O.I. Nalivaiko, PhD, Associate Professor
A.M. Mangura, Senior Lecturer
L.G. Nalivaiko Senior Lecturer
S.I. Mangura, Senior Lecturer
Poltava National Technical Yuri Kondratyuk University

Traditional prevention and remove methods of asphaltene, resin and paraffin deposits and new approaches of this problem solving, for example technologies and devices, based on magnetic fields use are considered in this article. When constructing the MAD computer model, six blocks of axially magnetized permanent magnets have been formed.

Keywords: *paraffin, asphalten, resin, investigation, well, magnets, oil extraction.*

Peculiarities of Magnetic Anti-Paraffin Device (MAD) Modeling in COMSOL Multiphysics Software

Introduction. At the modern level of science and technics development, mathematic modeling has wide spread occurrence wherein the study of phenomena is carried out on the model, imaged into mathematical system of correlations, which describe all about this or that process.

Generally modeling is the process of model building and study, and also obtaining new information about the subject of research that can be used for the development of more optimal systems, according to some criteria, among them instrumentation equipment.

Adequate choice of permanent magnets is very important. At the basis of this choice there is a necessity of device parameters maintenance, their stability in difficult exploitation in a field conditions, corrosion resistance and their lower cost.

Materials and Methods. To calculate the magnetic aggregates, designed to prevent asphaltens-resins-paraffins deposits (ARPD), a software package is used, intended for finite element analysis in different spheres of physics and engineering, including the consideration of related (metaphysics) tasks, methodology of calculation and constructing - COMSOL Multiphysics (www.comsol.com).

AC / DC Module – module for the calculation of electromagnetic action, including electrostatics, magneto statics, electromagnetic quasi statics. It consists of a special elements library for 2D and 3D modeling.

Extremely important for oil and gas extracting is Earth Science Module – module for the analysis of downhole filtration that gives an opportunity of a quite difficult processes modeling, occurred while exploitation. It is designed specifically for the study of oil and gas filtration in porous medium, modeling of groundwater flows, and spread of contamination through soil. Richards, Navier-Stokes and Darcy and Brinkman equations are implemented in it.

AC/DC module is used by the engineers and scientists for predicting and calculating electric and magnetic fields in statics. It allows users to quickly and accurately predict the distribution of electromagnetic field, electromagnetic energy and scattering in the proposed model. The module includes stationary and dynamic electric and magnetic fields in two-dimensional and three-dimensional coordinates. Along with traditional there are methods of passive and active devices modeling.

All models are based on Maxwell's equations and Ohm's law. Simulation is available through the user interface, which allows sets up and solves the electromagnetic model (Figure 1)

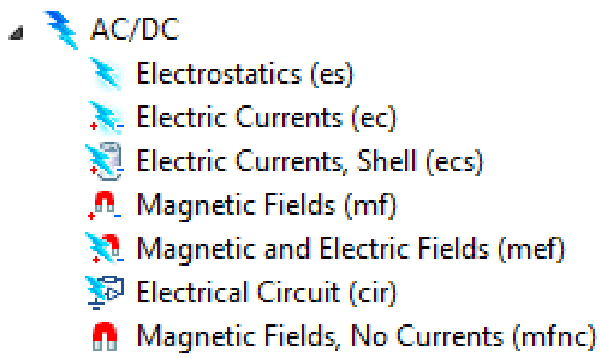

Fig. 1. Module interface AC / DC

AC / DC interface formulates and solves differential forms of Maxwell's equations with initial and boundary conditions. The equations are solved using the finite element method. Flow work in the AC / DC module is simple and can be described by the following steps: define the geometry, choose materials, and choose the right AC / DC interface to define the boundary and initial conditions to determine the finite element mesh, visualization of results. The solution is usually done automatically with default settings that are configured for each AC / DC interface.

For the MAD modeling, which consists of the permanent magnet system, used in this scientific work, a section «Magnetic fields» was used.

Output data for MAD modeling. Devices of this kind are easy to implement with magnetized in a predetermined sequence magnets installed in conduit, alternating directions of magnetization (reversely magnetized blocks of magnets).

Using this installation, it is possible to get multi reverse (with a large number of reverse) magnetic field with mostly perpendicular to fluid flow direction of force lines, with high intensity and gradient.

In this case there are no difficulties in a significant increase of a field reverses number. According to this principle, a very large number of magnetic devices have been implemented. However, it is difficult to obtain large areas with long high gradient fields. Therefore, the high gradient fields region usually constitute only a small part of the whole length of the channel and only in this small part of the length a highly magnetic treatment of liquids is carried out.

In this regard, to improve the efficiency of magnetic devices and their mass and size characteristics, the development of devices in which high gradient field regions of magnetic field are placed inside regions with unidirectional field deserves special attention.

In MAD each of these pairs (blocks) magnets is rotated around the axis of the tube by 180 ° along of the channel's length in relation to previous so that each side of the pipe, polarity facing her pole magnets, alternating, created multi reverse magnetic field of any desired length of interaction region and with any total length of the sites with high gradient field.

The chain of cylindrical permanent magnets that is fixed in the conduit has reversible axial magnetization, created so that outer poles have the same polarity and opposite polarity is formed in the middle of its length that makes it possible to receive multi reverse magnetic field mostly perpendicular to the direction of fluid flow lines with high intensity and gradient.

When building a computer model of MAD six blocks of axially magnetized permanent magnets were formed, the distance between them was 15 mm. The first pair of blocks has a magnetic induction of 50 mT and 150, respectively. The next pair was magnetized to the same values of 150 mT and was returned at 180° in relation to the previous block so that the second block of the first pair and the first block of the second pair were rotated to each pole of the same pole. The latter, the third pair of blocks and was also returned at 180° relative to the previous and the first block of three couples had a magnetic induction of 150 mT, the second - 80 mT.

Permanent magnets of magnetic materials were used to form magnetic blocks. Geometric dimensions of the magnets were 32 × 12 × 8, their number in one block amounted 10 units. Thus the total length of MAP is equal to 450 mm. As outer casing served the pipe of tubing with $D_{out.} = 73\,mm$ and wall thickness $\delta = 5{,}5\,mm$. Conduit containing magnets had $D_{out.} = 62\,mm$ and wall thickness $\delta = 5{,}5\,mm$ was made of a material that is not magnetized.

Environment under magnetic effect was advocated oil, containing ARPD (3,5-11,2%),the part of water in production was more than 5%, the velocity of oil did not exceed $0{,}5\ \mathrm{m/s}$.

During modeling it was necessary to introduce a relative dielectric constant:

• for the pipe of tubing it was - 100;

• for the conduit - 0.999994;

• oil and ARPD have almost the same value -1.000002, but water in the oil was present with a specific dielectric constant - 0.999992, part, 5%.

It is necessary to calculate this value for multi-component environment according to the formula (1):

$$\mu_{сер.} = \mu_н \cdot n_н + \mu_в \cdot n_в \qquad (1)$$

$\mu_н$ - the relative dielectric constant of oil;
$\mu_в$ - the relative permittivity of water;
$n_н$ - share of oil-containing ARPD;
$n_в$ - portion of water.

So, $\mu_{cep} = 1{,}000002 \cdot 0{,}95 + 0{,}999992 \cdot 0{,}05 = 1{,}0000015$

The «Magnetic Fields» section solves Ampere's law for the magnetic vector potential. It is used for the modeling of magneto statics, alternating current and magneto dynamics.

Magnets, magnetic actuators, motors, transformers are calculated in this tab.

Ampere law function adds to the magnetic field defining value-related properties such as relative permeability and electrical parameters.

From the list, it is necessary to select the regions for the magnetic vector potential defineining and the equation from Ampere's law, which calculates the potential.

It is necessary to point out the macroscopic properties of the medium (for magnetic induction B and the magnetic field H) and apply material properties such as relative permeability.

The formula used to calculate the MAD model:

- calculation of relative permeability (2)

$$\mu_r = \mu^{'} + i\mu^{''} \tag{2}$$

μ', μ''- real and imaginary permeability, respectively, $T \cdot m / A$;

- calculation of permeability (3):

$$\mu = \mu_0 \mu_r \tag{3}$$

μ_0 - magnetic constant, $T \cdot m / A\left(\mu_0 = 1{,}2566 \cdot 10^{-6}\right)$;

- calculation of magnetic induction B, T (4):

$$B = \mu_0 \mu_r H + B_r \tag{4}$$

B - magnetic induction, T;

H - magnetic field strength, A / m;

μ - magnetic field, A / m;

B_r - residual magnetization, T.

- calculation of the magnetization M, A / m (5), (6):

$$M = H - \frac{B}{\mu_0} \tag{5}$$

$$M = \lambda_m H \tag{6}$$

λ_m - magnetic susceptibility;

- calculation of magnetic susceptibility (7):

$$\lambda_m = \mu_r - 1 \tag{7}$$

- current density, A/m^2 (8):

$$J = \frac{B_r}{\mu_0} \tag{8}$$

Results of MAD modeling in COMSOL software

a) The distribution of the magnetic induction in the MAD

Magnetic induction is a vector physical value, the main characteristics of the magnetic field strength and direction. Magnetic induction vector is usually denoted by Latin letter B. In the CGS system the magnetic induction field is measured in gauss (Gs) in the SI-system - in Tesla (T).

The distribution of magnetic induction can be observed in Fig. 2 and 3.

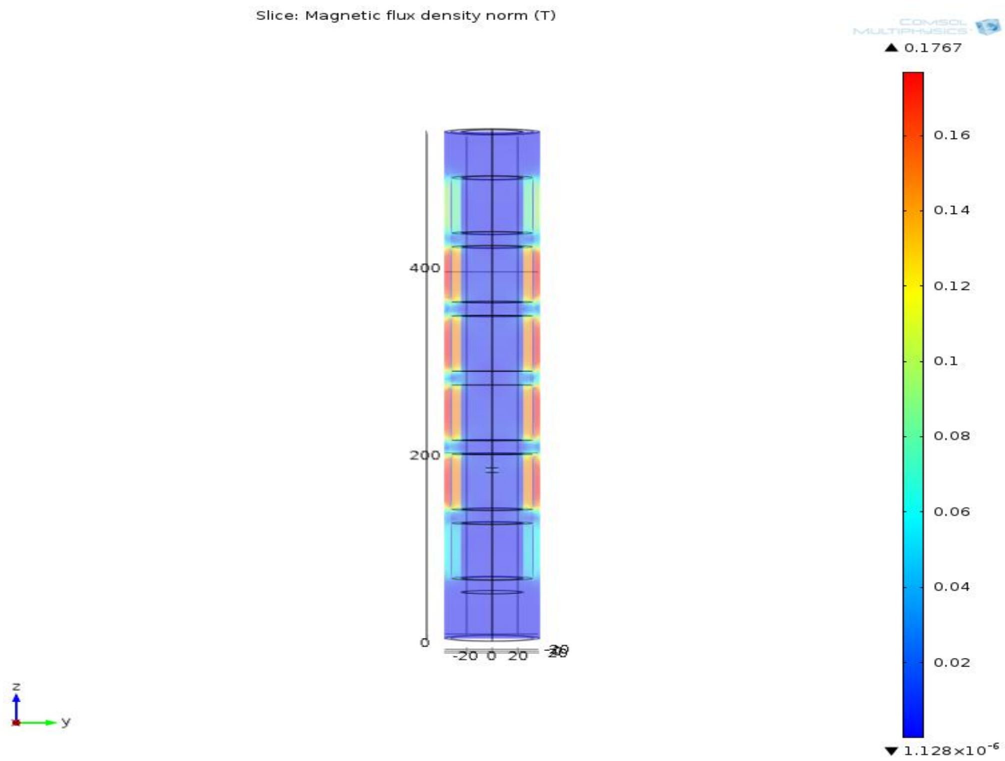

Figure. 2. The distribution of magnetic induction in the MAD

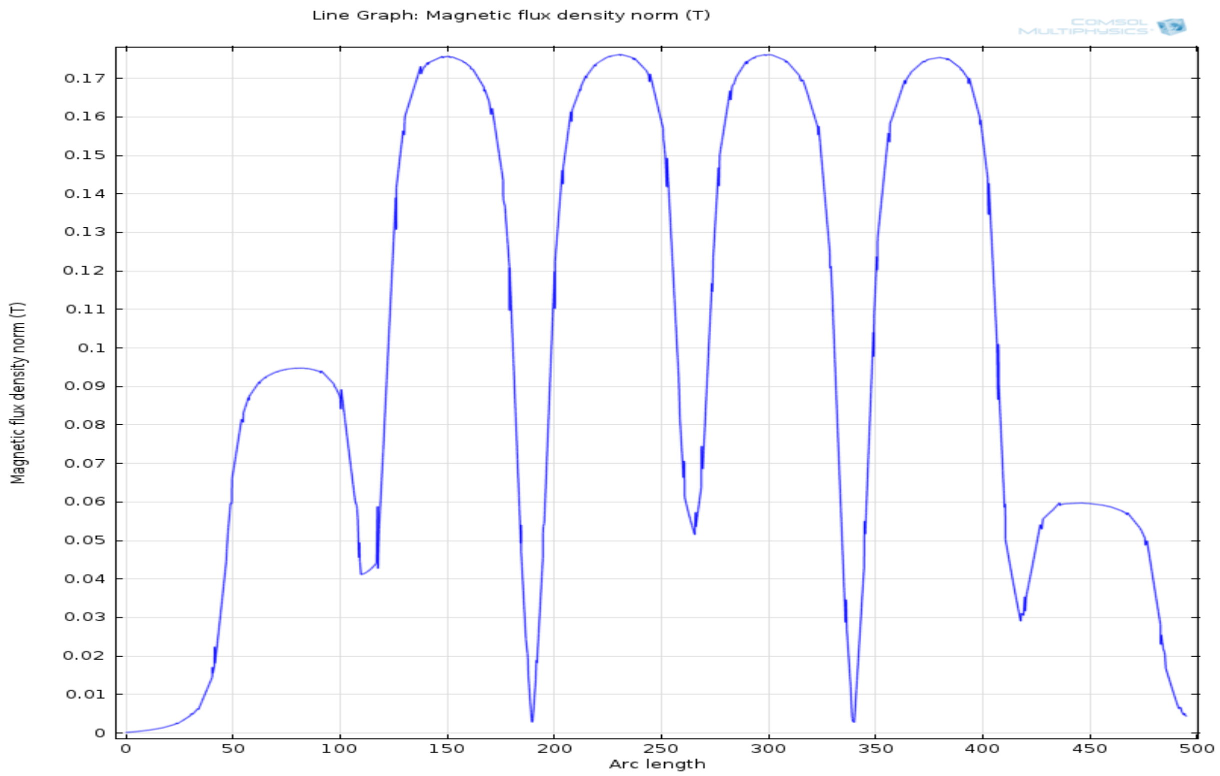

Fig.3. The graph of magnetic induction distribution on the length of MAD

As a result of obtained values, we can see that while the maximum residual magnetic induction of 150 mT, which we pre-assigned in the initial terms in Figs 2 and 3, the maximum value after calculation is 187.5 mT. This change can be easily explained by the fact that the pipe is made of steel, which is ferromagnetic, i.e. the magnetic field strength increases, so we observe the pipe magnetization process.

b) The distribution of the magnetic field in the MAD

The magnetic field strength is a vector characteristic that determines the magnitude and direction of the magnetic field at present point and present sample time.

It is usually denoted by Latin letter H, measured in Oersted in the CGS electromagnetic system and ampere-turns per meter $\left(A \cdot V / m\right)$ in the SI system.

The distribution of the magnetic field depicted in Fig. 4 and 5.

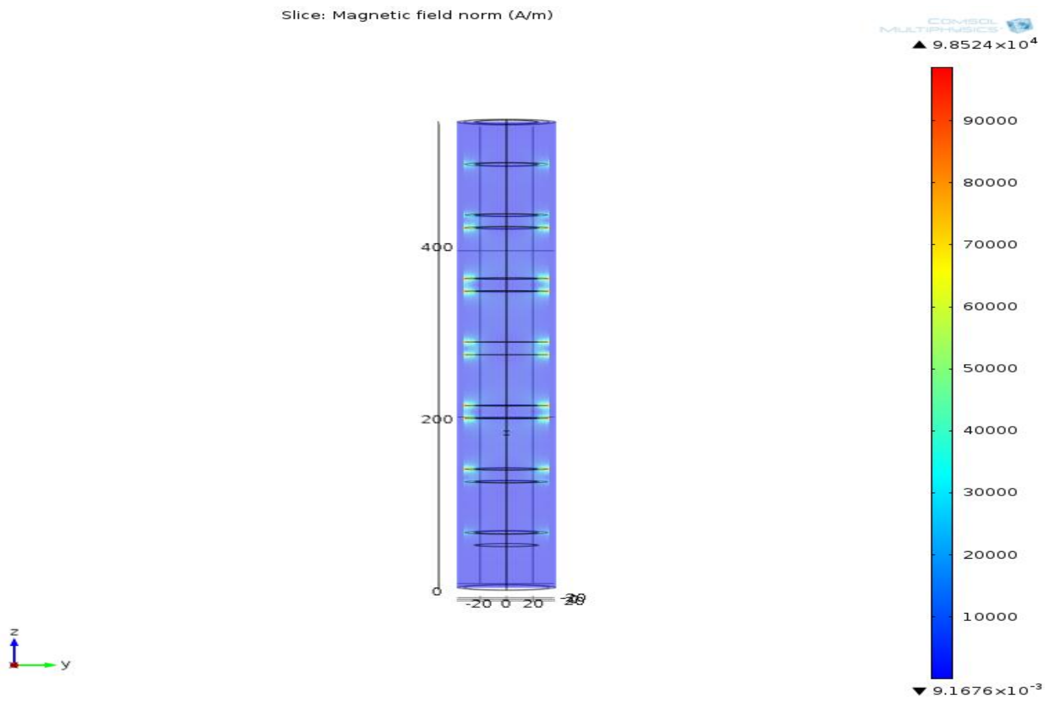

Figure. 4. The distribution of the magnetic field in the MAD

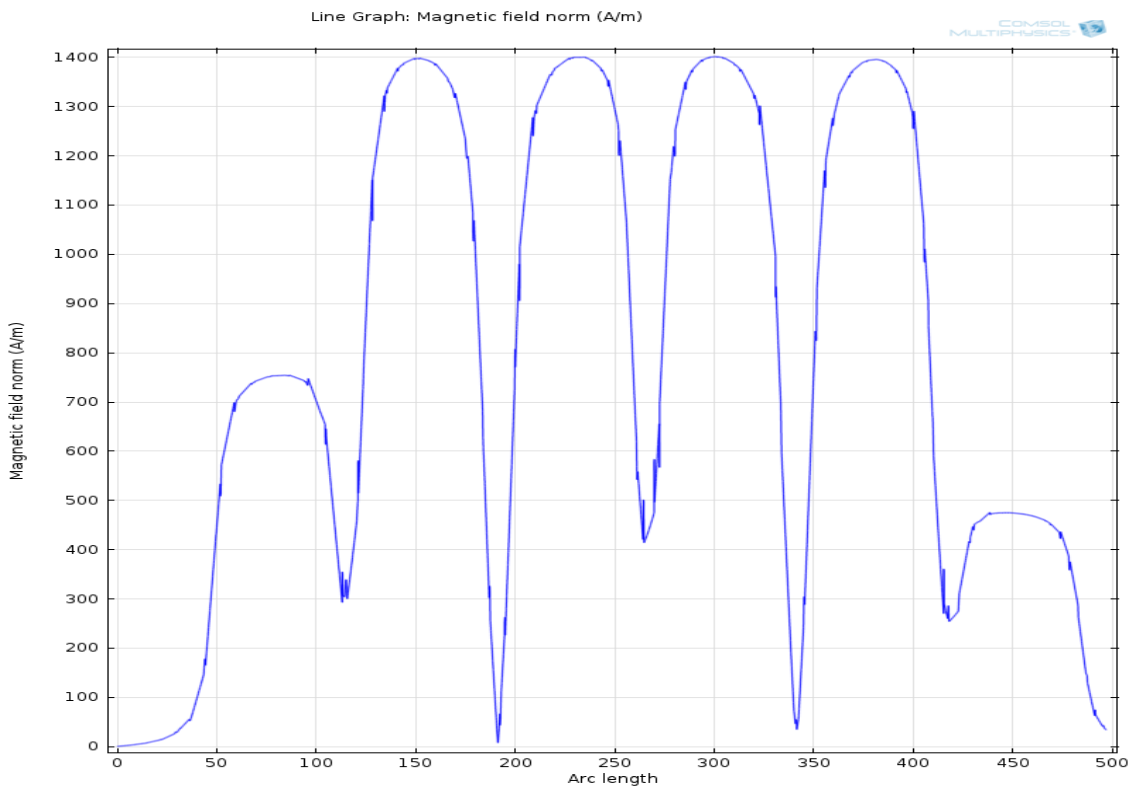

Figure. 5. Graph of the magnetic field distribution

along the length of installation

After obtained results we can see that the concentration of magnetic field strength is observed at the end points of the magnets. On the graph is clearly observed a significant potential drop in the range of 190 and 340 mm due to the fact that the given points a pair of magnets rotated to each other with the same poles, i.e. there is some "compensation" of the magnetic field.

c) Distribution of the scalar potential in the MAD

Vector field scalar potential A (often a potential vector field) - is a scalar function ϕ such that at all points of the domain of the field $A = grad\,\phi$ where $grad\,\phi$ denotes the gradient. In physics, potential is a magnitude, converse (force potential, power potential of the electric field).

Distribution of the scalar potential in the MAD depicted in Figure 6.

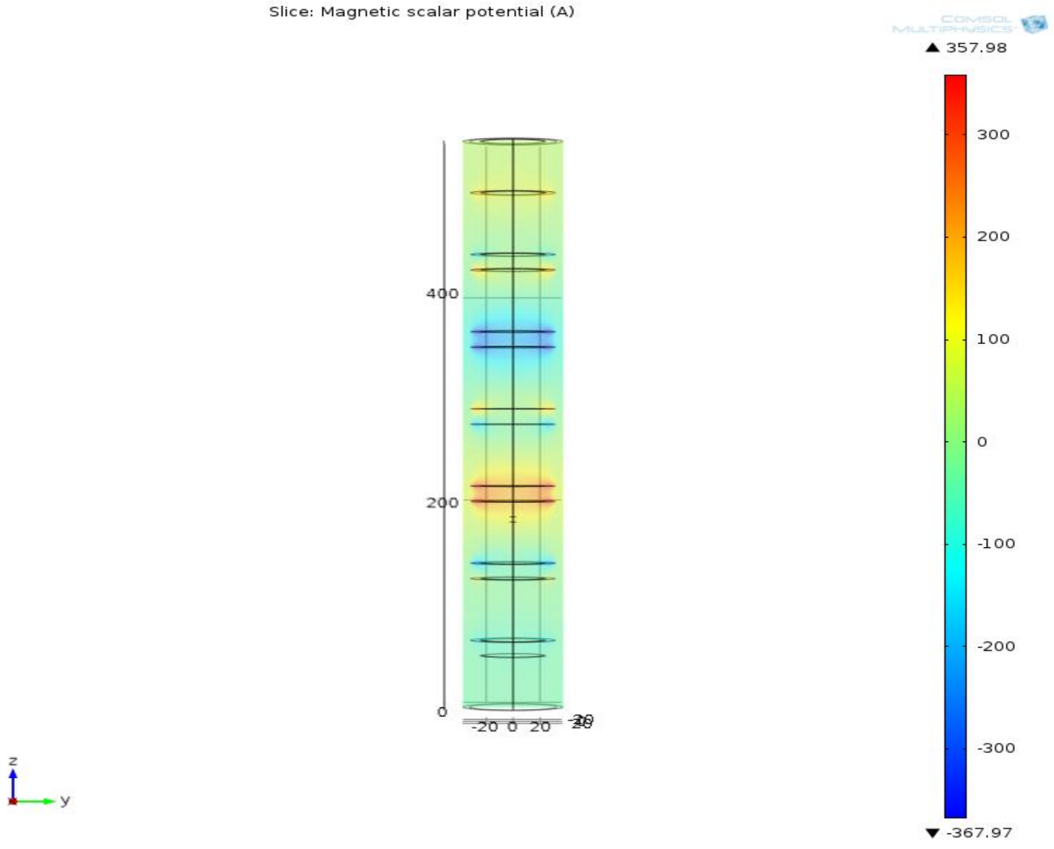

Figure. 6 Distribution of the scalar potential in the MAP

The maximum and minimum values of the scalar potential are observed in places where the magnetic blocks converge rotated to each other with the same poles.

d) Influence of MAD on mechanical impurities

The presence of impurities in the flow of oil fosters formation of ARPD crystallization centers, so if you remove these elements from the stream, the rate of sediments formation will significantly reduce. In Figure 8 is depicted how the MAD effects on mechanical impurities. In the process of modeling into the liquid flow was put a piece of cylindrical form metal in radius and height of 5 mm. Usually, these particle sizes in the oil are extremely rare, but for the visualization of magnetic field influence such simplification will to be appropriate.

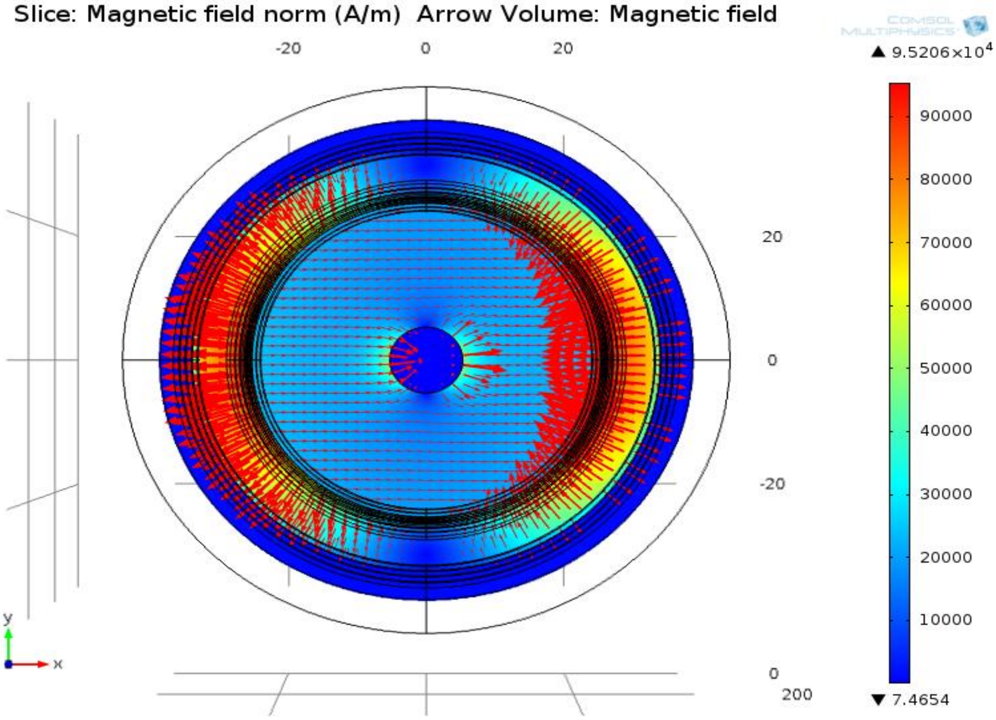

Figure. 7. Influence of magnetic field on mechanical impurities

As can be seen, the magnetic field affects the mechanical impurities, as evidenced by the line flow. Thus there is a definite change in the magnetic field around the metal impurities. This is the process of agglomeration and removal of fluid flow particles can serve to the formation of ARPD.

d) Graphs showing the patterns of magnetic fields distribution

For better clarity, in Fig. 8 and 9 the magnetic field lines and the 3D model of the distribution of magnetic induction are exemplified.

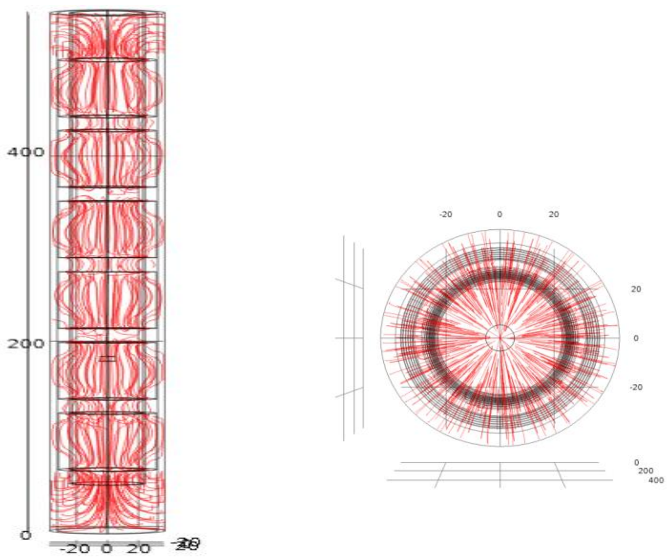

Figure. 8 Lines of the magnetic field

In Figure 8, one can observe the patterns of magnetic field lines distribution. It should be noted that the magnetic field passes through the oil and has impact on the entire internal environment.

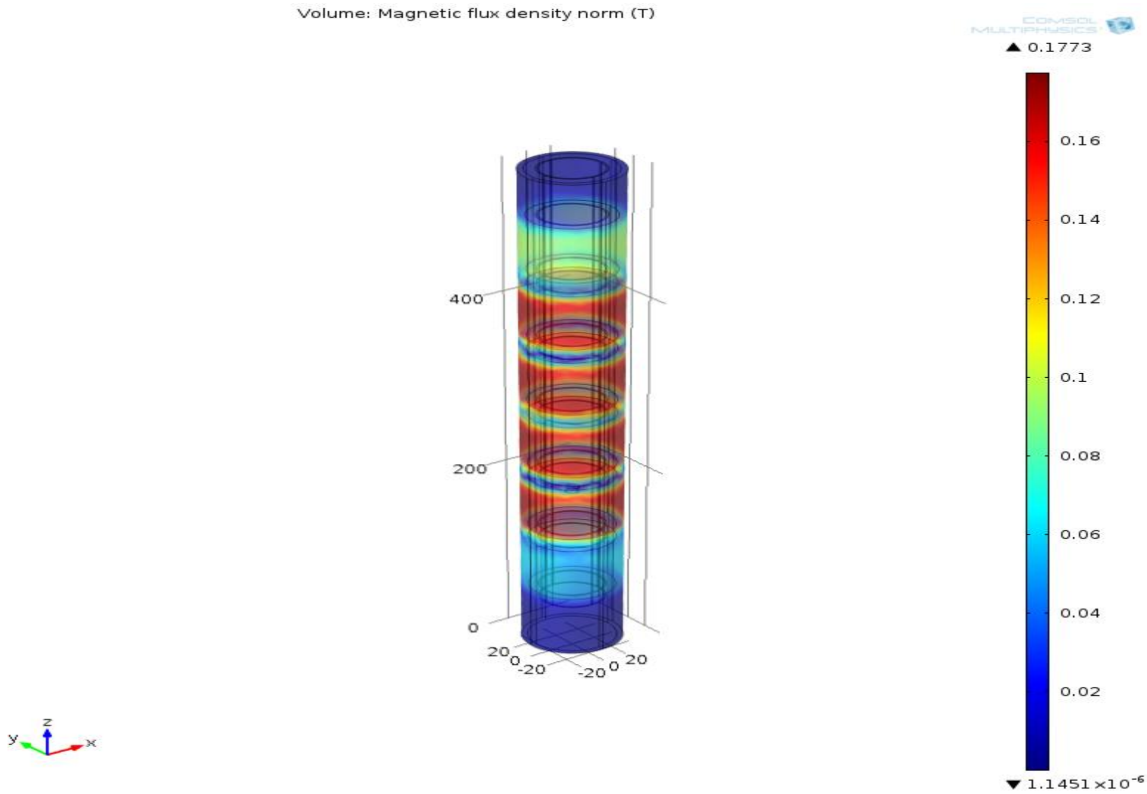

Figure. 9. 3D model of magnetic induction distribution

Different color intensity of the first and sixth magnets caused by the fact that they have a magnetic induction of 50 mT and 80, respectively, and all the latest

150 mT. Also, on the border between 2-3 and 4-5 there is a significant drop in magnetic induction, due to the fact that these magnets are rotated to each other with the same poles.

Conclusions. The description of magnetic devices modeling, ranging from theoretical concepts to the formulas used in the calculation, are exemplified in the work.

A set of data that enables to work in COMSOL Multiphisics software was formed, as in its module AC / DC, whose resources were used to solve the equations.

The theoretical and laboratory studies have allowed us to use the results of MAD on wells of highly paraffinic crude oil.

The modeling process of constant magnetic field on the fluid that moves through tubing, especially by the distribution of magnetic fields in the environment, has been held.

In the process of modeling various reservoir fluid properties have been used, as they affect the environment and the permeability and change the intensity distribution of the magnetic field characteristics in the flow of liquid.

The illustrative modeling results allow observing the work of the magnetic anti-paraffin device.

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