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OIL DISPLACEMENT IN MISCIBLE CONDITION

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After primary oil recovery in reservoirs remains about 70% of unexploited oil. To improve the recovery of the remaining reserves, injection of a fluid provide the extra energy in a mehanical form. Oil displacement can be achieved by gas injection of lean natural gas, mainly methane, carbon dioxide etc. Oil displacement can be in immiscible or miscible conditions. This paper deals with mechanism of miscible gas drive. On the basis of simulation of the oil displacement process by gas injection into oil field Žutica the character of process, i. e. a degree of miscibility or immiscibility between the injected fluid and reservoir oil was determined.

Ključne riječi: Utiskivanje fluida, Djelotvornost istiskivanja nafte, Uvjeti miješanja ili nemiješanja, Otparavanje u plinsku fazu, Kondenzacija u tekuću fazu, Dinamičko miješanje

Smanjenjem produktivnosti bušotina nakon primarne faze proizvodnje u ležištu zaostaje više od 70% početne količine nafte. Dalje povećanje iscrpka preostale nafte moguće je postići utiskivanjem fluida u ležište čime se dobiva dodatna energija u ležištu u mehaničkom obliku. Istiskivanje nafte postiže se utiskivanjem suhog prirodnog plina, pretežito metana, ugljik dioksida i dr. Proces istiskivanja može se odvijati u uvjetima nemiješanja i miješanja fluida ovisno o ležišnom tlaku i temperaturi. Opisani se mehanizmi istiskivanja nafte utiskivanjem plina u uvjetima miješanja. Za naftno polje Žutica na temelju simulacije istiskivanja nafte utiskivanjem plina određen je karakter procesa odnosno stupanj miješanja ili nemiješanja utisnutog fluida i ležišne nafte.

Introduction

Oil remaining after primary and secondary recovery is the target of *»Enhanced Oil Recovery« EOR*. Therefore EOR methods are often reffered to as tertiary recovery processes. Their use is not restricted to a particular phase in the production life of a reservoir.

Injection of a displacing fluid may began very early, long before the complete depletion of the field by primary recovery. Most principles applied in Enhanced Oil Recovery methods have been known for a long time. Numerous laboratory studies and field pilots have been carried out, starting in the 1960s.

To prevent oil entrapement by capillary forces we have to use a displacing fluid that is miscible with oil.

Miscibility is the ability of two or more fluid substances (gases or liquids) to form a single homogenous phase when mixed in all proportions. For petroleum reservoirs, miscibility is defined as that physical condition between two or more fluids that permits them to mix in all proportions without the existence of an interface. Miscibility hydrocarbon gas flooding acts mainly on the displacement efficiency at the pore space scale, by annihilating the capillary forces.

Dynamic miscibility

In miscible flood processes some combination of transfer of components from the oil displaced to the injected fluid and from the injected fluid to the oil takes place as the phases flow through the porous medium. When the required transfer is efficient enough, local displacement efficiency can approach 100%.

Some hydrocarbon gases, with a high proportion of intermediate molecular weight components (C_3,C_4,C_5) are miscible with oil under pressure and temperature conditions encountered in some oil reservoirs.

Moreover, under much wider condition the displacement of oil by hydrocarbon gases may lead, through component exchange between oil and the gas, to creation of transition zone in which the composition varies continouosly between the composition of the displacing fluid and the composition of the oil (Blackwell & al., 1959).

Injected fluids such as ethane, propane, butan or mixtures of liquefiable petroleum gas (LPG) mix directly with reservoir oil without any multiphase behavior, developing a »first contact miscibility« process. It is a simplest way to achieve miscibility, but solvents that give this type of miscibility are expensive.

In other cases, the injected fluid (Benham & al., 1960) such as methane, natural gas, carbon dioxide or flue gas, undergoes phase separation from the oil. Light to intermedate components are exchangd between oil and injected fluid. A transition zone spreads out in which both fluids are miscible. This type of miscibility is called *»multiple-contact miscibility«* or *dynamic miscibility,* and develops following processes:

- *vaporising gas drive,*
- *condesing gas drive.*

A practical way to visualize the development of both processes is to drow a ternary diagram (Latil, 1980).

Vaporising gas drive

Vaporising gas drive is a praticular case of *multiple-contact miscibility.* It is based on the vaporization of intermediate components from the reservori oil to the injected gas creating a miscible transition zone. The C_2–C_5 fraction is preferently extracted. This mainly occurs at high pressure, by injecting natrual (hydrocarbon) gas, flue gas or nitrogen.

Three poles of ternary diagram are defined as:

– light component, methane C_1

– intermediate components, generally C_2 to C_6

– heavy components, for example C_{7+} (heptane and heavier fractions)

Under determined condition of pressure and temperature (p, and T), the dew and bubble point are plotted inside the triangle, thus defining the two-phase zone. Point C is representative for the mixture of three pseudocomponents, which has T and p as critical temperature and pressure. The high-pressure injected gas is represented by the point G, and the original oil by point O.

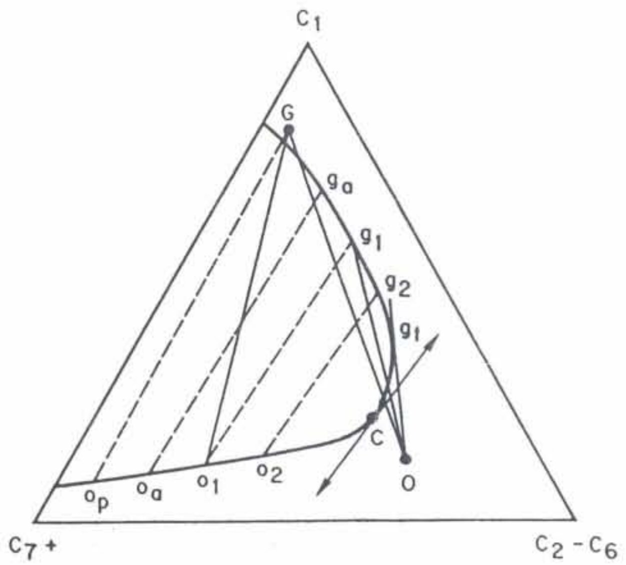

Fig. 1. Ternary diagram: vaporising gas drive process (after Latil, 1980)

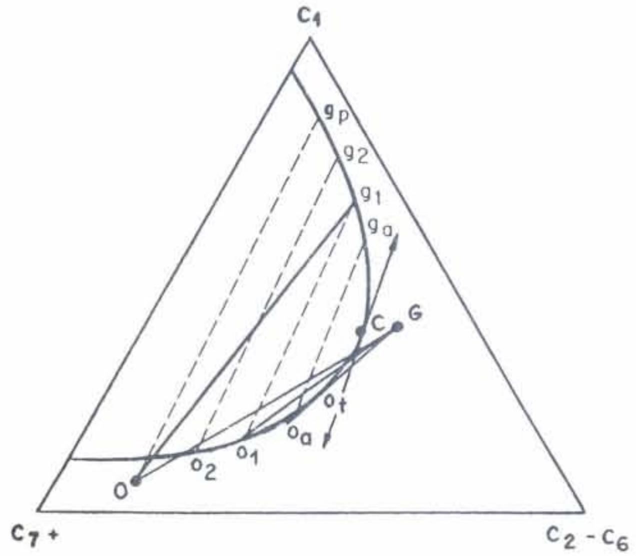

Fig. 2. Ternary diagram: condensing gas drive process (after Latil, 1980)

If miscibility is to develop, the representative point of the oil should be on the right side, and the point of the injected gases should be on the left side of the critical tie line (i. e. the tangent to the phase envelope at point C). This implies that oil is relatively rich on intermediate components.

Initally, virgin oil and injected gas are immiscible, and a representative line GO passes through the two-phase zone. This implies that near the wellbore some residual oil with original composition O remains unchanged. As oil and gas are not in equilibrium, thermodinamic exchange occurs, and the gas is enriched in intermediate and heavy components.

Oil o_1 generally occupies a smaller volume than oil O, gas g_1 moves ahead, chased by the fresh injected gas G, while the oil remains in place. At that step of the process, g_1 contacts virgin oil O, and they are not in equilibrium so they divide into two phase g_2 and o_2. On the other hand, oil o_1 in contact with gas G gives oil o_a which is even poorer in intermediate components. This whole process will go on until the gas in contact with virgin oil reaches point g_b which is defined as the intercept of the tangent to two-phase envelope from the oil representative point O. There, full miscibility is achieved and no residual oil remains.

Behind the miscible bank, previously formed residual oils o_1, o_2 etc., continue becoming poorer in light fractions while in contact with fresh G. The extreme composition of these residual oils is o_p, placed on the tie line that passes through G gas composition. This o_p, oil does not exchange any intermediate component with gas G, and will remain trapped in the reservoir.

Condensing gas drive

Until 1980, condensing gas drive was considered to be a well-known phenomena which arises when rich gas is injected in to medium heavy oils. This process is probably a dual *vaporising/condensing gas drive.* When a rich gas is injected into a relatively heavy oil, oil and gas are initially immiscible, but a miscible bank forms through condensation of intermediate components from gas into oil. This implies that the injected gas is rich in intermediate hydrocarbons. On the other hand, the oil to be recovered is relatively heavy (for a light oil, a lighter gas, i. e. poorer in intermediate components, it is sufficient and cheaper to for achieving miscibility). Representation of process is shows on a ternary diagram (Latil, 1980)

– the representative point for gas is, G, is nearer to the C_2–C_6 pole than for lean gas injection, and the representative point for oil O is close to the C_{7+} pole. It is absolutely necessary for this type of miscibility to develop that the representative point of the oil has to be on the left side of the critical tie lie and that of the solvent is situated on the right side of this line.

Once injection starts, since fluids are immiscible, a classical immiscible displacement takes place, and virgin oil O is left behind the front in contact with fresh gas G. A process similar to that described for vaporising will develop. Oil behind the front becomes progressively richer unitl it reaches o_t oil composition. Gas in contact with virgin oil at the front becomes progressively drier, (G, g_1, g_2, etc.) and loses all its intermediate fractions until it reaches g_p composition as defined by the tie line passing through point O, where it no longer exchanges components with the oil.

The succesive oils O, o_1, o_2,,,o_t formed behind the front occupy a greater volume than the original oil because of swelling due to the intermediate fractions solubilization. This will cause the mobilization of an oil bank with o_t composition.

If the phase equilibria between oil and gas are true two-phase liquid-vapor equilibria i. e. no solid phase is precipitated such as, for example, asphaltenes and heavy fraction, and no resiudal oil will be left in the reservoir if condensing gas drive occurs. Conversely, in vaporising gas drive the resulting o_p oil is unrecoverable. The dry gas produced ahead of the bank is generally continously dissolved in the virgin oil that it contacts.

The miscible displacement mechanism yields significantly high recovery. The high efficiency is a result of displacing essentially all of the oil in the area contacted except for the by-passed islands of oil which are large compared to a pore space. Even this by-passed oil con-

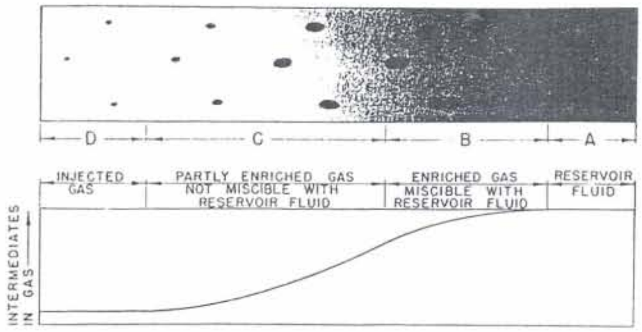

Fig. 3. Shematic representation of miscible displacement

tinue to flow as long as it is surrounded by material miscible with it.

The reservoir fluid is represented by the dark area A, and the lean gas injected to displace the oil by the white area D. As the injected gas moves through the reservoir, its extracts intermediate components from the residual oil in this path. This enrichment of the gas is represented by the gray area, B and C. Reservoir fluid by-passed at the front (area B) by the enriched gas which is miscible with oil is represented by dark gray areas of the same color as the reservoir fluid inasmuch as they have the same composition. Over an interval (area B) the by-passed oil units flow along with miscible phase surrounding it, but at a slower rate because of their higher viscosity. In this step the by-passed oil units are somewhat reduced in volume as a result of mixing. This mixing also adds material to the enriched gas which helps maintain the condition of miscibility required for the proces. In zone C when miscibility is lost, the by-passed oil no longer flows with the gas, but is gradually extracted, with lighter hydrocarbons going into the gas phase. Finally, residual oils is shown in section D as a black area, the darker shade being used to show a concentration of heavy ends as a result of loss of intermediates to the displacing gas (Stalkup, 1984).

Simulation of the process in Žutica oil field

Simulation of oil displacement process in the Žutica oil field by maintaining reservoir pressures has be done (Jüttner, 1995) up to defined process characteristicts (miscibility or immiscibility conditions).

To simulate the process, an unidimentional reservoir simulator COMP3 was used (Scientific Software Intercomp, 1984.) A 9-component system was required in the formulation of fluid composition (adjusted to Peng-Robinson Equation of State). It was also assumed that the pore space contains only saturated oil, and either the influence of petrophysicial heterogenities of the reservoir rock, or the viscous fingering of fluid were considered. In fact, only the thermodynamic aspect of the process was investigated, as well as the value of minimum miscibility pressure (MMP).

The minimum miscibility pressure (MMP) is the minimum pressure required to achieve multiple contact miscibility between injected gas and oil. This pressure is perfectly defined by thermodynamic data of the process, i. e. oil and gas composition and temperature. Variations of those parameters will affect the value of the MMP. A standard way to determine MMP is to perform several displacement tests with gas to be injected into the reservoir oil under various values of pressure, whatever the type of dynamic miscibility may be – *vaporising or condensing gas drive.*

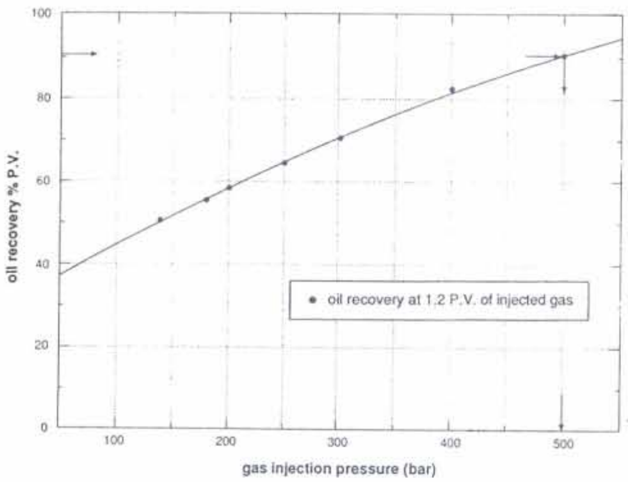

Fig. 4. Results of displacement simulation after Jüttner, (1995)

Simulation of dynamics, displacement process at set constant pressure of gas injection has already been performed under various pressure values. The results of simulation are presented on Fig. 4.

According to criterion (Yelling & Metcalfe, 1980) the minimum miscibility pressure is that particular gas injection pressure when 1.2 pore volume (P. V.) of injected gas over 90% of present oil is displaced.

Miscible condition in the system of saturated oil Žutica – methane can be achieved only after application of a very high injection pressure (MMP). Fig. 4. (Jüttner, 1995) shows that the MMP of system is 500 bar.

In the interval of real applicable gas injection pressures (200 bar) the process will proceed under immiscible condition.

Dissolution of some components of the injected gas in to the residual oil may increase its volume (oil swelling), and decrease its viscosity and its interfacial tension with gas, and therefore faciliate oil mobilization. But, the injected dry gas is poorly dissolved in already satured oil and swelling of oil and decrease of oil density are low.

Conclusion

To produce more oil, pressure in the reservoir must be maintained by injecting an another fluid.

Oil displacement in the Žutica oil field by maintaining reservoir pressure by dry (methane) gas injection at actual pressure of 130 bar occurs under immiscible conditions.

If the process should be performed at higher pressure (up to maximum possible reservoir pressure of 200 bar), it cannot be expected to get a higher contribution to miscibility displacement in the total production.

Low wolume of methane is dissolved in the reservoir oil, so changes in properties of saturated oil (swelling) are indistinct.

Contribution of multiple contact mehanism of hydrocarbon vaporising in total oil displacement is negligble.

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