TOPICAL SCIENTIFIC RE-SEARCHES INTO RESOURCE-SAVING TECHNOLOGIES OF MIN-ERAL MINING AND PROCESSING

Multi-authored monograph

Publishing House “St.Ivan Rilski”, Sofia,
2020

MAGNETIC TREATMENT OF PRODUCTION FLUID WITH HIGH CONTENT OF ASPHALT-RESIN-PARAFFIN DEPOSITS

Makarenko V.D.
National University "Yuri Kondratyuk Poltava Polytechnic"
DCs (Engineering), Professor, professor of the Department of Oil and Gas Engineering and Technology, Ukraine

Kharchenko M.O.
National University "Yuri Kondratyuk Poltava Polytechnic"
PhD in Technical Sciences, associated professor, associated professor of the Department of Oil and Gas Engineering and Technology, Ukraine

Manhura A.M.
National University "Yuri Kondratyuk Poltava Polytechnic"
Senior Lecturer, Department of Oil and Gas Engineering and Technology, Ukraine

Petrash O.V.
National University "Yuri Kondratyuk Poltava Polytechnic"
PhD in Technical Sciences, associated professor, associated professor of the Department of Oil and Gas Engineering and Technology, Ukraine

Absract. Justification of magnetic fields treatment to prevent asphalt-resin-paraffin deposits (ARPD) on oil and gas equipment, and consider some current views on the state of ARPD problem on oilfield equipment and possible methods for its solution using magnetic treatment.

Analysis and generalization of magnetic treatment results of production fluid using COMSOL Multiphysics software.

The technology of magnetic fields effect to prevent asphalt-resin-paraffin deposits was introduced in the article. The results of production fluid magnetic treatment made it possible to use it in oil-wells equipped with oil-well pumping units and also at free flow production method or in wells operated by electric-centrifugal pump, as well as in oil pipelines.

The use of high energy magnets based on rare earth materials can reduce asphalt-resin-paraffin deposits in the oil equipment.

The proposed magnetic treatment creates opportunities for field exploitation at the later stages of development which are characterized by a high content of asphaltenes, resins and paraffins. Results of production fluid magnetic treatment have proved the efficiency of this treatment, which has doubled a turnaround time.

Keywords: development of oil fields, asphalt, paraffins, resins, sediments, asphaltene deposits, salt deposits, the magnetic field, the magnetic anti-paraffin device.

1. Introduction

Characteristic features of the current stage of oil industry development in Ukraine are the following: reduce of oil production volume, increase of inactive and low-debit wells, water cut production, scaling and solids, etc. Relevant industry task now is to reduce the number of inactive, not pumping and complicated wells.

It is known that the formation of asphalt-resin-paraffin deposits (ARPD) in producing wells is accompanied by accidents, mainly due to breakages of sucker rod and polished rod that repeatedly reduces their turnaround time (TT) and production volumes.

Different methods are used to control ARPD: the use of scrapers, well treatment by hot oil and water, flushing with distillate, organic solvents, aqueous solutions of surface-active agents (SAA), electric bottom-hole heating, magnetic treatment and inhibiting of borehole production, use of hydrocarbon oxidizing bacteria, etc. [1]

However, all the known methods of ARPD control are limited depending on conditions of specific fields. For example, biotechnological method is limited to high formation pressure and gas factors, a high content of hydrogen sulfide in the oil and temperatures above 40-50 °C and is recommended for wells operated by rod pumps.

Magnetic treatment has its own requirements to applicable environment, such as gas factor (20-300 m^3/m^3), the presence of ferromagnetic particles in well production, content of asphaltenes and resins no less than content of paraffin in oil and so on. Electrical methods have quite complex ground equipment for supplying electricity to underground heating equipment [1-3].

However, the problem of ARPD in the oil fields is actual and needs further improving methods for its solution. Research and experience have discovered the advantages and disadvantages of different ways of ARPD control in conditions of specific fields.

Many deposits of Ukraine are characterized by high temperature of oil saturation with paraffin that reaches 48-50 °C. In addition, a typical part of paraffin deposits is ceresine - crystalline high-paraffin, the number of carbon atoms in which reaches to 36-56 poorly soluble in oil, which melting point is 80-92 °C. The corresponding composition of paraffin is presented in Table 1.

Table 1

Homologous composition of paraffins

Components	Mass fraction of components in the wells of Boryslav OGCF, %			
Resins	2,33	1,55	3,53	2,47
Asphaltenes	2,19	3,96	5,49	2,30
Paraffins	23,82	26,54	56,29	30,57
Ceresin	5,00	11,00	34,00	25,00

Ceresin content in the composition of ARPD can be predominant. For example, according to the data in one of the production wells 70,5% of selected sediment was ceresin.

The industrial observations found that paraffin deposits in producing wells of Ukraine deposits decrease with increasing debits of wells and at insignificant water content in the oil.

There are two stages of ARPD formation and growth. The first stage is the crystal nucleation and growth of paraffin crystal directly in contact with the oil surface. The second stage – precipitating of larger crystals on the surface covered with paraffin.

The formation of ARPD is significantly affected by the following factors:

- reducing of pressure on the bottom hole and the related hydrodynamic equilibrium of gas-liquid mixture (GLM);
- intensive gassing;
- reducing the temperature in the reservoir and borehole;
- changing the speed of the GLM and its individual components;
- hydrocarbon composition in each phase of the mixture;
- ratio of phases;
- surface condition of the pipes.

The intensity of ARPD formation depends on the prevalence of one or more factors that may vary over time and depth, so the number and nature of the deposits are not permanent [4-8].

When bottomhole pressure is less than saturation pressure of oil aeration, the equilibrium system is disturbed, which increases the volume of the gas phase and liquid phase becomes unstable. This leads to the separation of paraffin not only in reservoir but also in a well, starting from the bottomhole.

When pumping an operating pressure at pump sunction may be less than the saturation pressure of oil aeration. This can lead to paraffin deposition in the receiving part of the pump and on the walls of the production string. In the tubing above the pump, there are two zones. The first zone - directly above the pump: the pressure increases dramatically and occurs more saturation pressure. The probability of deposition in the area is minimal.

Second - zone of pressure reduction to saturation pressure and below, where intensive paraffin precipitation starts.

In a flow wells while maintaining pressure in bottomhole, equal to saturation pressure, can be expected a paraffin precipitation in the tubing.

Practice shows that the main objects in which ARPD are formed are well pumps, tubing, flow line from the well, gathering stations [5].

The most intensive paraffin deposition is on the inner surface of the tubing. The thickness of sediments gradually increases from the starting point of their formation at a depth of 500-900 meters and reaches a maximum at a depth of 50-00 meters from the wellhead, and then reduced to the thickness of 1-2 mm in the wellhead (Fig.1).

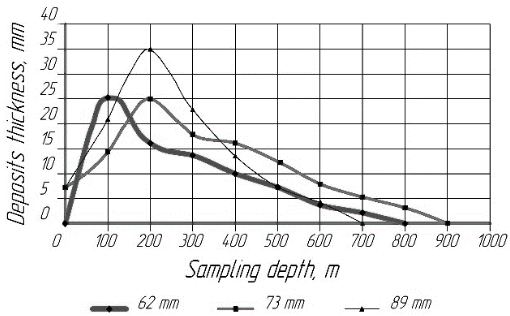

Fig.1. The deposition of ARPD on depth of well

With the decrease of depth is observed the reduction of asphalt-resins in ARPD and the increase of solids and solid paraffins (Fig. 2)

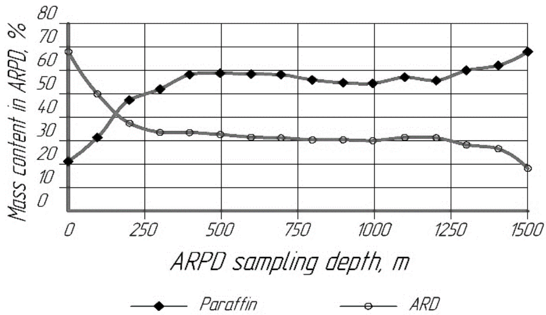

Fig.2. The deposition of ARD and paraffins on the depth of wells

The closer to the wellhead, the more ceresin in ARPD composition and, consequently, higher structural strength of deposits.

Oil is a complex mixture by chemical composition of components that, depending on the structure and the external environment may be in different states of aggregation. Temperature reduction causes a change in the physical state of the components, leading to the formation of paraffin crystallization centers and their growth.

Laboratory studies have shown that the rate of paraffins formation has an effect on allocation process and behavior of gas bubbles in the flow of mixture. It is known that gas bubbles have the ability to float suspended particles of paraffin. When bubbles contact with the pipes surface the paraffin particles come in contact with the wall and deposit on it.

In the following, the process of paraffin deposition increases because of its hydrophobicity. On the wall of the pipe is formed a layer of paraffin crystals and bubbles in the gas. The smaller gas-saturated layer, the greater density it has. Therefore, more dense sediments are formed at the bottom of the lifting pipes where gas bubbles are small and have greater strength adhesion to paraffin crystals and pipe walls.

The intensity of ARPD formation largely depends on the rate of fluid flow. At low flow rates, the formation of ARPD is quite slow. With speed increase (at transition to turbulent flow regime) deposits intensity initially increases. Further increase of liquid-gas mixture speed (LGM) leads to decrease of ARPD intensity as the high rate of fluid flow allows paraffin to keep the crystals in suspension state and take them out of the well. Furthermore, the flow tears a part of deposits from the walls of the pipes, which explains the sharp decrease of deposits in the range of 0-50 m from the wellhead. At high speeds the flow of the mixture cools slower than at small. In turn at low speeds the formation ARPD slows [6].

On the formation of deposits also has an effect on the state of surface pipes. Microroughnesses are the sources of vortex formation, and speed retarders on the wall of the pipe. This is the reason for formation of crystallization centers, sticking of paraffin crystals to the surface of the pipe, blocking of their movement between the asperity and valleys of the surface.

The process of ARPD formation has an adsorption character. Adsorption processes are accompanied by the occurrence of double electric layer on the surface of paraffin contact with gas-oil flow.

When mechanical equilibrium violation of layer on the surface of the pipe or paraffin layer appear uncompensated charges of static electricity, in other words electrification takes place on the pipe surface and on the surface of paraffin crystals that intensifies the adhesion paraffin to metal.

It is assumed that magnetic fields effect is one of the most advanced physical methods. The use of magnetic devices to prevent ARPD began in the fifties of the last century, but because of low efficiency it did not become widespread. In particular, there were no magnets that could work long and steadily in well.

In a 1995-2015 the interest in the use of magnetic field effect on ARPD increased significantly, due to market appearance of a wide range of high-energy magnets from rare earth elements.

2. The main part

Recently, interest in the use of magnetic fields for treatment of production fluid to prevent ARPD increased significantly, due to the appearance at the market of a wide range of high-energy magnets from rare earth materials. It has been established that under the influence of a magnetic field in a moving fluid is the destruction of units consisting of submicron ferromagnetic microparticles of iron compounds, which are at a concentration of 10-100 g/t in the oil and associated water.

Each unit contains from several hundred to several thousands of microparticles, because the destruction of units causes a sharp (100-1000) increase in the concentration of paraffins crystallization and formation on the surface of ferromagnetic particles of micron size gas bubbles. As a result of units destruction paraffin crystals fall as finely dispersed, volume, stable suspension, and the growth of deposits rate is reduced proportionally to the reduce of average size of fallen paraffin crystals in the solid phase [7].

Formation of gas micro bubbles in the centers of crystallization after magnetic treatment provides, according to some researchers, the gas-lift effect, leading to the growth of wells production rate. Magnetic treatment of oil, including oil and gas mixtures produced in wells was intended to prevent (or significantly reduce) the formation ARPD and salts in the tubing and reduction of surface corrosion of pipelines [8].

One of the most important results of magnetic treatment is the occurrence of gas micro bubbles formed on the surface of the iron particles. Studies have shown that these micro bubbles have electric charge and high adsorption activity with respect to organic and mineral deposits.

After magnetic treatment such bubbles provide liquid detergent properties similar to those that occur when washing powder or soap are added to water. For effective magnetic treatment effect in a number of processes is necessary a combination of several factors. This explains the poor reproducibility typical for magnetic treatment [6-8].

However, the methods of analysis of the substance and hydrodynamic conditions of liquids flow make it possible to create or select technological processes in which consistently appear industrially important effects. It is possible to predict the expected effects in each case, and to prove from a physical point of view those already observed.

The effect of magnetic field on the formation of paraffin deposits in the lab helped to solve several problems in the selection of permanent magnets for this or that well in particular field.

Ferromagnetic particles test in borehole production - the first crystals seeds of ARPD by filtration of oils, can find out reasonability of magnetic field processing of the product. In the study of rheological behavior of oils after magnetic treatment was noted that magnetic field has an effect on their properties in different way (Table 2).

Table 2

Rheological parameters oil before and after magnetic treatment oil Boryslasv OGCF

Oil	η, мPa·s	τ_c,Pa	$E_{акт}$kJ/mole
Before magnetic treatment	778,1	303,2	12,84
After magnetic treatment	605,0	267,3	8,21

Decrease of rheological characteristics for oil are observed – dynamic viscosity by 28%, the yield stress at 13%, the activation energy of viscous flow by 56% [3].

In case of a sufficient content of asphalt-resinous substances and trace iron in the borehole fluid, the analysis of static magnetic field effect on it in the lab, makes it possible to determine the exact topology and the magnetic field and the desired temperature for effective operation of instrument that determines the previous installation depth of the magnetic device.

The magnetic device is convenient in operation because it does not require maintenance and supply of any kind of energy. The most effective is the use of magnetic devices immediately after wells cleaning from existing deposits [4].

Magnetic device for ARPD control is installed on the tubing string. Production fluid stream that passes through the activator comes under influence of strong magnetic fields of permanent magnets, which prevents the formation of deposits asphaltenes, resins, paraffins and salts on the inner surface of the tubing [1-5].

It is considered that the use of magnetic devices can increase the production of wells during overhaul period by 2-5 times, leading to considerable economy and can increase oil production.

The magnetic device is convenient in operation because it does not require maintenance and supply of any kind of energy. The most effective is the use of magnetic devices immediately after well cleanup from existing deposits.

Magnetic fluid magnetizing device consists of a body-pipeline with a soft magnetic material and fixed to the axis of the magnetic system, which is a consistent set of permanent magnets with sequential magnetization directions along a body-pipeline. These permanent magnets have a circular shape and radial magnetization and placed on the magnetic circuit. On the outer surfaces of permanent magnets are fixed pole pieces, and magnets are placed between the pads of a nonmagnetic material [9].

The outer surface of the magnetic system with nonmagnetic spacers between the magnets and pole pieces placed on permanent magnets shaped like a cylinder and as a working channel for the treated liquid is the annular gap crossing between the magnet system and the body-pipeline. Figure 3 shows a diagram of the installation of a magnetic device in the well

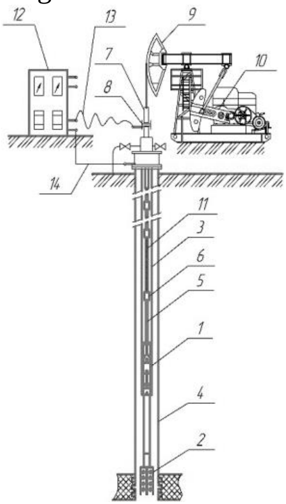

Fig. 3. ARPD control technology in the producing wells equipped with sucker-rod pumping unit: *1* - deep pump; *2* - magnetic device; *3* - tubing string; *4* - column casing; 5 - column rod (steel); *6* - centrators-protectors; *7* - polished rod; 8 - insulating insert; *9* - balance; *10* - drive unit; *11* - fiberglass rod; *12* - station of cathodic protection (power supply); *13* - cable (flexible); *14* - cable

Magnetic device is a body of ferromagnetic pipe. At one end of the pipe is fixed a sleeve joint for tubing. On the inner surface of the housing permanent magnets are fixed.

Device is installed in the tubing string under the bottom-hole pump or in the necessary part of the tubing string. With the passage of a mining fluid through the body it is treated by magnetic field.

Some characteristics of the magnetic device:

- the diameter of the device, mm - 73;

- working life, years, not less - 30;

- performance - explosion-protected;

- working pressure, MPa - up to 15;

- weight of magnetic device, kg – not more than 10;

- operating temperature range of production fluid – 10-120 °C;

- production fluid composition in which is guaranteed the efficiency of the magnetic device - watering at least 25%, mineralization of at least 150 g/kg [10].

The use of magnetic device increased the average turnaround time of wells complicated by the formation of emulsions and ARPD, on average twice. Chemical treatment of the wells was stopped.

At Boryslav OGCR the use of magnetic device made it possible to increase the turnaround period of wells in 2,2 times and to decrease the number of thermal and chemical treatments, respectively, in 2 and 5 times.

The use of magnetic device in wells complicated by ARPD allowed increasing their average turnaround time in 2 times at stopping chemical treatments of wells.

Magnetic treatment is aimed to increase turnaround period of wells by directional magnetic field effect [11].

The use of magnetic treatment can be effective, as in case of flowing, and the operation of the depth-rod, by centrifugal and diaphragm pumps and also on oil pipelines to increase their anti-corrosion resistance.

Payback of magnetic devices to prevent the ARPD formation depending on the turnaround period and geological characteristics of the particular wells ranges from one to three months.

3. Conclusions

In the article is proposed magnetic treatment of production fluid as a method of ARPD control. Magnetic device runs into the well and this ensures the effectiveness of magnetic treatment of the whole volume of liquid that passes through the device in the same conditions of high-gradient field with sufficient duration of treatment.

Magnetic treatment differs from other methods of treatment fluid so that work does not require any power supply to the unit, as it is based on permanent magnets.

Magnetic Anti-Paraffin Device can work in large diameter pipelines, thus providing the necessary magnetic field and magnetic induction. Therefore, in our opinion, it should be used in the wells with high content of ARPD deposits.

References

1. **Chow, R., Sawatzky, R., Henry, D., Babchin, A., Wang, Y., Cherney, L., & Humphreys, R.** (2000). Precipitation of Wax From Crude Oil Under the Influence of a Magnetic Field. Journal of Canadian Petroleum Technology, 39(06).

2. **Gavriluk O. V. , Glazkov O. V.** (2001) The application of magnetic liquide treatment in oil fields of West Siberia. IOR - 11th European Symposium on Improved Oil Recovery 19-25

3. **Ivakhnenko, O. P.,** (2006) Magnetic analysis of petroleum reservoir fluids, matrix mineral assemblages and fluid-rock interactions. Thesis, Institute of Petroleum Engineering, Edinburgh, UK, 210 pp.

4. **Klassen, V.** (1982). Omagnichevanie vodnykh sistem. *Khimiya*, 1982.

5. **Nalivaiko, O., Mangura, A., Mangura, S., Nalivaiko L.** (2015). Peculirities of magnetic anti-paraffin waxes device (MAD) modeling in Comsol multiphysics software. *Problems of Energy Saving and Nature Use*. 58-67.

6. **Pisareva, S.I., Kamenchuk, Y.A., Andreeva, L.N.** (2005) The Nature of Formation and Dissolution of Asphalt-Resin-Wax Deposits Chem Technol Fuels Oils 41: 480.

7. **Suzuki, Hirofumi., Kodera, Sunao; Matsunaga, Hiroyuki; Kurobe, Toshiji** (1993) Study on magnetic field-assisted polishing (2nd Report) - effect of magnetic field distribution on removal distribution. *Journal of the Japan Society for Precision Engineering*. Nov; 59(11): 1833–1838

8. **Swapan Kumar Das** (2008) Electro Magnetic Heating in Viscous Oil Reservoir International Thermal Operations and Heavy Oil Symposium, 20-23 October, Calgary, Alberta, Canada

9. **Tung, N., Vuong, N., Bui Quang, K., Vinh, N., Hung, P., Hue, V., & Hoe, L.** (2001). Studying the Mechanism of Magnetic Field Influence on Paraffin Crude Oil Viscosity and Wax Deposition Reductions. *Proceedings of SPE Asia Pacific Oil and Gas Conference and Exhibition*.

10. **Wang L. J., Wang W., (2014)** Paraffin Depositing Mechanism and Prediction Methods of Paraffin Removal Cycle ", Applied Mechanics and Materials, Vols. 675-677, pp. 1512-1516

11. **Zhang, W. W., Wang, T. T., Li, X., & Zhang, S. C**. (2013). The Effect of Magnetic Field on the Deposition of Paraffin Wax on the Oil Pipe. *Advanced Materials Research, 788*, 719-722.

12. **Zhang, W. W., Wang, D. D., Wang, T. T., & Zhang, S. C.** (2015). Study on the Mechanism of Magnetic Paraffin Con-trol of Crude Oil Based on the Reorientation of Paraffin Crystals Induced by Magnetic Field. *Applied Mechanics and Materials, 743*, 137-141.