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APPLICATION OF ENHANCED OIL RECOVERY METHODS TO OIL DEPOSITS

1. OIL RECOVERY METHODS

When describing the methods, or phases of oil recovery, we can most frequently meet the following division: the primary, secondary and tertiary phases of recovery.

The tertiary phase of recovery includes various special methods, e.g. non-hydrocarbon gas injection into the deposit (e.g. CO_2, nitrogen, combustion gases), the LPG method (liquefied natural gas or propane), the application of enhanced water flooding methods (injection of water enhanced by surface-active agents, polymers or other chemical agents), the use of heat for decreasing the viscosity of oil (underground combustion, steam or hot water injection), the use of metabolic activity of anaerobic bacteria, etc. The aim is to intensify the inflow of "residual" oil that has not been exploited during the primary and secondary phases of recovery. The secondary and tertiary methods are often summarily designated as EOR methods (Enhanced Oil Recovery methods) [3, 4] in foreign literature.

The main mechanisms of EOR methods for the displacement of oil from pores of reservoir rocks by the influence of injection of medium of certain type are as follows:
- solvent extraction to achieve the process of miscibility,
- a reduction in interfacial tension,
- a change in oil or water viscosity and an increase in pressure due to injected medium.

2. MODELLING METHODS USED FOR THE HYDROCARBON DEPOSIT OF ŽDÁNICE – EARLY MIOCENE

In the Early Miocene deposit of Ždánice (it was selected on the basis of knowledge of workers of company, MND, a.s., and the expected low level of primary recovery estimated

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at about 5–6%), a project of EOR method modelling (EOR screening-predictive modelling and economic appraisal) was prepared, in which chosen methods were verified, and on the basis of which the results of production and economic appraisal at using these methods were forecast.

To the horizon of interest, predictive models as given below were applied from the point of view of the determination of possible recoveries and overall economic effectiveness [3]:

- Water Flood Predictive Model (EOR process with water injection),
- Steam Flood Predictive Model (EOR process with steam application),
- In-Situ Combustion Predictive Model (EOR process influenced by combustion),
- Polymer Flood Predictive Model (EOR process with polymer application),
- Chemical Flood Predictive Model (EOR process with chemical substance application),
- CO_2 Miscible Flood Predictive Model (EOR process with CO_2 application).

3. POLYMER INJECTION

For a comparison of laboratory results and results obtained by screening modelling, one of the most promising methods – the method of oil displacement by means of polymer injection was selected.

The water intended for injection is thickened by the addition of polymers of high molecular weight, which will elevate its viscosity. Mobility will be reduced and the area of contact of injected mixture with the deposit medium will increase [4].

4. BASIC EXPERIMENTS DONE WITH AN EXPERIMENTAL DEVICE

For basic laboratory measurements, an experimental device designed and produced by staff members of the Institute of Geological Engineering of Faculty of Mining and Geology at VŠB-Technical University of Ostrava was used, namely a measuring filtration apparatus MAF VII (already in the year 1990, the inventor's certificate No. 257904 was granted by the Office for Inventions and Discoveries on the prototype apparatus).

The measuring apparatus consists of three main parts: a filter chamber (a rock specimen examined is placed there), an accumulation chamber (for the accumulation of injected medium), a pressurising chamber (containing a compression tube with an air piston). For details see Figures 1 and 2.

For the purpose of measurement, the reservoir water and dewatered oil from the Early Miocene deposit of Ždánice were used. Furthermore, two polymers, PoL-1, PoL-2, and two surface active agents, PAL-1, PAL-2, were selected after consultation with workers of the company, MND, a.s.

The chemical substances for experimental measurements were provided by the Slovak company UNICHEMA s.r.o. At laboratory measurements concerning oil displacement, concentrations of these substances were determined on the basis of data acquired from literature and adapted after consultations with workers of the above-mentioned companies [2].

Fig. 1. The measuring instrument of MAF VII series with the pressurising piston (model 2005)

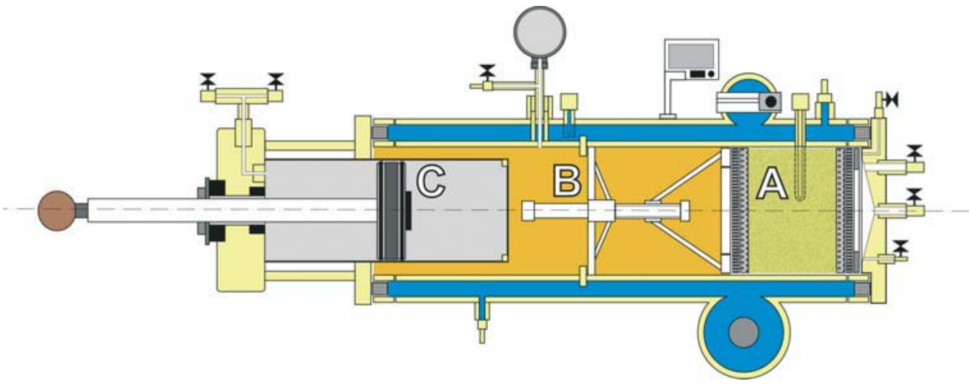

Fig. 2. MAF VII – diagrammatic section of device: A – filter chamber, B – accumulation chamber, C – pressurising chamber (part of accumulation chamber)

An equivalent rock specimen (original samples of reservoir rocks from the deposit under investigation were not available) was prepared from sand used in water treatment VP 2, from which the fraction of grain-size moving from 1 to 2 mm was separated by sieving [1].

5. MEASURING PROCEDURE

The equivalent rock specimen consisting of separated fraction of sand used in water treatment VP2 was saturated with oil in 65% by volume of open porosity. In this way, a reservoir layer of oil deposit, where primary recovery amounted to 35% of ultimate recovery, was simulated.

The formed mixture of sand and oil was placed into the filter chamber of measuring apparatus. After that, the accumulation chamber was filled a displacing fluid. For individual measurements of displacement efficiency, the following was used: reservoir water itself (L);

two polymer specimens (PoL-1), (PoL-2) dissolved in the reservoir water to produce three different concentrations (0.0025%; 0.01% and 0.1%); the reservoir water being treated by two types of surface active agents (PAL-1), (PAL-2) having the concentrations of 2.5%.

The laboratory measurements themselves were taken at two different pressure gradients, namely 50 kPa and 100 kPa, at the temperature of 30°C (reservoir temperature).

The sampling of oil being replaced was performed in five phases for volumes of displacing solution corresponding to 33%, 66%, 99% and 200% and 300% by volume of open porosity. For the spontaneous separation of oil from the samples taken, only gravitational separation was used. The measurement of efficiency of individual displacing fluids was always made on a new rock specimen.

6. THE EVALUATION OF OIL DISPLACEMENT ON THE LABORATORY DEVICE MAF VII

By the measuring device MAF VII, altogether five substances were tested, i.e. reservoir water, two surface active agents (PAL-1), (PAL-2) of concentration of 2.5% in the displacing solution, and further two polymers (PoL-1), (PoL-2) of concentrations of 0.0025%, 0.01%, 0.1%. The displacement was performed at the injection pressures (pressure gradient) of 50 kPa and 100 kPa and the temperature of 30°C.

It was the reservoir water (L) that had the lowest displacing ability (as expected); at the injection pressure of 100 kPa, recovery increased merely by 6.7%. For details see Figure 3 and Table 1.

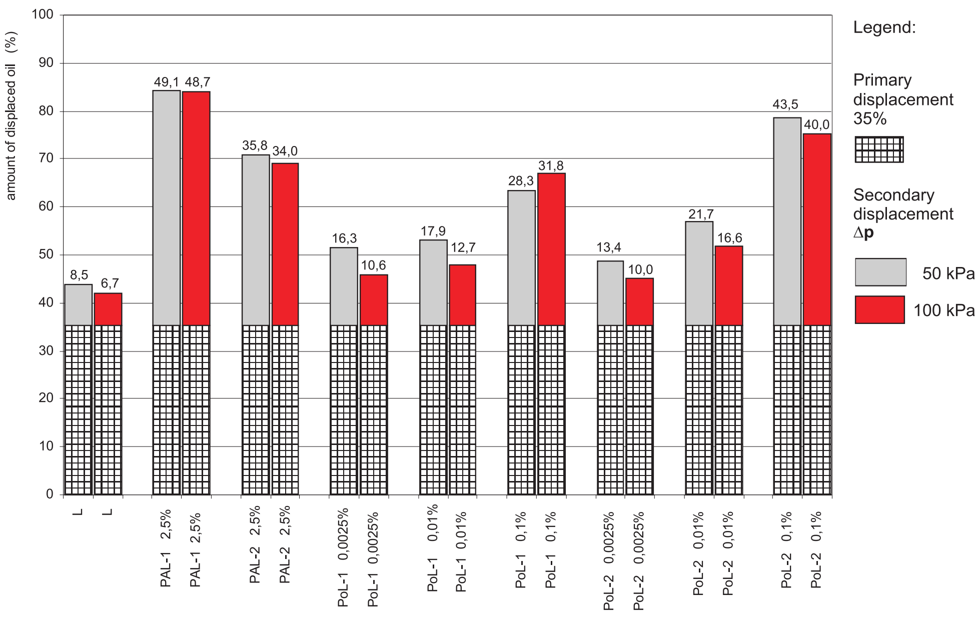

Fig. 3. Overview of overall efficiency of individual displacing fluids at pressure gradients of 50 and 100 kPa

Table 1
Resultant values of total displacement of oil by displacing fluids at pressure gradients of 50 kPa and 100 kPa

Amount of displaced oil [%]	Primary displacement	Secondary displacement	
Displacing fluid concentration		Δp = 50 kPa	Δp = 100 kPa
L	35.2	8.5	6.7
PAL-1 2.5%	35.2	49.1	48.7
PAL-2 2.5%	35.2	35.8	34.0
PoL-1 0.0025%	35.2	16.3	10.6
PoL-1 0.01%	35.2	17.9	12.7
PoL-1 0.1%	35.2	28.3	31.8
PoL-2 0.0025%	35.2	13.4	10.0
PoL-2 0.01%	35.2	21.7	16.6
PoL-2 0.1%	35.2	43.5	40.0

On the contrary, in the case of surface active agent (PAL-1), the highest value of recovery was achieved. At both the tested pressures, the value of displacement reached approximately the same value (49%), which would have meant an increase in ultimate recovery to 84.3%.

By comparison of displacing abilities of polymers, a trend presented in [2–4] that the higher concentration of polymer had also higher displacement efficiency was confirmed. If we see only this factor separately without the expenses of financing, then the concentration of 0.1% has proved to be the best of three tested concentrations. At this concentration of both tested polymers, a polymer (PoL-2) has the highest efficiency, and this reaches, at the injection pressure of 50 kPa, 43.5% of overall saturation, and thus an increase in ultimate recovery to 78.5%.

It is evident from Figure 1 that with almost all the tested substances (with the exception of PoL-1, concentration of 0.01%) a trend appeared that higher effects of displacement were achieved at the lower pressure gradient (50 kPa). This is probably connected with producing a slow “piston effect” of displacing front.

The above-presented results of laboratory measurements confirm foreign findings [4, 5] and verify the results obtained for the Early Miocene deposit of Ždánice by screening modelling. The use of polymers, or surface active agents, in the course of application of enhanced oil recovery methods will lead to a significant increase in ultimate recovery. We propose operational testing the method in a form of pilot test on selected boreholes in the deposit concerned.

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