Possibilities for Enhancing Oil Recovery by Hot Water Injection

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ABSTRACT

The paper presents briefly the research and design works for achieving a hot water injection experimental plant.

The plant offers possibilities for extension of hot water injection to enhance oil recovery, providing cost reductions related to investments and operation, of about 3 times less as compared to the current facilities used for hot fluids injection, while avoiding at the same time fresh water consumption from natural sources.

The plant will be fed with purified produced water and will be tested in an experimental pattern made up of an injection well and five output wells, on a reservoir located at a depth of about 750 m.

Laboratory investigations constitute the background for an effective treatment in order to reduce corrosion and scales deposits, and for increasing the efficiency of the process by adding surfactants to the injection water.

The process consists in heating the formation water to 150 °C, in a closed system, at a pressure of 0.6 MPa, and its injection at a pressure up to 10 MPa.

The plant is made of transportable skids which facilitate its installation near the injection well and its transfer to other wells following completion of the experiment.

By preliminary thermal calculations it is estimated that the duration of continuous hot waterflooding will be limited to about 2 years, following which the heat losses to the injection well and to the layers adjacent to the productive formation will surpass 70% of the injected heat.

1. INTRODUCTION

To enhance oil recovery by thermal method in situ combustion is being applied on 6 reservoirs, located at depths down to 850 m, and steam injection is being applied on 2 reservoirs located at depths down to 300 m. in Romania.

Literature data [1,2,3,4] show that hot water injection is a thermal method that can be applied efficiently following conventional water injection and even after steam injection.

The experience gathered so far regarding purification of reservoir water [5] and regarding the equipment and heating systems [6, 7, 8] created a background for the investigations carried out in order to achieve an experimental plant for hot water injection (with the plant to be supplied with purified produced water).

The use of these heating equipments and systems in oil dehydration and desalting plants have diminished the heating costs by about 4 times as compared to the previous practice.

The plant will be manufactured and tested on an injection well belonging to an experimental pattern over a reservoir located at a depth of about 750 m, whose main characteristics are shown in Section 2.

Laboratory investigations, presented in Section 3 were meant to treat injection water (3.1) to reduce the corrosion and scaling effect associated with water heating; to determine the characteristics of produced fluids (3.2) and to evaluate the effect of surfactant addition (3.3) to injection water.

By the preliminary mathematical modelling - presented briefly in Section 4 - heat losses in the injection well and the adjacent layers to the productive formation were evaluated, which will surpass 70% of the heat input to the well after about 2 years of operation.

The process is briefly presented in Section 5, together with the heating system (5.1) and the flow sheet (5.2.)

The plant is to be manufactured on transportable skids which facilitate the assembly /removal and transportation operations in the vicinity of the injection wells.

2. MAIN RESERVOIR PARAMETERS

The productive horizon selected for the test is the Șotânga Meotian, which belongs to a structural align-

ment bearing characterized by an intricate tectonics, being located in an area of diapiric folds. The reservoir rock is made up of sands, marly sands, with marls and gritty marls intercalations. The reservoir is of the stratiform, vaulted type.

The physical parameters of the horizon of interest were estimated based on the available data, on the well surveys, well logs and correlation curves, and the following values were accepted:

- initial reservoir pressure: 6 MPa (853 psi)
- reservoir temperature: 30°C (86°F)
- porosity: 25%
- interstitial water saturation: 25%
- average thickness: 5 m (16 ft)
- absolute permeability: 0,3 μm^2 (300 mD)
- effective oil permeability: 0,1 μm^2 (100 mD)
- dip: 2-12 deg.

A conventional water injection process has been previously applied to this horizon. Solution gas drive and gas cap expansion are specific to this reservoir.

The experimental pattern is made up of wells 79 MP, 73 MP, 72 MP, 53 MP, 63 MP which make up the output cluster, and of well 74 MP, which will be an injector (Fig. 1)

Fig. 1 - TEST PATTERN

The technical condition of well 74MP is as follows:

- casing: 5 1/2 diameter, up to 773 m (2536 ft)
- intermediate casing: 9 5/8 in diameter
- surface casing: 13 3/8 diameter up to 148 m (485 ft)
- perforated interval: 748 - 745 m (2454 - 2444 ft)
- the well was brought in in April 1987.

3. LABORATORY INVESTIGATIONS

Laboratory investigations were meant at:

- injection water treatment;
- properties of produced fluids;
- evaluation of the influence of added surfactants.

3.1. INJECTION WATER CONDITIONING

An experiment is being carried out on the Șotânga reservoir, consisting of conventional injection of purified reservoir water from a plant with a capacity of

Fig. 2 - BLOCK DIAGRAM OF WATER CLARIFICATION PLANT

2 x 2000 m³/d, and comprising the following steps:

- settling;
- oil extraction from water using a light solvent;
- removal of solvent traces and dissolved gases (CO₂ and O₂) by natural gas stripping;
- quartz sand filtering [5].

The plant was operated during the period 1980-1985 to purify formation water, necessary for polymer solution injection, on Drăgăiești field.

The block diagram of the plant is shown in Fig. 2. Currently the gas stripping stage has been discontinued and purified water is conventionally injected and no corrosion and scaling difficulties are being encountered. Injection water and reservoir water characteristics are shown in Table 1

Table 1

INJECTION WATER AND PRODUCED WATER CHARACTERISTICS

Characteristics	MU	Inj. Water	Prod. Water
Density	kg/m ³	1,098	1,090
pH		6.10	6.6
Hydrocarbons	p.p.m.	4	108.5
Sediments	p.p.m.	33	63

Chemical Composition p.p.m.

	Inj. Water	Prod. Water
Na	53,770	39,848
Ca	3,741	2,918
Mg	1,513	1,492
Cl	93,365	70,645
SO ₄	151	10
HCO ₃	549	515
Fe ₂ O ₃	85	67
Al ₂ O ₃	3	-
Total dissolved salts	153,177	115,495

Sediments represent iron salts which settle rapidly. Following sediments removal the waters are compatible. Heating promotes the increase of the corrosion rate and of the scale formation [9,10] which was confirmed by laboratory tests. Sediments built up by heating are not adherent and have a high iron content. Physical-chemical treatments were tested in the laboratory to reduce the corrosion rate and the scale deposits within the experimental plant. The effectiveness of the treatment was evaluated by determining the corrosion rate and Fe₂O₃ content at a temperature of 90° C and at atmospheric pressure, for the treated water, as compared to the same type of determination at 20°C and atmospheric pressure for untreated water. The comparative results for corrosion rate and indices are shown in Figure 3.

Fig. 3 - COROSION RATE AND INDEX FOR TREATED AND UNTREATED WATER

The reduction of the Fe₂O₃ content in the water reduces the tendency for scale deposits. The treatment results are represented graphically in Fig.4.

These results are deemed satisfactory and will be checked under static laboratory conditions at the pressure and temperature of the experimental plant (0.6 MPa and 150° C). The device manufactured for this testing is shown in Figure 5.

The results will also be tested under dynamic conditions within the experimental plant by means of a device installed in the plant.

Fig.4 - Fe₂ O₃ CONTENT IN TREATED AND UNTREATED WATER

Fig. 5 - SCALE AND CORROSION EVALUATION APPARATUS

3.2. PRODUCED FLUIDS CHARACTERISTICS

The main characteristics of the produced water were shown in Table 1. Gas composition is shown in Table 2.

Table 2

Produced Gas Composition	
Components	% vol.
CO ₂	0.33
Methane	97.81
Ethane	1.41
Propane	0.22
Butane (i)	0.04
Butane (n)	0.06
Pentane (i)	0.03
Pentane (n)	0.02
Hexane	0.03
Heptane+	0.05
TOTAL	100.00

The main characteristics of net oil are the following:

- density at 20° C: 923 kg/m³ (21.5° API)
- pour point: - 21°C
- initial boiling point: 170°C
- molecular weight: 380.

Figure 6 shows the oil kinematic viscosity variation with temperature.

Figure 7 shows the oil volume factor variation with temperature.

It is mentioned that the determinations for the viscosity and volume factor variation were made using clean oil (free of dissolved gas).

3.3. EVALUATION OF SURFACTANTS ADDITION

Hot water flooding diminishes insignificantly the oil/ water interfacial tension [1].

Laboratory investigations carried out in Canada [11] have shown that addition of sodium hydroxide or carbon dioxide to hot water increases oil recovery at temperatures around 100° C under reservoir conditions.

Currently, there is no carbon dioxide available at site, while the high mineralization of injection water renders inappropriate the use of sodium hydroxide which precipitates in contact with the injection water.

Various surfactants for reduction of oil/injection water interfacial tension were tested. Determinations were made at 30, 40, 50 and 60° C.

The best results were obtained using an ethoxylated block-copolymer [12, 13] under current manufacture in Romania. This surfactant reduces the interfacial tension by about 40 times (from 42 mN/m to 1.1 mN/m) with and optimal dose of 500 ppm at a minimum temperature of 40° C.

Displacement tests were carried out using an artificial core made of 0.3 mm diameter glass balls set inside a thermostated metal tube, with a length of 5 m.

Fig.6-VISCOSITY VARIATION WITH TEMPERATURE

Fig. 7 - OIL VOLUME FACTOR VERSUS TEMPERATURE

The cores were saturated with reservoir water and then with oil. Cores porosity was about 23% and cores permeability of about $18\mu\text{m}^2$ (18 D).

Determinations were made using injection water and injection water with 400 ppm additives. The injected water volume was about 3 pore volumes.

Figure 8 shows the comparative determinations results.

Fig. 8 - SURFACTANT EFFICIENCY EVALUATION

Figure 8 illustrates the positive effect of addition of a dose of 500 ppm surfactant at a temperature of 40°C .

4. PRELIMINARY MATHEMATICAL MODELING OF THE PROCESS

In order to evaluate heat losses and the temperature distribution in the formation a mathematical model was prepared based on the extension of Marx and Langenheim [14] results by Lauverier [15] in a linear system, and by Malafeev [16] in a radial system. Calculated temperatures for a plane radial model based on time and distance from the injection well are shown in Fig. 9.

Preliminary calculations performed using this mathematical model show that after about 2 years of continuous injection, heat losses in the injection well and in the layers adjacent to the productive formation will surpass 70% of input heat.

Fig. 9 - TEMPERATURE VERSUS RADIUS FOR SEVERAL VALUES OF TIME

The analytical method of evaluation of hot waterflooding is being assessed.

5. THE PROCESS

For designing the process, the specific site conditions and the own experience in heating systems operation were taken into account using high efficiency heating equipments. These systems and equipments are used for heating crude oils with a high water content (70% vol. to 90% vol.).

The experimental plant will be located near the injection well and will have a nominal capacity of $60\text{ m}^3/\text{d}$ and a maximum capacity of $120\text{ m}^3/\text{d}$.

5.1. HEATING SYSTEM

A vertical metal heater will be used for injection water heating. Its main characteristics are shown in Figure 10. During the last five years, vertical metal heaters [6] have been used within a crude heavy oil heating system [7, 8] by overheating produced water.

Application of these systems and equipments to the experimental plant will entail a considerable cost reduction owing to the following reasons:

- no investments or operating costs are necessary for supply with fresh water from natural sources;
- no investments or operating costs are necessary for the current facilities and processes of advanced conditioning of produced water to be used for feeding the plant [9, 17];
- vertical metal heaters are not expensive, have a high thermal output and necessitate a reduced ground area for installation.

Hot water injection is, of course, an improved oil recovery process. Commercial application of such a process depends greatly on the facilities and equipments used for heating and water injection. Investments and operating costs associated with the use of the equipment and plant presented in this paper, which are sensibly lower

Working pressure : 0.6 MPa
 Maximum temperature : 160 °C
 Heating capacity : 7-10 KJ/h
 Thermal rendement : 0.92

Fig. 10-VERTICAL HEATER

1. Water tank
2. Water pumps
3. Vertical heater
4. Injection pumps
5. Injection well

**Fig.11-BLOCK DIAGRAM OF
EXPERIMENTAL PLANT**

tank (1) through a system precluding water vaporisation. To complete the experiment's data, the following devices will be mounted in the plant:

- backwashing metallic cartridge filter;
- device for testing corrosion rate and scale deposits in the process;

-device for testing the effectiveness of various thermal insulations on injection wells for hot fluids.

The thermal insulation on the injection well will be achieved by altering the ratio of the tubing/casing surfaces and by feeding heavy clean oil (with the initial boiling point temperature over 200°C) within the annulus of the injection well.

Movable skids were designed for the water pumps and the injection pumps which facilitate mounting/dismantling and transportation operations for the experimental plant.

It should be mentioned that the skid of the injection pumps is equipped with outlet fittings with a nominal working pressure of 10 MPa, which allows for extension of the applicability field to other reservoirs.

CONCLUSIONS

1. The plant offers possibilities for extension of hot water injection to enhance oil recovery providing cost reductions related to investments and operation of about 3 times less as compared to the current facilities used for hot fluids injection, while avoiding at the same time fresh water consumption from natural sources.

2. Laboratory investigations constitute the background for an effective treatment in order to reduce corrosion and scales deposits, and for increasing the efficiency of the process by adding surfactants to the injection water.

3. The process consists in heating the produced water to 150 °C, in a closed system, at a pressure of 0.6 MPa, and its injection at a pressure up to 10 MPa.

4. The plant is made of transportable skids which facilitate its installation near the injection well and its transfer to other wells following completion of the experiment.

than the current costs related to hot water injection, will contribute their share to increase the chances for applicability of hot water flooding.

Injection water will be heated in a closed system within the experimental plant, to 150° C , at a pressure of 0.6 MPa.

5.2. Flow Sheet

The process was designed in a closed system with a feeding stage at low pressure, with a heating stage, and an injection stage at high pressure.

The experimental plant block diagram is shown in Figure 11.

The water tank (1) is fed with purified water, which is pumped (2) at a pressure of about 0.6 MPa . through a vertical heater (3) where it is heated to about 150°C, and injected (4) at a pressure of about 2 MPa, into the injection well (5).

The plant is provided with back pressure regulators which maintain constant pressures in the process stages. Excess of hot water will be recirculated into the water

5. The experimental plant for hot water injection will be fed with purified formation water and will be tested in an experimental pattern made up of an injection well and five output wells, on a reservoir located at a depth of about 750 m (2460 ft).

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