sample of a magnetohydrodynamic pump for oil production is developed with the well conditions taking into account. It includes a body and a liner for placing permanent magnets and electrodes.

It is advisable to conduct further studies to determine the hydraulic and electrical characteristics of the laboratory sample for the magnetohydrodynamic pump.

Acknowledgments

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