Use of nitrogen and carbon dioxide injection in exploitation of light oil reservoirs

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Vstrekovanie dusíka a oxidu uhličitého pri ťažbe ľahkej ropy z ložísk

The secondary recovery processes in oil reservoirs may be performed using various techniques, e.g. the conventional waterflooding, water alternating gas injection or the double displacement process. The use of high nitrogen content gas obtained from a Polish Lowland natural gas field by separation is considered for the injection process.

***Key words**: nitrogen, carbon dioxide, gas injection*

Introduction

Displacing of oil from a porous medium through the fluids mixing with oil found an application in the technologies of secondary oil reservoir exploitation methods (EOR). Those methods include: the injection of gases like CO_2, N_2 or the natural gas. The gas injection reduces the pressure decline connected with the production of oil from the reservoir. However, the gas injected affects the equilibrium composition of the gas/oil system in the reservoir. A selective reduction of ingredients in the oil phase (VGD – Vaporising Gas Drive) is observed. It may also occur the inverse phenomenon which involves a condensation of some ingredients from the gas phase (CGD – Condensing Gas Drive) or gas and oil may also have an inclination for mixing with each other at the first contact (FCM – First Contact Miscibility). The research state concerning displacing is described in the Stalkup's works. The miscibility at the first contact occurs in the reservoir if the original reservoir fluid and injected gas are miscible. This means that all possible mixtures for initial compositions lead to the formation of a single-phase system.

In case of the condensing-drive process (CGD), the original reservoir fluid and the injected gas are not miscible; later the miscibility could be obtained near the injection well. In this process, intermediate components selectively condensate from the gas injected to oil.

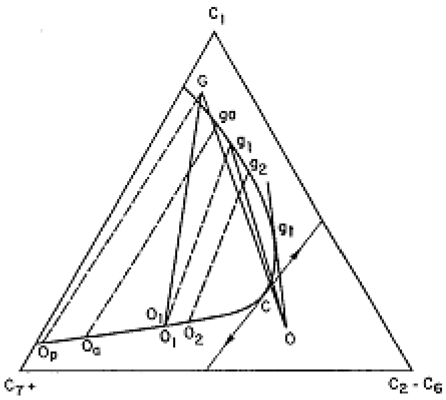

Fig. 1. Minimum Miscibility Pressure determination in the triangle diagram.

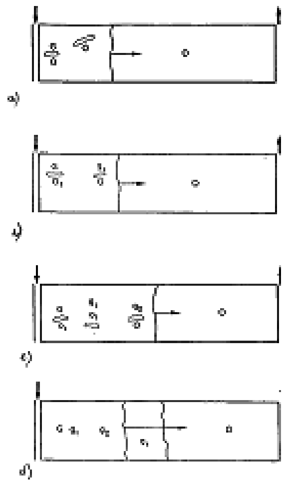

Fig. 2. Formation of the mixing zone (a.) the start of the injection,(b.) the start of the mixing zone, (c.) the continuation of the process, (d.) the origin of the mixing zones

To illustrate the mixing process, the triangle diagrams are used, dividing the mixture composition into three component groups:

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1. light components: $C_1 + CO_2 + N_2$
2. intermediate components: C_2 - C_6
3. heavy components: C_{7+}.

Each vertex represents 100 % content of the component group. The arbitrary concentration between 0 - 100 % is represented in the diagram in the form of an appropriate segment. The bubble and dew curves for the specified pressure and temperature values determine a two-phase area, marked in the picture by the thick line, the point C is the critical point of the pseudo-mixture.

The gas injection with the evaporation process (VGD) is shown in Fig. 1 and Fig. 2ad. The points G, ga, g1, g2, gt pertain to the injected gas, whereas the points Op, Oa, O1, O2 pertain to the displaced oil. The points G and O represent the initial compositions of the injected gas and oil, whereas the points g1, g2 and O2 indicate changes in the compositions of both fluids during the injection process which leads to the formation of the mixing zone (Fig. 2ad). The presented mixing process occurs in a distance of few meters from the injection well and involves the situation in which the injected gas is the natural gas. The process of mixing of fluids (injected and displaced) occurs at the specified pressure and the specified reservoir temperature (Fig. 3).

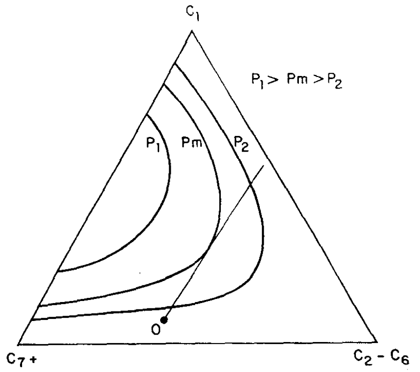

Fig. 3. Minimum Miscibility Pressure as a function of the oil and injection of gas compositions in the reservoir temperature.

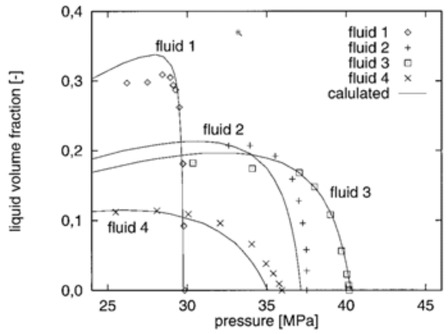

Fig . 4. Liquid phase fraction for four mixtures in the laboratory EOR processes (Sanger&Hagoort 1998).

Specification of the minimal mixing pressure for methane and nitrogen as an injecting medium

The first dependence of this type was published by Stalkup (1984). However, the author suggested a careful use of this method. The main disadvantage of this work was an unsatisfactory number of researches targeting at its confirmation. Two years later, Firoozabadi and Aziz (1986) published a correlation based on numerous experimental data. However, they did not sufficiently included the temperature influence on MMP. Meanwhile Glaso (1988) proposed a number of MMP correlations for the natural gas, CO_2 and N_2. His work is based on the Benham et al. data. Unfortunately this correlation is not very accurate.

Numerous works involving MMP, nitrogen and natural gas as an injecting medium, were published by Glaso (1988) and Hudgins et al. (1988) for nitrogen as a displacing fluid, Nouar and Lock (1988) for the natural gas and Eakin and Mitch (1988) for all types of gases and mixing processes (CO_2, N_2 and the natural gas). The work of Nouar and Flock (1988) differs widely from the other ones. The authors performed a very precise interpretation of the three-components diagram for methane as the displacing gas. It is the graphical correlation, based on the numerous experimental data. The obtained results are convergent with those given by Hudgins et al. (1988).

The most important parameters having a direct influence on the mixing of the reservoir fluid with nitrogen or the natural gas are: the content of intermediate pseudo-components (hydrocarbons C_2-C_6, CO_2, H_2S), the molecular weight of heavy fractions M_{C7+} and the temperature.

Problem of specification of minimal mixing pressure for oil reservoirs with the gas cap and the compositional grading reservoir fluid

The extensive considerations according to the variation of the minimal mixing pressure are included in the Hoeier & Whitson (2001). Analyzing the MMP variation for the depth function, the variation of MMP reaches 10 MPa and is a depth function and MME (Minimum Miscibility Enrichment – see Zick (1986)). Such analysis could be performed after obtaining full and reliable thermodynamic data regarding the total composition of the reservoir fluid attributed to the specified depth.

Minimal mixing pressure of nitrogen for the hypothetical oil reservoir

Hanssen is correlation was used for the estimation of the minimal mixing pressure of the oil (light) and the nitrogen system. Because of lack of the total composition of the system, the calculations should be treated with an appropriate carefulness. In case of a Polish reservoir the value varies between 56 and 70 MPa (see Tab. 1).

Content [%] **C_2-C_6**	**Molecular mass** **C_{7+}**	**MMP** [MPa]
8.2	160	56.2
8	200	64.0
7.5	220	69.6

Tab. 1. Presentation of the initial and forecasted minimal miscibility MMP pressure for a typical reservoir from the Polish Lowland.

Processes of displacing of oil and condensate by methane and nitrogen

The process of displacing of oil/condensate by nitrogen is less efficient than displacing by pure methane or by carbon dioxide or another gas containing fumes. In this field several research works were performed inter alia in the Netherlands – Hagoort et al. (1988), Boersma & Hagoort (1994), Sanger Bjørnstad, Hagoort (1988), Wendschlag et al. (1993). The most important factors affecting the efficiency of the process of displacing condensate/oil are geological conditions (type of the lateral and vertical heterogeneity) and maintaining the work of reservoir above the saturation pressure of the mixing system. The fluid displacing should always be realized as the miscible process because of flow resistances caused by decreasing the effective permeability as a result of the changes of saturation, viscosity and the surface tension between two phases.

Key issues concerning the gas injection into the oil reservoir

Three elementary questions require a precise geological-reservoir analysis (Massonnat et al., 1997):

1. what is the level of the reservoir heterogeneity?
2. could the defined in the foregoing point heterogeneity be modeled ?
3. what is the rate of the displacing process („flow patterns”)?

A range of the research bound with the answer to those three questions almost depletes all geological aspects in modeling of displacing oil by gas. The indicated issues could be modeled based on the estimation of variation of bed layers lithological properties with the usage of stochastic modeling. In such an analysis it is necessary to define two border-situations: the most profitable and the least profitable from the displacing process view. The analysis performed by Massonnat et al. (1997) indicated the necessity to carry out a research with the usage of the statistic modeling: the litho-stereographic correlation, directions of dips, three-dimensional distribution of reservoir parameters, heterogeneity range, frequency of heterogeneity changes, and the statistical distributions of the reservoir parameters.

Tab. 2 Composition of the injected gases show in Fig. 4.

Component	**fluid1**	**fluid2**	**fluid3**	**fluid4**
	Molecular content			
N_2	0	0.0978	0.1483	0.072
CH_4	0.7648	0.7236	0.6838	0.7355
nC_4H_{10}	0.1782	0.1339	0.1259	0.1278
$C_{14}H_{30}$	0.0570	0.0447	0.0420	0.0295

Negative and positive aspects of injecting nitrogen into the reservoir

1. Numerous negative phenomena were observed during the injection of nitrogen into the gas-condensate and light oil reservoirs (both in the laboratory scale and in the industry). The most important factors are the following:
   - Increase of the minima mixing pressure in comparison with carbon dioxide, combustion gases or buffer injection of LPG with methane (see Hanssen 1988)
   - Significant decrease of efficiency of the heaviest hydrocarbons in the reservoir recovery; supplying nitrogen causes an increase of constants of the lightest equilibrium and an decrease of the heaviest components of the hydrocarbon system (Hagoort, J. et. al. 1988).

2. Fig. 4 presents the content of liquid phase (condensate/oil) resulting from the exploitation with the injection of four basic displacings during the laboratory research mixtures. These are the fluids mentioned below in Tab. 2. The content of nitrogen varies from 0 to 15 %. The fluid 1 differentiates

from others by the high content of butanes. The increase of the nitrogen content relevantly increases the reservoir pressure, necessary for a single-phase (miscible) flow inside the reservoir.

3. One of benefits of the nitrogen usage for the injection (leading to the increase of the reservoir pressure) is its availability. The second possibility for the source of nitrogen is the separation from "the nitrogen high content" natural gas the cryogenic installations.
4. In the possible EOR project – the case of injection of CO_2 may be useful. In the first stage, CO_2 is injected and in the later phase the classical nitrogen injection process may be consider.

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