Application of magnetic units for intensification of water treatment

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Abstract. The article investigates the main problem of the standard water treatment system which requires high consumption of reagents and the need to systematically select the optimal dosage (depending on the changeable environmental conditions). The proposed technology of magnetic-reagent treatment of water allows intensifying the stage of reagent treatment. With the implementation of this technology the costs for the reconstruction of the object will not be significant. Bench and test-industrial tests at oil contaminated and drinking water treatment facilities showed the effectiveness of the proposed method, caused by a decrease in time of gravitational separation of coagulated globules and a reduction in the reagent consumption. It is shown that the proposed technology can be considered both as an upgrade of existing water treatment stations operating under a typical scheme, and in the design of new facilities.

Many branches of industry, medicine and agriculture made attempts to use magnetic treatment of water systems in order to improve them [1]. Moreover, the results of its use presented in the Russian and foreign scientific and technical literature, and in patent information are contradictory in many ways. This is the main explanation of the limited and cautious use of magnetic treatment (MT) devices.

Researches from Novocherkassk Polytechnic Institute (M.I. Platov South-Russian State Polytechnic University), Moscow Power Engineering Institute, Azerbaijan State Research and Design Institute of Oil (Azerbaijan State Oil and Industry University), Ufa State Oil Technical University, and other organizations [2-7] laid the theoretical groundwork for wide application of magnetic treatment in order to reduce scaling at thermal power sector facilities, to enhance features of materials in construction activities, to reduce postoperative complications in medicine, and to eliminate water-oil emulsions in oil industry [8].

Magnetic treatment proved to be effective in field areas. Nevertheless, there are problems with obtaining continuous satisfactory results in practice [9, 10].

Due to the particular characteristics of oil-field equipment, apparatus with permanent magnets (as they are easy-to-install and do not require specific training of maintenance engineers) were most widely spread [11]. Though, such apparatus were not able to perform a wide range of tasks because of their low efficiency resulted from low magnetic field intensity. Another type of apparatus used is electromagnetic units. They have a completely different design, but (as apparatus with permanent magnets) also lack magnetic field intensity.
The apparatus we offer belongs to the second type of magnetic treatment units, but it operates in a completely different pulse-mode. This type of apparatus provides a high-tension magnetic field that has the maximum impact on the treated environment [12]. The Magnetic Pulse Unit (MPU) consists of a low-frequency current generator and a solenoid cable connected to it, mounted by a flange connection to the pipe section. The unit allows the fluid passing through the solenoid to be exposed to a strong (400 kA/m) low frequency pulse magnetic field (<50 Hz).

**Treatment of oil-contaminated waste water**

The most widespread pollutants in waste water of the fuel and energy complex (FEC) facilities are oil products: an unidentified group of hydrocarbons of oil, oil residuum, kerosene, oils and their impurities. According to UNESCO, they belong to the top ten most dangerous pollutants due to their high toxicity. In some cases, the amount of pollutants in discharged waste water of the FEC facilities is thousandfold higher than allowed (by the standards) [13].

Petroleum production and solid mining enterprises are the main sources of pollution with crude oil and refined products. As a rule, FEC waste treatment facilities do not cope with large amounts of oil-contaminated wastewater. Therefore, its discharge leads to pollution of surface and groundwater. The analysis of the enterprises’ activity revealed that more than 50% of waste water is discharged in under-treated condition.

It is common for the oil industry to use water injection method (pumping water into the reservoir in order to retain reservoir pressure). Due to the constant water cut increase, the existing treatment equipment does not cope with such volumes of formation water, which results in pumping raw water into the reservoir.

When flooding producing layers of formation water with high residual oil content, a noticeable decrease in well reception (up to the complete cessation of pumping) can occur. Typically, it is oil with a significant content of ARPD (asphalt, resin and paraffin deposits) dispersed in the aqueous phase. Residual oil that penetrates larger capillary channels of BHFZ (bottom-hole formation zone) can significantly reduce well reception due to its tendency to gradual coalescing and accumulating.

Thus, improving the quality of wastewater treatment at existing facilities is the most urgent issue. Since full or partial reconstruction is generally not possible because of the cost-effectiveness of the proposed solution method, organizations are looking for a cheap and effective way to upgrade existing treatment facilities. One of the most promising technologies of water treatment intensification is the technology of treating water-oil zones with magnetic field.

As the MF affects the globules of the oil product that contains ferromagnets (ferrous oxides) and paramagnetics (ARPĐ), there is an increase in the dynamics of sedimentation (breakdown of water-in-oil emulsions) when treating water-in-oil systems by pulsed magnetic field. The molecules of such substances easily navigate within a magnetic field and their coagulation occurs as a result of magnetic interaction [14]. The navigation of such particles (pulling and gravitation) is determined by the gradient of field strength (variations of magnetic field over time). It is the parameter that allows the pulsed magnetic unit surpasses its direct competitors and shows the best aftereffect.

The efficiency of magnetic treatment of oil contaminated water was confirmed experimentally. The task of the research was to estimate the quality of separated water that was treated (within various scenarios) with the adoption of photometric method. The method is based on the extraction of oil from water by an organic solvent (chloroform), which dissolves oil, but does not practically dissolve itself. Dissolved oil colors chloroform. Color intensity is proportional to the concentration of oil. Procedural error is ± 1%.

Produced separated water with the following parameters (table 1) was used as testing environment.

| №  | Properties                        | Unit of measurement | Values   |
|----|-----------------------------------|---------------------|----------|
| 1  | Water density (standard conditions) | kg/m³               | 1007.00  |
2. Overall mineralization $g/dm^3$ 12010,70
3. pH $\text{pH}$ 7,6
4. Temperature $^\circ\text{C}$ 20
5. Residual oil content ppm 58 - 60

The following water treatment options were tested in the course of the studies (table 2):

- The magnetic treatment of oil-contaminated wastewater accelerates the process of natural breaking of the water-in-oil emulsion after treatment preconditioned by basic sediment;
- Residual oil content in the initial water sample is 58 mg/dm³;
- The use of hydrophobic filter reduces residual oil content down to ~ 30 ppm;
- Magnetic treatment of water reduces residual oil content down to ~ 16 ppm;
- The complex application of the 22 Hz electromagnetic field treatment and hydrophobic filter results in an increase in the efficiency of water purification from oil products. This synergistic effect surpasses the effect of using a magnetic field treatment or hydrophobic filter separately;
- It is possible to reduce residual oil content in water down to ~ 5 ppm.

Table 2. Laboratory testing results.

| Sample № | Treatment          | Concentration, ppm |
|----------|--------------------|--------------------|
| 1        | Blank*             | 57.7               |
| 2        | HPF                | 30.2               |
| 3        | MF*                | 16.3               |
| 4        | MF+HPF*            | 5.1                |

* Blank (a water sample that is not treated with magnetic field or filter).
* HPF (a water sample that is treated with hydrophobic filter).
* MF (a water sample that is treated with magnetic field but without the use of a filter).
* MF + HPF (a water sample that is treated with magnetic field and hydrophobic filter combined).

Treatment of drinking water

One of the urgent tasks related to improving the health of the population is the possibility of water consumption. The quality of drinking water in this case ought to comply with the standards. It is worth noticing that only 1% of drinking and fishery water (according to the World Health Organization data) in the world can be consumed without preliminary treatment. In all other cases, water purification, including decontamination, is absolutely necessary. A particular water treatment technology is chosen depending on the physical and chemical composition of water and its microbiological pollution.

Most of the existing water treatment plants use the classical reagent clarification system designed in the 1960s. Coagulants are incorporated in the water to be cleaned. It contributes to the binding of particles (that are responsible for colour and turbidity) into flakes, which accelerates their settling out in the clarifier tanks. For deeper clarification, water is filtered in order to detain residual suspended matters in the filter bed. Along with clarification (through coagulation and filtration), bacterial contamination in water is also reduced. Thus, the quality of water is improved from a sanitary view.

Hence, the introduction of new innovative water treatment techniques into the technological scheme at water treatment facilities is necessary. This does not provide for the complete reconstruction of existing systems, but allows modernizing them effectively. One of the state-of-art solutions is application of magnetic-reagent method of water treatment.

Numerous studies performed in laboratory and experimental-industrial conditions [15-17] revealed that magnetic field reduces chemicals consumption (including corrosion inhibitors, deparaffiniser and demulsifiers).
It was suggested that the magnetic field can have a positive effect on purification of drinking water at the coagulation stage due to the similar mode of action of reagents used in oil industry and water treatment [18, 19].

Therefore, the purpose of our research was to study the effectiveness of magnetic-reagent water treatment technology at a water treatment facility in Vsevolozhsk district (Leningrad region). In the course of our research we studied the change in the dynamics of water clarification, pre-treated with coagulation reagents, with and without the use of a magnetic field.

A two-stage water treatment involving reagent treatment is used at this facility. A water treatment scheme is as follows: water is supplied from the source by the pumps of the intake pump station, and then water passageways deliver it into the mixing basin of draining system. Water clarification reagents (analyte to decontaminate water, coagulator, floculant and soda) are added gradually into the mixing basin. After that, water is delivered into sludge blanket clarifier where flakes are formed and their main part is precipitated from water. Following that, partially clarified water is sent to high-rate filters for final purification. Chlorine treatment is used for water decontamination.

In the framework of our research, we installed the MPU-2 pilot apparatus at the water supply section of the mixing basin (figure 1) in front of six simultaneously operated clarifying tanks. This allowed for magnetic treatment of the entire water flow that passed the stage of reactant purification.

We assessed the efficiency of magnetic treatment by a step-by-step change in the technological parameters of water treatment, namely, by reducing the number of simultaneously operated clarifying tanks (there are six of them at this facility) and reducing the reagent consumption.

Over the course of our experiments, we constantly monitored water quality indicators (colour, turbidity, residual aluminum) as soon as the magnetic apparatus was on. To compare the effectiveness of water treatment at this facility, we took data from similar seasonal periods over the previous years when magnetic treatment was not used.

Test procedure:

- We collected statistics on the operation of the object before the introduction of the magnetic apparatus.
- We started testing in February 2019.
We gradually reduced the number of operated clarifying tanks from six to two, by means of increasing the supply of water to the remaining devices. However, since the capacity of the object in this case was not enough to provide the village with water, the water flow was raised and the number of operated clarifying tanks was increased to four. This forced loss of capacity of the object by 10% of the standard mode is caused by hydrodynamic limitations of the clarifiers (sludge blanket is destroyed by increased water pressure), not by a throughput capacity of the magnetic apparatus.

The obtained results are presented in table 3.

**Table 3.** Annual comparative data on water quality at Leskolovo object, before and after the use of IM-2 magnetic apparatus.

| Dates       | Time period | Lake water data | Reagent consumption, l/h | Clarified water data |
|-------------|-------------|-----------------|--------------------------|----------------------|
|             |             | Colour | Turbidity | N<sup>a</sup> | Qw<sup>b</sup>, m³/day | Coagulator | Alkali | Colour | Turbidity |
| February 2017 |            | 280-320 | 1.5-1.7 | 6 | 1000 | 4.3-4.7 | 35-40 | 16-21 | 0.6-0.7 |
| March 2017   | Entry of a month | 317-340 | 2.2-3.5 | 6 | 1000 | 3.7-4.2 | 25-30 | 17-20 | 0.6-0.7 |
| April 2017   | End of a month<sup>c</sup> | 330 | 8-14 | 6 | 1000 | 2.8-3.7 | 20-25 | 18-20 | 0.6-0.7 |
| February 2018 |            | 180-140 | 1.7-1.9 | 6 | 1000 | 1.8-2.4 | 20 | 18-20 | 0.6-0.7 |
| March 2018   |            | 200 | 0.7-0.9 | 6 | 1000 | 3.6-4.2 | 40 | 13-15 | 0.6-0.7 |
| April 2018   | Entry of a month | 220-230 | 0.9-1 | 6 | 1000 | 3.3-3.7 | 35-40 | 18-20 | 0.6-0.7 |
|             | End of a month | 230-260 | 1.2-3 | 6 | 1000 | 3.1-3.4 | 20 | 16-15 | 0.6-0.7 |
| February 2019 |            | 140-120 | 2.5-3 | 6 | 1000 | 1.9-2.4 | 40 | 17-18 | 0.6-0.7 |
| March 2019   |            | 160-180 | 1.5 | 2 | 900 | 3.1-2.5 | 15 | 17-20 | 0.6-0.7 |
| April 2019   |            | 230-260 | 1.5-2 | 4 | 1000 | 2.4-2.7 | 10 | 15-20 | 0.6-0.7 |
|             |            | 230-240 | 2-2.3 | 4 | 1000 | 2.6-2.9 | 10 | 15-20 | 0.6-0.7 |

<sup>a</sup>N number of simultaneously operated clarifying tanks;

<sup>b</sup>Qw capacity of the water treatment facility;

<sup>c</sup> Due to ice melting, in the latter half of April there occurs a seasonal change in the quality of lake water.

Experimental tests showed that the use of proposed apparatus of magnetic water treatment allows ensuring equal high efficiency of water purification in various seasons, regardless of the water quality in the source of drinking water supply (Lake Lembolovskoe).

The studies yielded the following practical results:

- to reduce the time required to purify water and remove sediment, thus twice decreasing the amount of water clarification tanks cleaning;
- to almost double the speed of flocculation and precipitation into "dense cotton";
to reduce reagent consumption, compared to earlier periods when no magnetic treatment was used (coagulant by 25-30% on average, alkali by 50-60%);

- to keep (regardless of the source water seasonal quality) the same quality of water supplied to the water supply network in Leskolovo village.

The proposed technology of preliminary treatment of a mixture of water and coagulant with the use of a magnetic fluid treatment apparatus allows applying it, both for modernization of water treatment facilities operated through a typical scheme, and for designing of objects under construction.

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