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THE DEVELOPMENT OF COMPLEX TECHNOLOGY FOR BOTTOMHOLE COMBUSTION IN BITUMEN WELLS

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A complex technology for thermal recovery from bitumen wells has been developed and tested in the field. It provides natural bitumen recovery enhancement and reservoir neutralization of the corrosive acidic components which result from the bottomhole treatment. The neutralization is accomplished with alkaline solutions. This technology allows to lower the bottomhole temperature for the purpose of casing string protection.

The main advantage of the thermal methods used in the Mordovo-Karmalskii bitumen field is for improving production efficiency through simultaneous hydrodynamic and thermodynamic stimulations. The added thermal energy influences all reservoir components (minerals and fluids) and changes communications and filtration conditions dramatically. As a result of these changes, bitumen viscosity is reduced, its mobility increases, its structural-mechanical properties change, the thicknesses of boundary layers decrease, and the surface tension characteristic of the displacing agent improves. The end result is that sweep efficiency and ultimate bitumen recovery increase.

However, using the thermal stimulation methods poses a number of problems, complicating reservoir development. Particularly, during the Mordovo-Karmalskii bitumen field development, the following troubles have been revealed:

- Permeability deterioration in the bottomhole zone of the wells
- Intensive sand fall-out

- Flow restrictions caused by fouling in the bottom of the tubing
- High water-cut in the well production
- Formation of strong water-bitumen emulsions
- Corrosion of the underground well fixtures and surface piping

An additional problem is that the recovered production is highly corrosive.

The corrosion activity of the water-bitumen emulsions changes over a wide range, depending upon the aqueous phase temperature, composition and occurrence of dissolved gases. When thermal recovery methods (especially *in situ* combustion) were applied, there were some cases of field equipment breakdowns in well production hardware and corrosion in wells.

After heat is introduced into a reservoir the complicated thermo-chemical reactions between rock minerals and fluids take place. As a result of these processes, hydrochemical zones of highly corrosive reservoir fluids are formed through changes in chemical composition. Reservoir waters in these zones become acidic ($pH < 7$). Sometimes wells have to be shut in for this reason. During *in situ* combustion processing, gaseous and liquid acid components are formed which increase well corrosion activity [1-2].

In order to solve this problem, we propose using chemical stimulation methods in bottomhole treatments, namely, use of alkaline aqueous solutions. This allows for neutralization of corrosive components in pore spaces and enhancement of bitumen recovery. Choosing fields for demonstrating this technology needs to be based on studies of the field geology, well logs, reservoir fluid composition, and reservoir temperature and pH. The technology for *in situ* thermal recovery from bitumen wells has been developed. The technology is designed for bitumen wells producing water-bitumen emulsions, where the reservoir waters have a $pH < 6$. The technology incorporates the periodic injection of an aqueous solution as a neutralizer into the bottomhole zone. This is followed by injection of at least 30 m^3 of fresh water in order to displace neutralization reaction products. The following aqueous solutions are used as neutralizers: Na_2CO_3, 0.5-2.5 % NaOH, and/or 0.5-1.5 % Na_2SiO_3.

The periodicity of the bottomhole treatment is defined as the time required for the pH of the produced water to reach its original value. The duration and efficiency of treatment depends on several natural and technological factors and is determined empirically for separate well conditions. The technology is complex as it combines several technological processes and provides bitumen recovery enhancement, decreases production water cut, neutralizes corrosive acidic substances and, as a consequence, lowers corrosive tendency of recovered products. Where a combustion front advances to bitumen wells and where high reservoir temperatures are observed, alkaline aqueous solutions (neutralizers) can provide several benefits. These solutions reduce resevoir bottomhole temperatures, protect casing strings and allow the subsequent well operation to proceed without a reservoir temperature drop after the combustion front advances.

The mechanism of the alkaline agent action is based on its capability to react with reservoir fluids and minerals. The result is that the surface characteristics of the "natural bitumen-aqueous phase-rock" system and, hence displacement conditions, are changed [3, 4]. The main factors determining bitumen recovery enhancement are reduction of surface tension, bitumen emulsification, variation in rock wettability (hydrophobic process), and reactions between alkaline agents and acidic bitumen components, which lead to surfactant formation. High reservoir temperatures intensify these factors.

The laboratory and field studies [5-14] proved the high neutralization capabilities of aqueous solutions of NaOH, Na_2CO_3, and Na_2SiO_3 for bitumen-bearing reservoirs in the Mordovo-Karmalskii, Spiridonoskii and other bitumen fields. As a result of the declining level of interfacial and interphase tension caused by 0.1-0.5 % aqueous solutions of Na_2SiO_3, natural bitumens of the Mordovo-Karmalskii field may be considered as "superactive oils". NaOH and Na_2SiO_3 solutions cause interfacial tension to be reduced at the boundary with the Mordovo-Karmalskii bitumen to values less than 0.01 m/Hm. Simultaneously with the reduction of interfacial tension, there is a decline in capillary resistance and an improvement in production of a film-like bitumen. These processes occur faster at elevated temperatures.

A review of the influence of alkaline solutions on field pipe corrosion shows that low-alkaline solutions contribute to the formation of dense, crystalline oxide films on pipe surfaces and cause a so-called iron "self-passivation" process. It has been established [15] that the corrosive impact of 1.5-2.0 % NaOH is less than water by a factor of about 150-200. Thus the aqueous alkaline solutions will not cause field equipment corrosion, but, on the contrary, possess protective properties and they can be utilized as inhibitors.

The test results in the Mordovo-Karmalskii bitumen field have confirmed the efficiency of the developed tehnology. For treatment application, one of the following sets of treatment stages are recommended:

1. Injection of Na_2CO_3 (NaOH) aqueous solutions followed by water pumping
2. Injection of Na_2SiO_3 and Na_2CO_3 (NaOH) aqueous solution, followed by water pumping. The ratio of Na_2SiO_3 to Na_2CO_3 volumes is 1 : 2

3. Simultaneous injection of Na_2SiO_3 and Na_2CO_3 aqueous solutions followed by water pumping. The ratio of Na_2SiO_3 to Na_2CO_3 volumes is 1 : 1

The use of Na_2SiO_3 is desirable for wells which have a water cut of more than 80 %. The choice of solution concentrations and volumes is based on an analysis of data for a specific well. The solution concentration to be used in a given application depends on the chemical analysis of reservoir waters from the well. The recommended concentration of the alkaline solutions can be selected from the Table, which shows the choice to be a function of the reservoir water pH.

Recommended Concentrations of the Solutions-Neutralizers Depending on pH of Associated Water

pH	Fraction of agents total mass, %		
	Na_2CO_3	NaOH	Na_2SiO_3
6–4	1	0.5	0.5
4–3	2	1.5	1.0
<3	3	2.5	1.5

The volume of solution to be used is a function of (a) the thickness of the stimulated interval in the reservoir (injectivity interval) h_{stim}, (b) the reservoir porosity m, and (c) the volumetric bitumen saturation β. The formula for calculating the injected solution volume is as follows:

$$V_{inj} = h_{stim} \times q_{inj}$$

where V_{inj} is rated volume of an injected alkaline agent, m^3;

h_{stim} is thickness of a stimulated reservoir interval, m;

q_{inj} is injection reagent volume per meter of thickness of a stimulated reservoir interval.

q_{inj} is determined from the graph in Fig. 1, considering the porosity m and volumetric bitumen saturation β of a pay zone in a particular well. Hot water (>70 °C) available in the Mordovo-Karmalskii field is used for preparing the alkaline solutions.

The technology has been tested in wells 282a, 168, 433, and 304a in the Mordovo-Karmalskii field.

Well 282 a

The pay zone is 9.4 m thick. It lies within the depth interval 102.0-111.4 m and represents a bitumen-saturated sandstone for which the porosity is 30 % and volumetric bitumen saturation is 80 %. A 6-m perforated reservoir thickness is within the depth interval of 102-108 m. By the end of 1993, the reservoir water in fluid samples had a pH of 3.7-5.1 and the reservoir temperature was 130 °C. With a flow rate of 1.5 m^3/day, the water cut was

70 %. In 1993, the bottomhole treatment was carried out with a 10 m^3 solution-neutralizer (1.5 % Na_2CO_3 at 60 °C). Na_2CO_3 was forced into the reservoir with 30 m^3 of fresh water at a temperature of 60 °C. During the year, fluid samples were recovered and the pH of the water was defined. The results are presented in Fig. 2, where it is seen that the treatment was effective for the year.

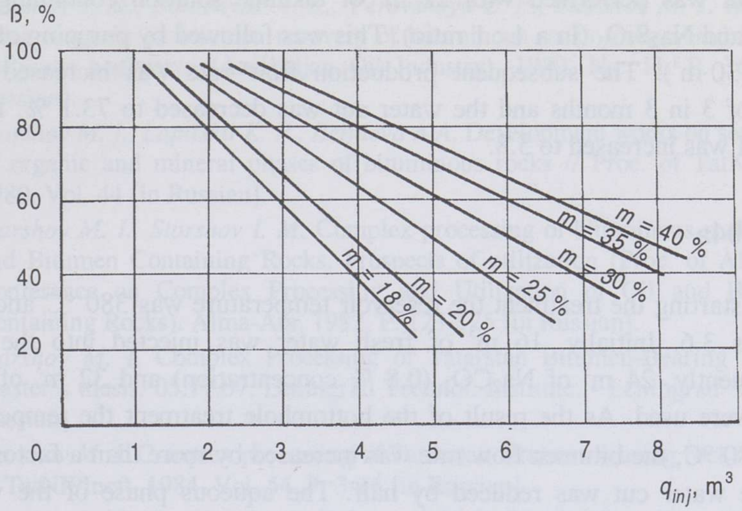

Fig. 1. The injection volume of the solution-neutralizer per a meter of a treated reservoir thickness depending on bitumen saturation (*β*) and porosity (*m*)

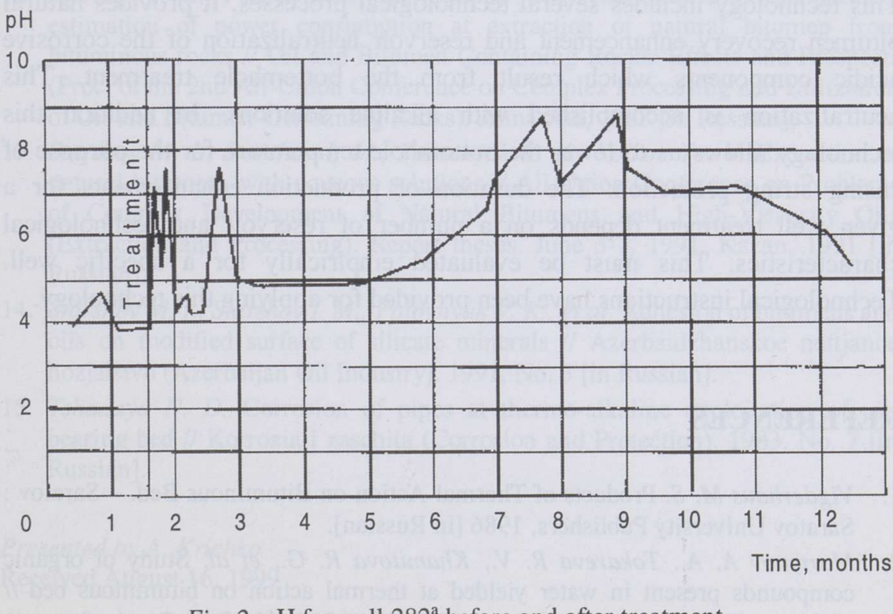

Fig. 2. pH for well 282[a] before and after treatment

Well 168

The productive zone is bitumen-saturated sandstone for which the porosity is 30 % and bitumen saturation is 87 %. Before treatment, the production water cut was 92.5 %. The pH of the aqueous phase was 2.8. The flow rate was 0.5 ton/day and the reservoir temperature was 115 °C. The bottomhole treatment was performed with 22 m^3 of alkaline solution containing 5 % NaOH and Na_2SiO_3 (in a 1 : 1 ratio). This was followed by pumping of fresh water (30 m^3). The subsequent production flow rate was increased by a factor of 3 in 3 months and the water cut was decreased to 73.1 %. In this case pH was increased to 5.8.

Well 304a

Before starting the treatment the reservoir temperature was 380 °C and fluid pH was 3.6. Initially, 16 m^3 of fresh water was injected into the well. Subsequently, 24 m^3 of Na_2CO_3 (0.8 % concentration) and 32 m^3 of fresh water were used. As the result of the bottomhole treatment the temperature fell to 80 °C, the bitumen flow rate was increased by more than a factor of 3, and the water cut was reduced by half. The aqueous phase of the water-bitumen emulsion had a pH equal to 7-8. The improved production efficiency after the treatment completion was also maintained.

Thus, the complex technology has been developed and tested in the field. This technology includes several technological processes. It provides natural bitumen recovery enhancement and reservoir neutralization of the corrosive acidic components which result from the bottomhole treatment. This neutralization is accomplished with alkaline solutions. In addition this technology allows us to lower the bottomhole temperature for the purpose of casing string protection. The duration of production enhancements for a given well treatment depends on a number of reservoir and technological characteristics. This must be evaluated empirically for a specific well. Technological instructions have been provided for applying this technology.

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