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Comparative Investigation on Enhanced Oil Recovery Methods with Special Reference to Hot Water Flooding and Alcohol Slug Injection

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ABSTRACT

With the increase in demand for energy, maximum recovery of oil from higher gravity oil fields has become a target of vital importance worldwide. However, a large part of the reserves of heavy oil cannot be recovered without improved technology. The new technical developments for improving oil recoveries fall under the broad heading of enhanced oil recovery.

In the present study, a comparative investigation on enhanced oil recovery methods has been carried out with special reference to hot water flooding and alcohol slug injection. Experimental work on Egyptian heavy viscous crude oils has shown that 70 to 75 % of oil recovery can be obtained by using hot water flooding and alcohol slug injection methods.

INTRODUCTION

Substantial quantities of oil remains in developed oil fields after conventional production is depleted. Until recently, most of this oil was regarded as impossible or uneconomic to recover. However, new developments in technology give promise that a large part of this otherwise neglected oil can be recovered.

In literature, several interesting attempts have been mentioned for improving oil recovery, such as nuclear explosives for recovering oil from oil shales. Unfortunately, the cost of breaking the shales with nuclear explosives is still uneconomical. Another attractive research was the use of direct electrical current, for enhancing reservoir energies during petroleum production, as introduced by Chillingar et al (1970). An oil reocovery process using a combination of oil soluble solvents, surface active agents and emphipathic solvents was provided by Csaszar (1961).

Water injection, the oldest recovery method still remains the most common. According to Kastrop (1972), 80 % of the oil produced by enhanced recovery in the United States in 1970 was produced by water injection. Oil recovery is increased by an improvement in sweep or displacement efficiency. The water may be injected into an underlying or neighbouring aquifer.

In addition to water, the other common injection fluid is gas. Injected gas may be either miscible or immiscible. If conditions are technically suitable for miscible gas injection it may be the best method, since the microscopic displacement efficiency will be improved. In the case of immiscible gas, water injection may be preferred especially for conditions of low gas/oil ratios or high premeability to water conditions. However, an important factor in water injection is that there is a time lag between the start of injection and the increase in production.

Gas injection in an oil reservoir takes place either into a gascap, if one exists, or directly into the oil zone. The injected gas is practically of a hydrocarbon base. Air injection has been attempted, but it has many disadvantages (well corrosion, oil oxidation, explosion risk, etc.). The principal factor involved in the decision to commence gas injection is the availability of a nearby source of cheap gas in sufficient quantities for reservoir pressure maintenance. Secondary gas is usually obtained either from an adjacent gas reservoir or from a nearby gas pipeline.

The nature of displacing fluid is of great importance in the optimization of oil recovery. Thus, a fluid miscible with oil is fairly preferred. The interfacial forces will in this case be eliminated and the microscopic displacement efficiency will be high. To attain miscibility it is sufficient to inject a "slug" of solvent of limited volume (a few percent of the swept pore volume) displaced by a much cheaper follow-up fluid.

Typical miscible displacement systems used are: (1) oil, LPG, gas, and (2) oil, alcohol, water. The first system suffers from the disadvantage that high reservoir pressures are required (atleast of the order of 1500 psi). Thus, this system cannot be used in shallow reservoirs, in which the pressures are low and which cannot always be recompressed because of the risk of fracturing the formation. Besides, the areal sweep efficiency is relatively poor because of the large mobility contrasts between gas, solvent and oil. An obvious possibility is the use of alcohols as a slug between the oil and the water, since they are miscible with both liquids. However, the alcohol slug would be progressively diluted and, below a certain critical alcohol concentration, would no longer be miscible with oil, at which stage the displacement would simply be water injection.

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Besides, the addition of surface-active agents to the injected water has not been a profitable oil reocovery method. This may be attributed to the high loss of the surfactant by adsorption on the grain surface of reservoir rock. The use of different salts and mixtures of petroleum sulphonate with broad equivalent weights has been reported as methods for reducing adsorption in low-tension floods with surfactant solutions. Moreover, several efficient enhanced recovery methods have been proposed and tested. These methods include polymer solutions, water-gas foam injection, carbon dioxide, wettability reversing agents, etc. However, according to Chierci (1980), the oil production provided in the U.S.A. using chemical processes constituted only 0.4 percent of the total enhanced oil recovery. This shortcoming may be attributed to considerations of economic conditions.

Finally, thermal recovery has seemed most applicable to reservoirs that contain very viscous oil at reservoir conditions. There are two categories of thermal methods: hot fluid injection and in-situ combustion. In the first case, the injected fluid carries the heat produced while in the second case the injected fluid is one of the reactants involved in an exothermic reaction taking place in the reservoir. Evidently, the heat lost will be much greater in the first case than in the second one. The common factor in all thermal methods is the increase in temperature of part of the reservoir. This involves specific mechanisms which improve both displacement and sweep efficiency, and increase the rate of production. In thermal recovery, the injected fluid is usually water in the liquid or vapour phase as it has a much higher heat transport capacity than any other fluid. According to Latil et al (1980), the recovery at breakthrough of the water front, for both hot water and steam injection, is always better than that achieved by cold water injection. The efficiency of thermal recovery may be further improved by combining with other recovery methods.

The present study is devoted to provide a comparative investigation on enhanced oil recovery methods. An experimental work was performed on both hot water flooding and alcohol slug injection techniques. The research is addressed to Egyptian heavy viscous crude oil.

EXPERIMENTAL PROCEDURE AND DISCUSSION OF RESULTS

Hot Water Injection

In this study, sand packs of fixed mesh size and known porosity and permeability were used to represent reservoir rock. The sand was firstly washed several times by fresh water and then it was completely dried.

Stainless steel tube of 5 cm inside diameter and 44 cm length, was packed with dry sand, and put under vacuum for several hours. Then the packed sand was fully saturated with synthetic brine water. The brine-saturated packed sand was then flooded with the crude oil until the production of the brine water was ceased i.e. oil production was 100%. The packed sand was then flooded with the synthetic brine water at 80 °F until the production of oil was ceased i.e. the production was 100% water. The cumulative produced oil during waterflood was measured. Then, the residual oil saturation, after waterflood, was calculated.

At this stage after waterflood, the model was ready for studying enhanced oil recovery using hot water flooding. To investigate the effect of temperature on oil recovery, the model was put in a water bath at different temperatures of 120, 140, 160, 180, 212 °F. Three crude oil samples of different viscosity values (4.5, 8 and 35 cp at standard conditions) were employed to study the influence of viscosity on oil recovery by hot water injection. The results are shown in Figures 1 to 8.

The figures reveal that the oil recovery increases with increasing of temperature and/or decreasing of viscosity. In addition, the figures clearly indicate that oil recovery goes up when volume of injected hot water increases and higher rate of increase takes place for low value of injected volume. Moreover, the oil breakthourgh was found to be faster as the temperature of hot water increased, for example, the injected pore volume of hot water at oil breakthrough was 0.1 of pore volume for the 4.5 cp oil at 120 °F, while it was only 0.04 of pore volume for the same oil at 212 °F.

Alcohol Slug Injection

For the investigation of alcohol slug injection, exactly similar model as that explained in hot water injection was employed. The above procedure was followed from its beginning until the stop of waterflood. The viscosity of oil used in this case was 4.5 cp. The oil was displaced by different slug volumes of different types of alcohol (methyl, butyl, isopropyl). Five slug volumes i.e. 5, 10, 15, 20 and 25 percent of pore volume, were used. The slugs of alcohol were injected and then followed by water.

The results for alcohol slug injection are represented in Figures 9 to 16. The figures illustrate the influence of slug volume, type of alcohol and volume of injected fluid on the oil recovery. A comparison of results, introduced in these figures, reveals that butyl alcohol is more efficient than both the isopropyl alcohol and the methyl alcohol. The latter type (methyl alcohol) is the least efficient but it is much cheaper than isopropyl alcohol. This can be attributed to the fact that both the methyl alcohol and the isopropyl alcohol rapidly absorb water i.e. preferentially soluble in water while butyl alcohol is preferentially soluble in oil. Thus, when butyl alcohol is used, the oil phase flows at a

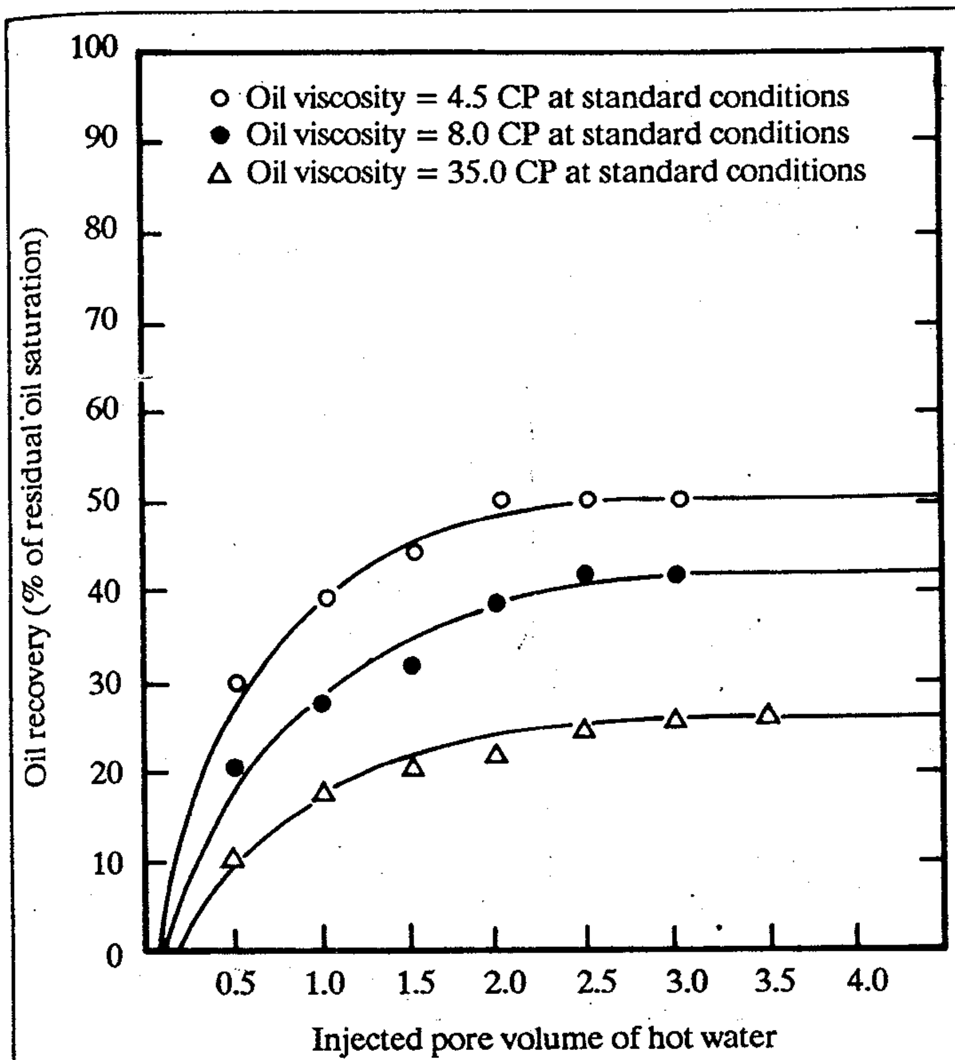

Figure 1— Oil recovery versus injected pore volume of hot water at 120 °F.

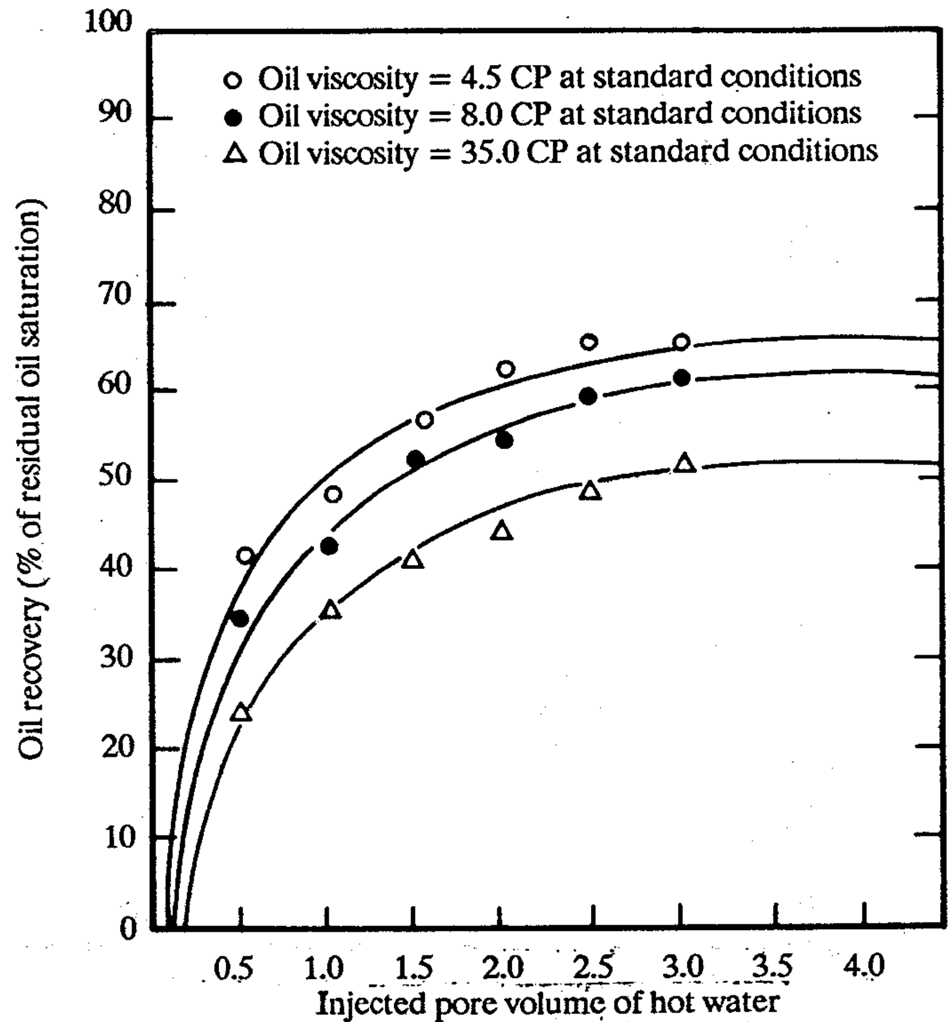

Figure 3— Oil recovery versus injected pore volume of hot water at 160 °F.

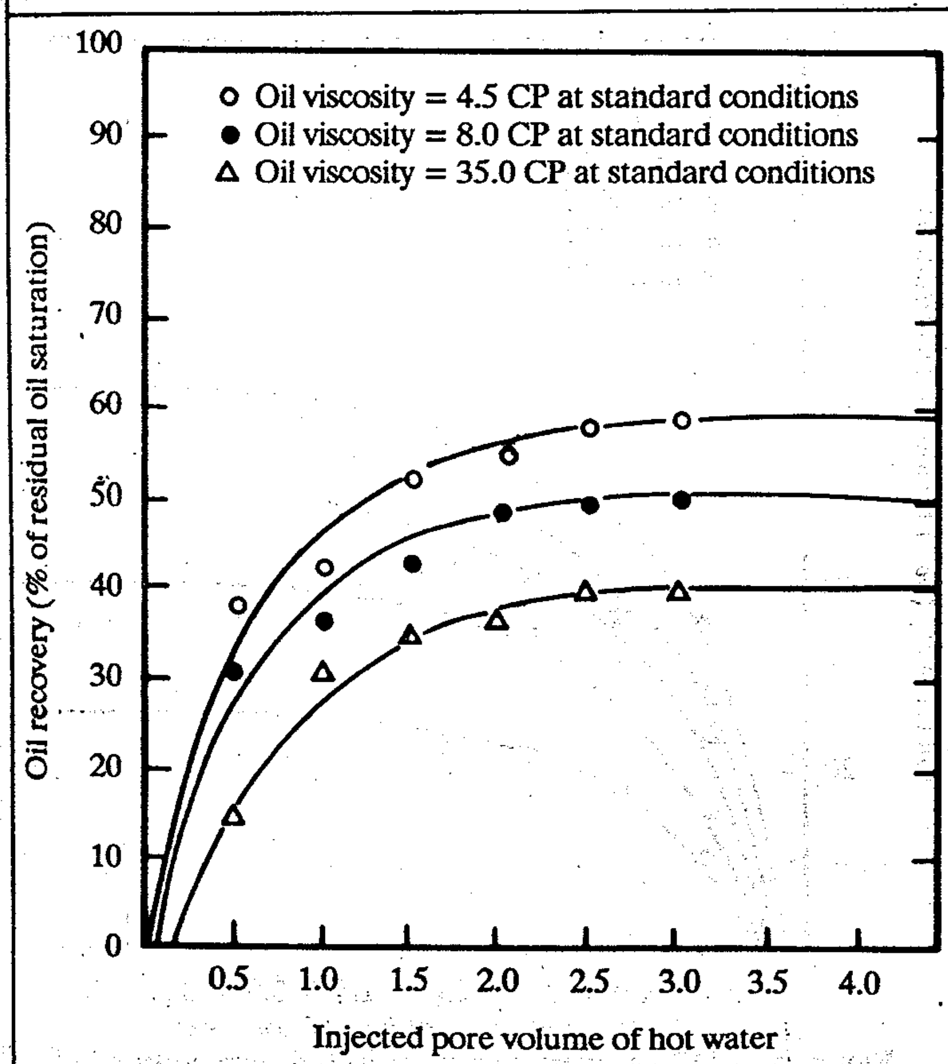

Figure 2— Oil recovery versus injected pore volume of hot water at 140 °F.

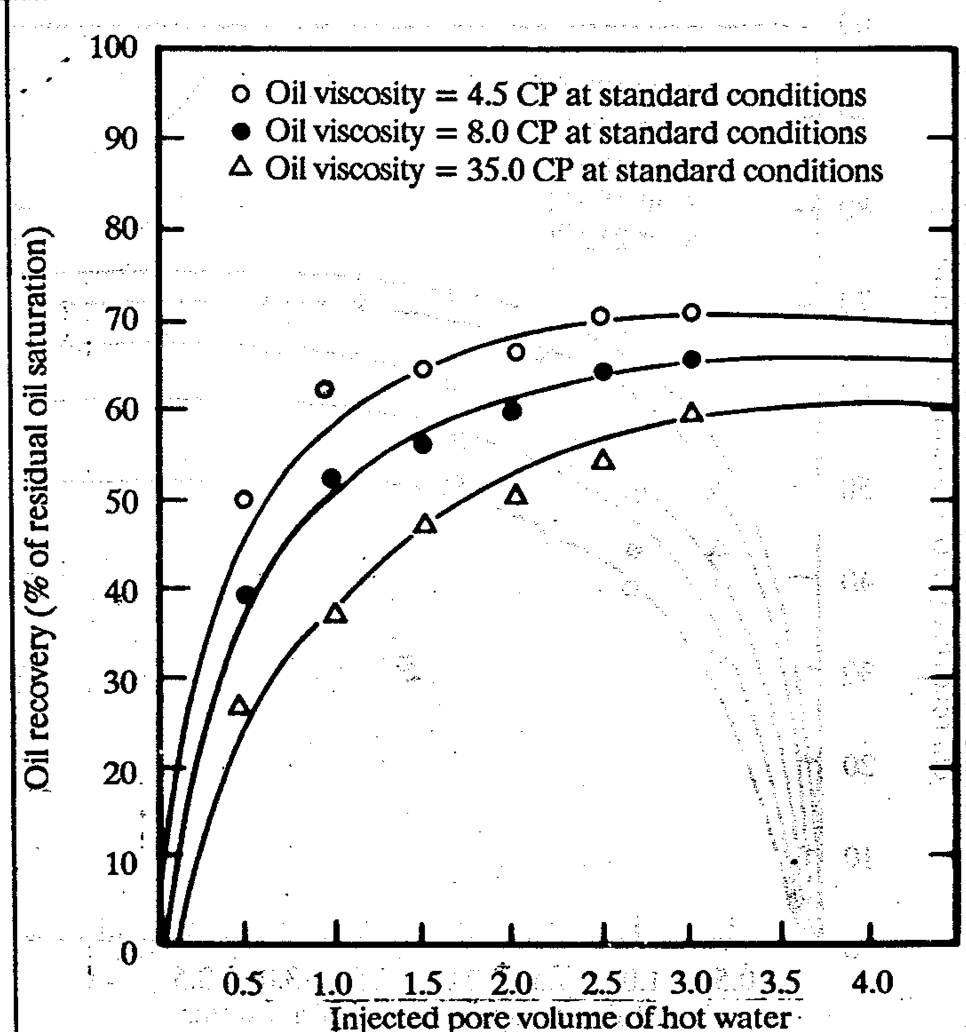

Figure 4— Oil recovery versus injected pore volume of hot water at 180 °F.

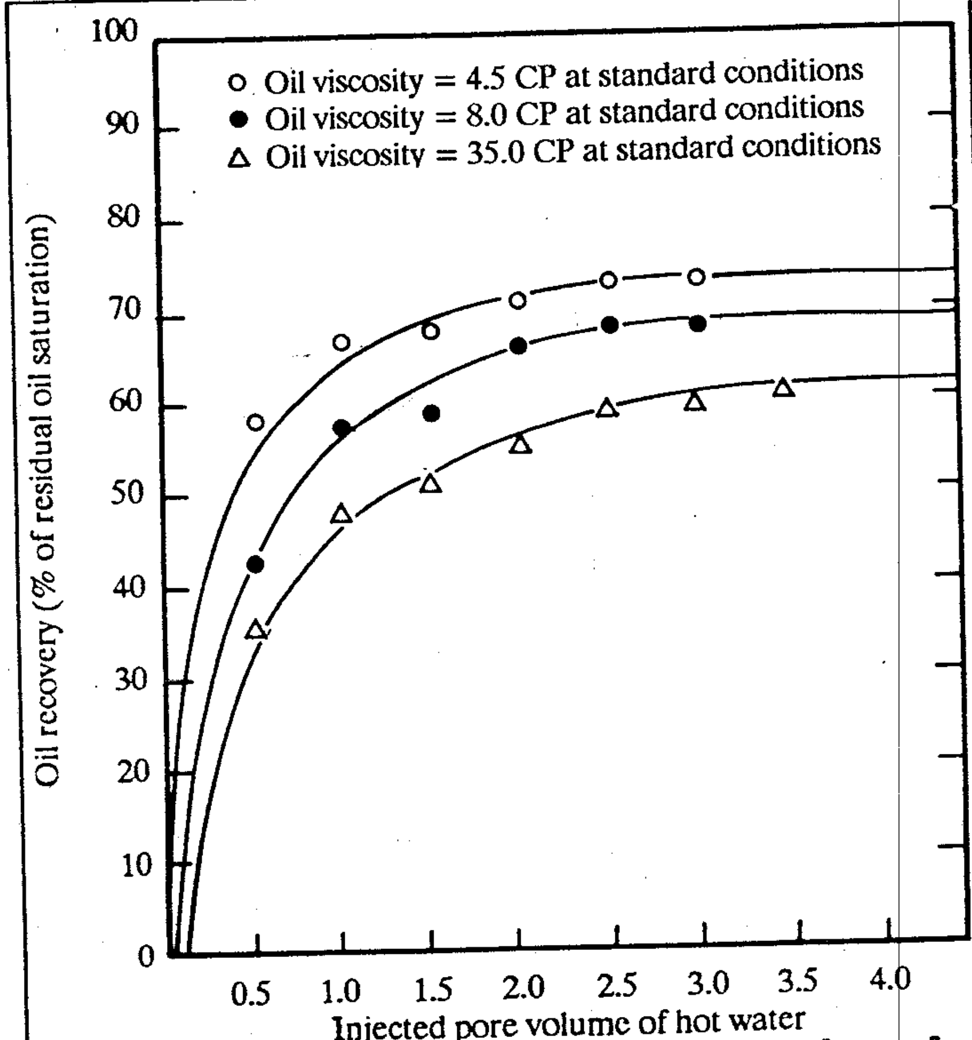

Figure 5— Oil recovery versus injected pore volume of hot water at 212 °F.

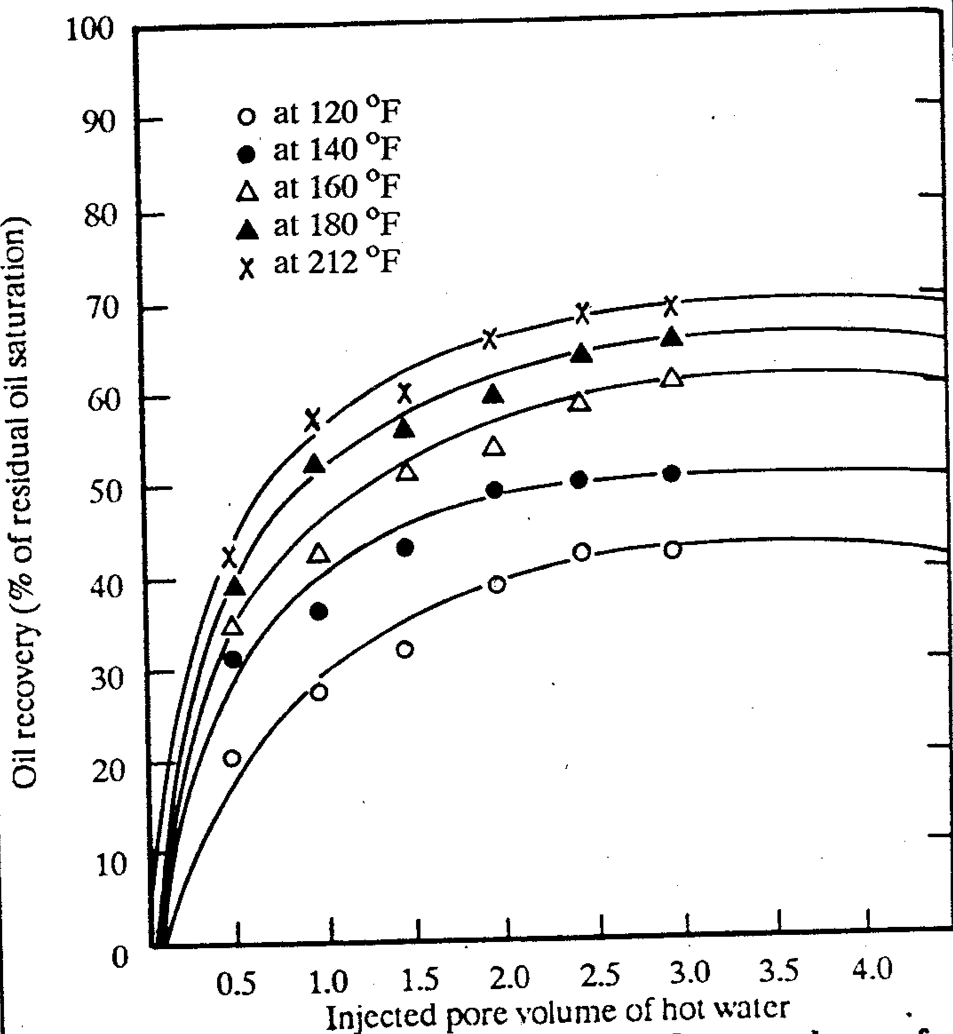

Figure 7— Oil recovery versus injected pore volume of hot water (oil viscosity = 8 CP at standard conditions).

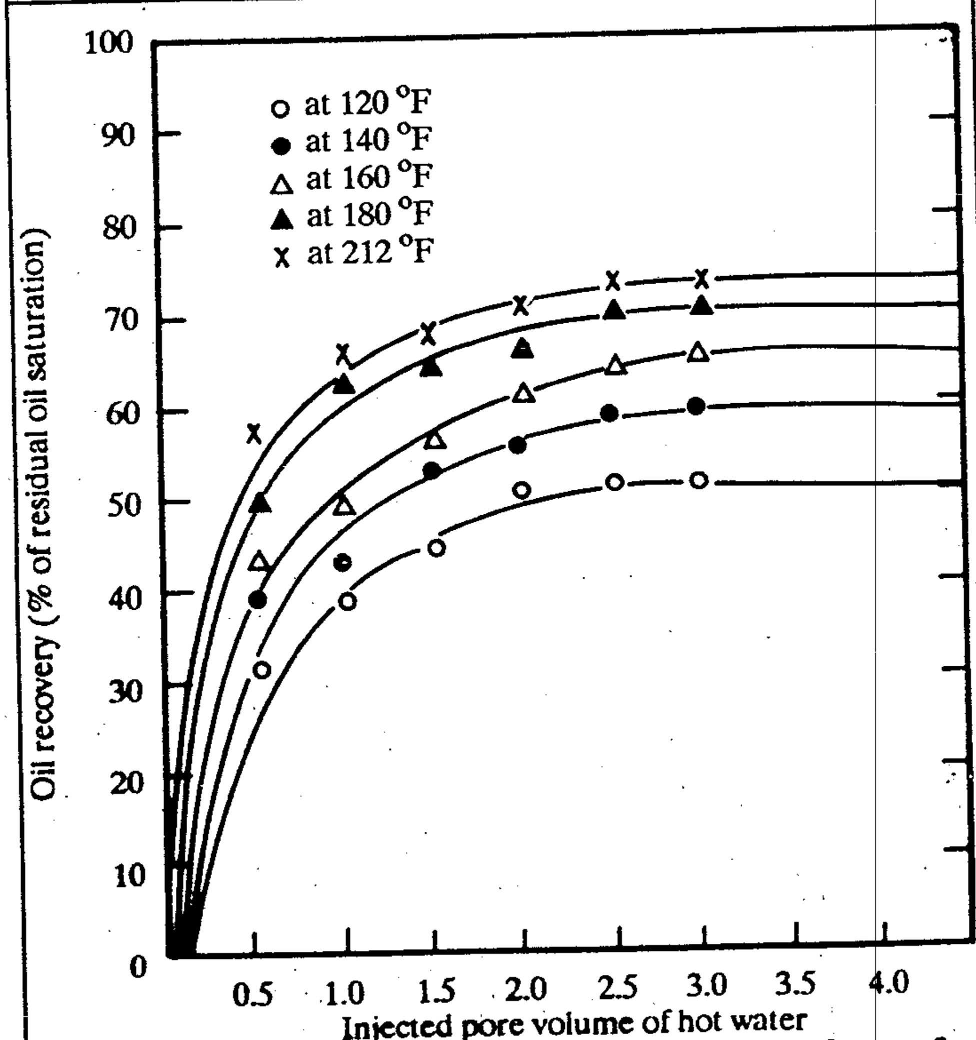

Figure 6— Oil recovery versus injected pore volume of hot water (oil viscosity = 4.5 CP at standard conditions).

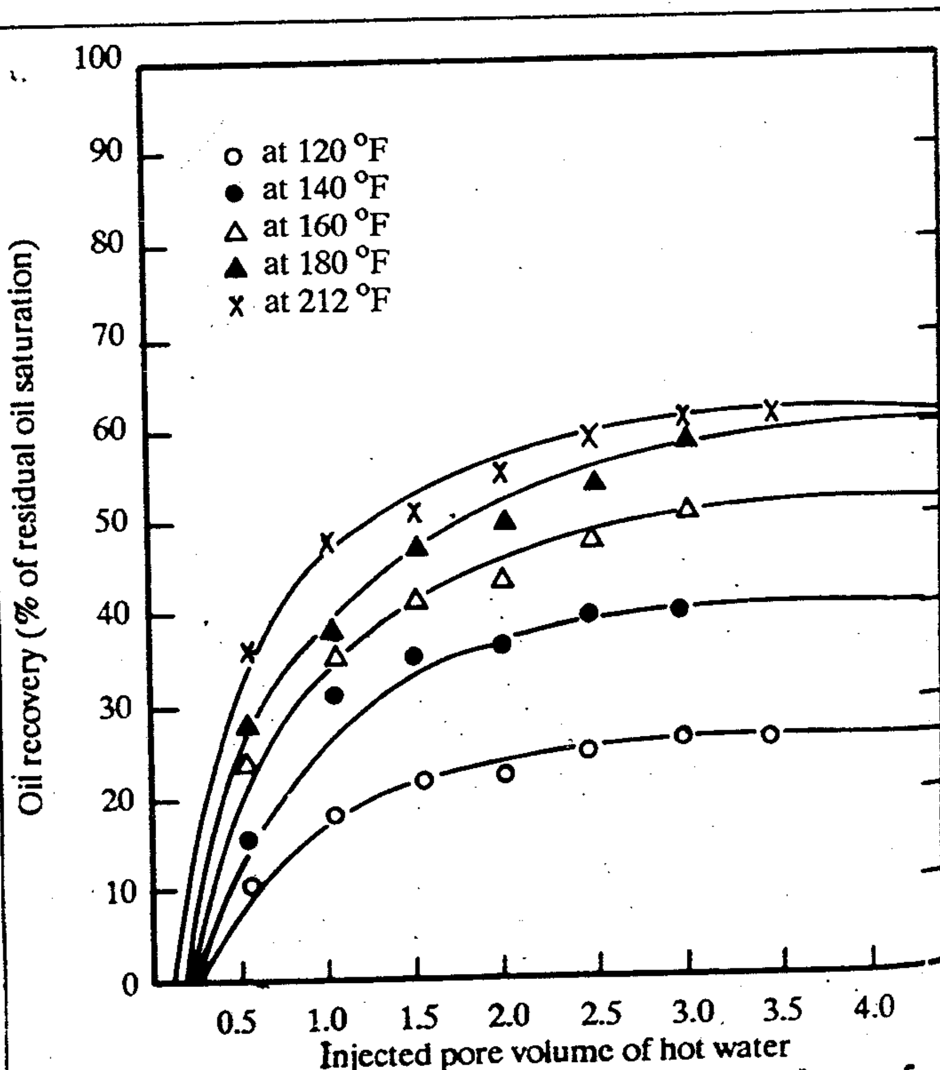

Figure 8— Oil recovery versus injected pore volume of hot water (oil viscosity = 35 CP at standard conditions).

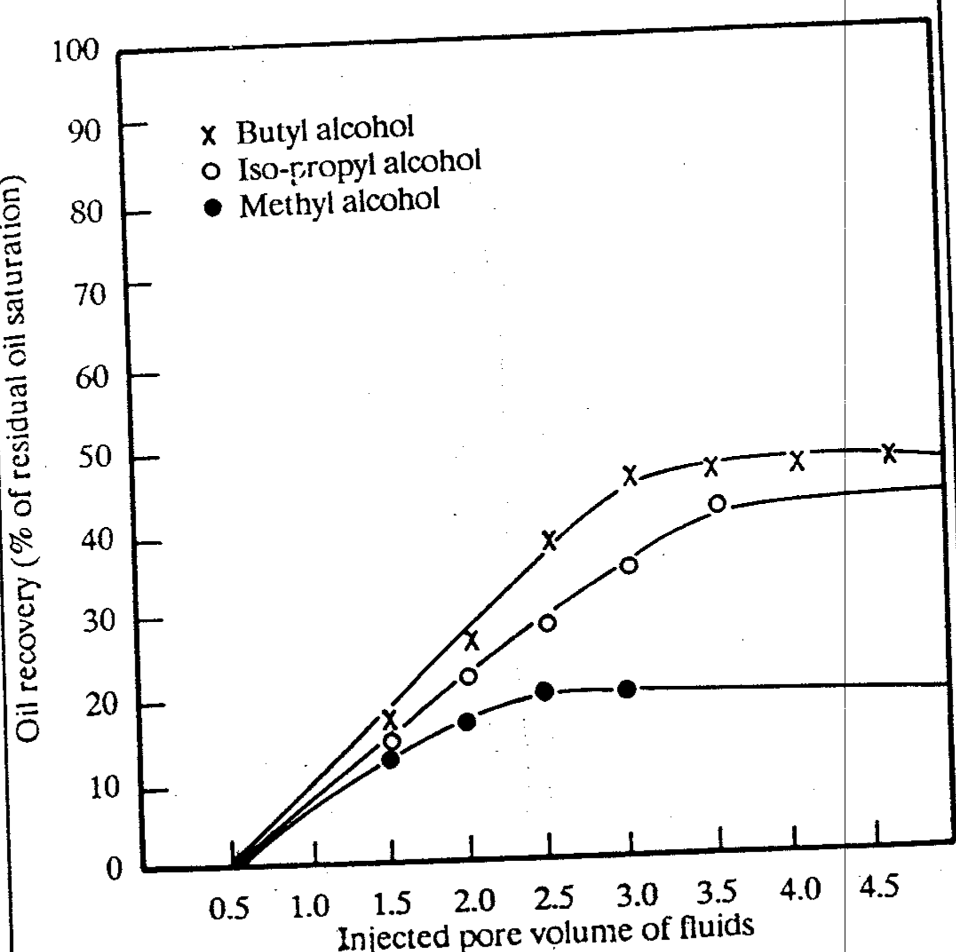

Figure 9— Oil recovery using 5% pore volume of alcohol.

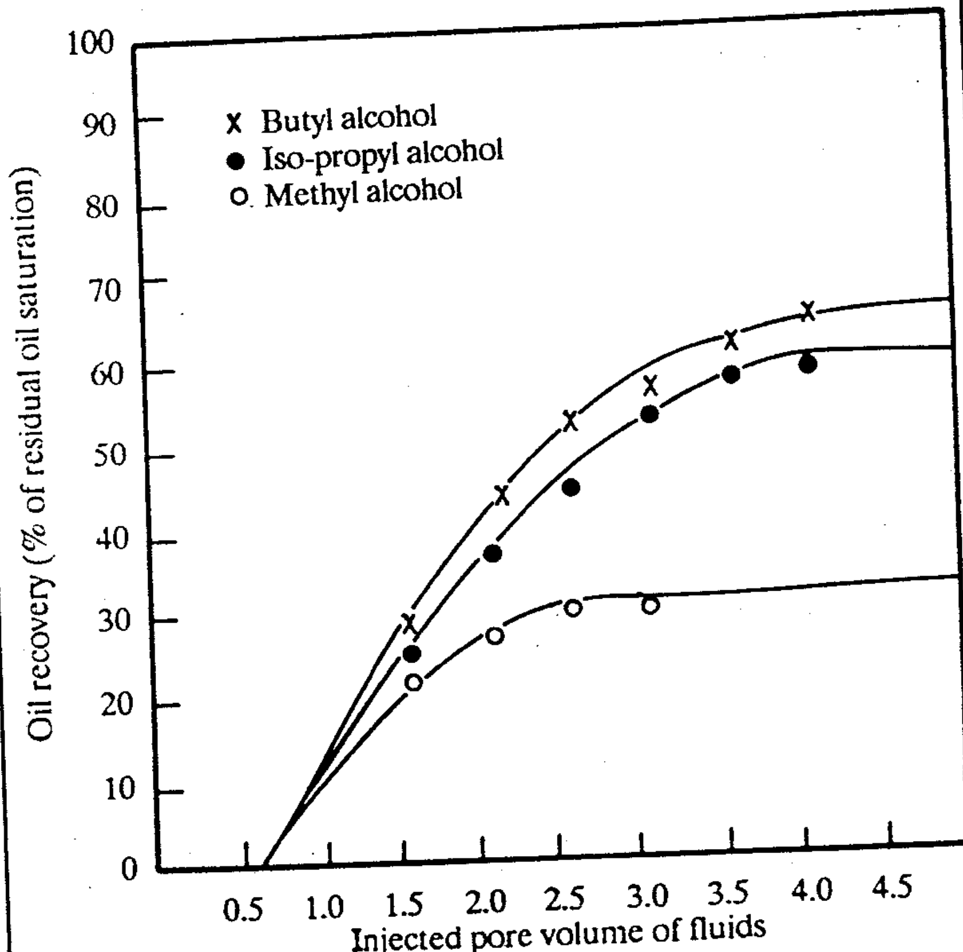

Figure 11— Oil recovery using 15% pore volume of alcohol.

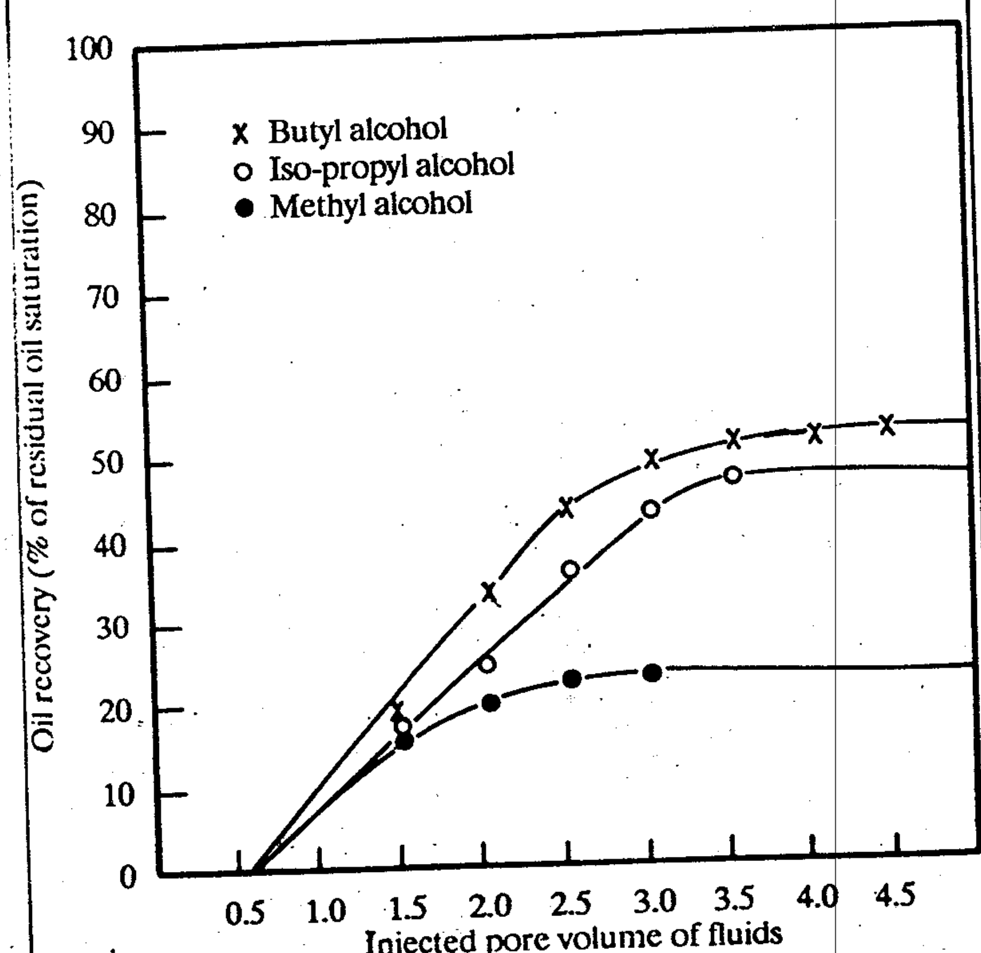

Figure 10— Oil recovery using 10% pore volume of alcohol.

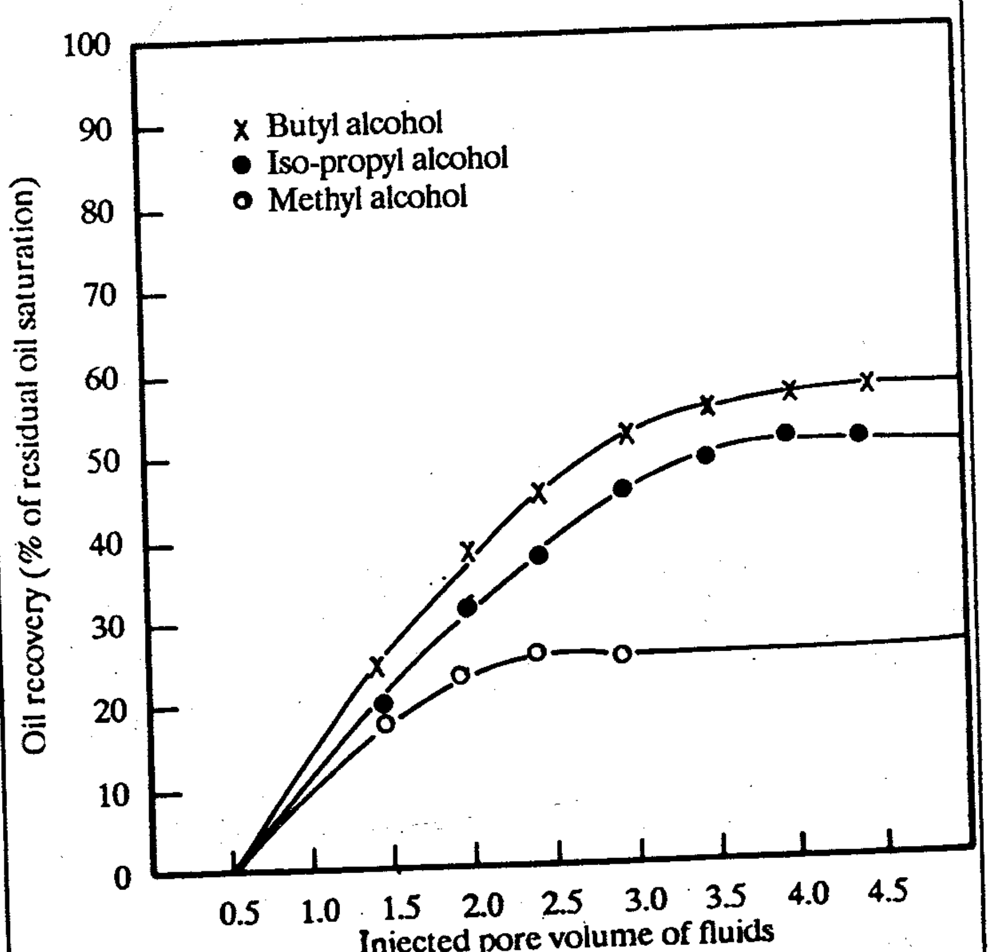

Figure 12— Oil recovery using 20% pore volume of alcohol.

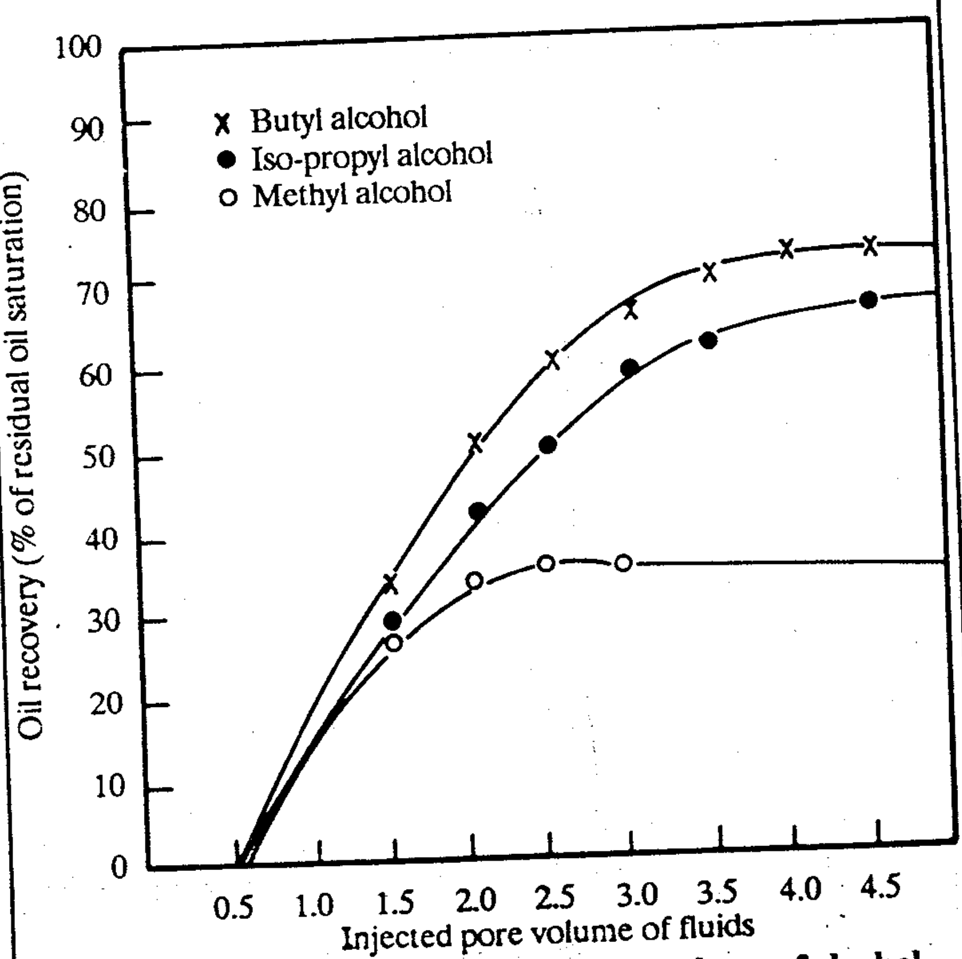

Figure 13— Oil recovery using 25% pore volume of alcohol.

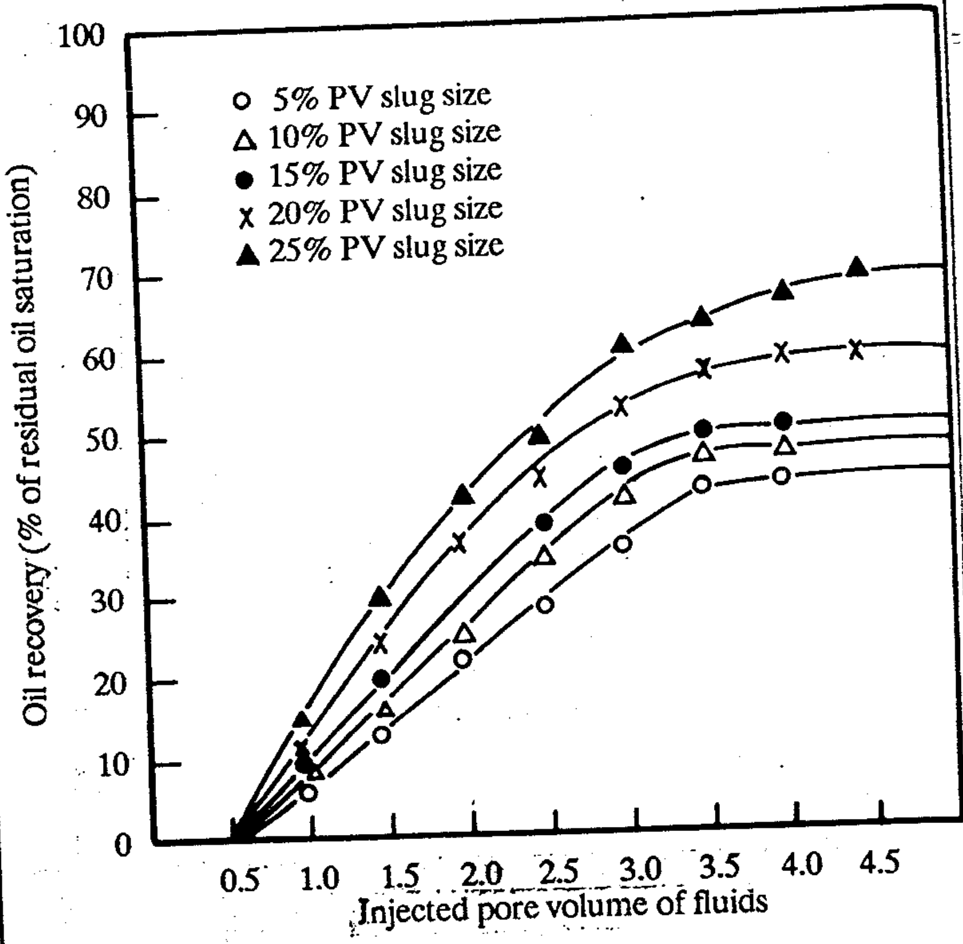

Figure 15— Oil recovery using iso-propyl alcohol.

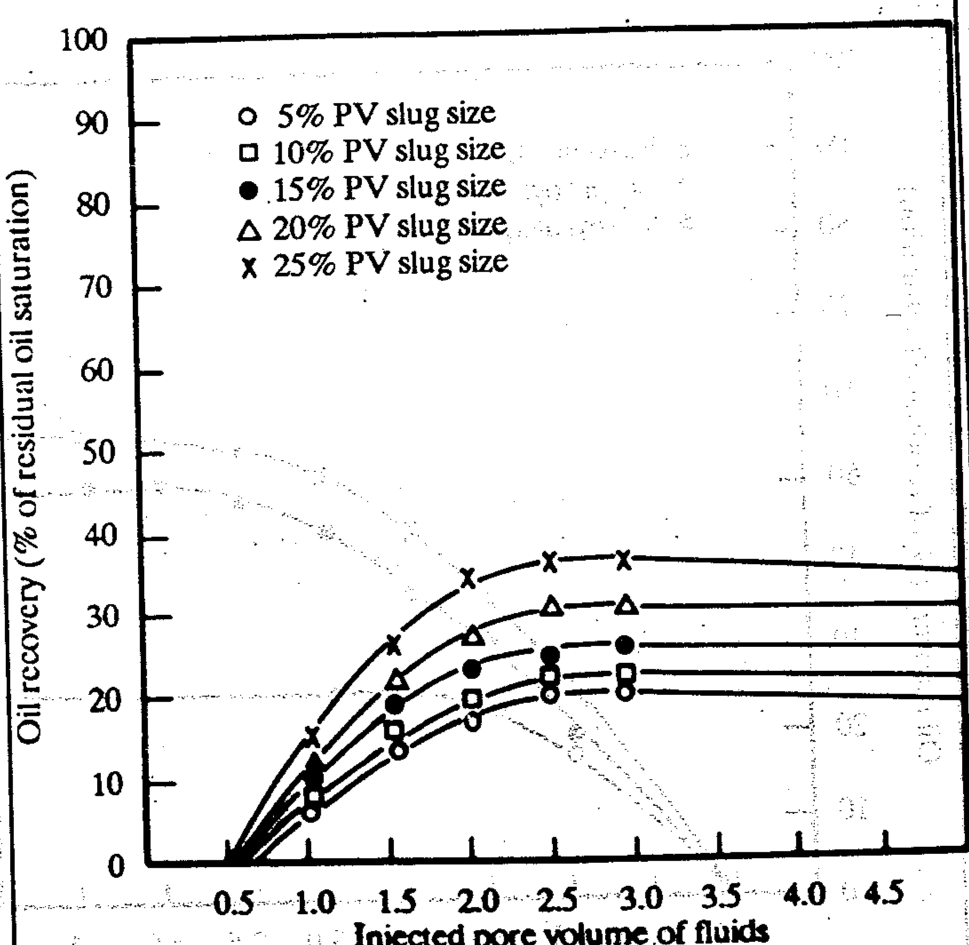

Figure 14— Oil recovery using methyl alcohol.

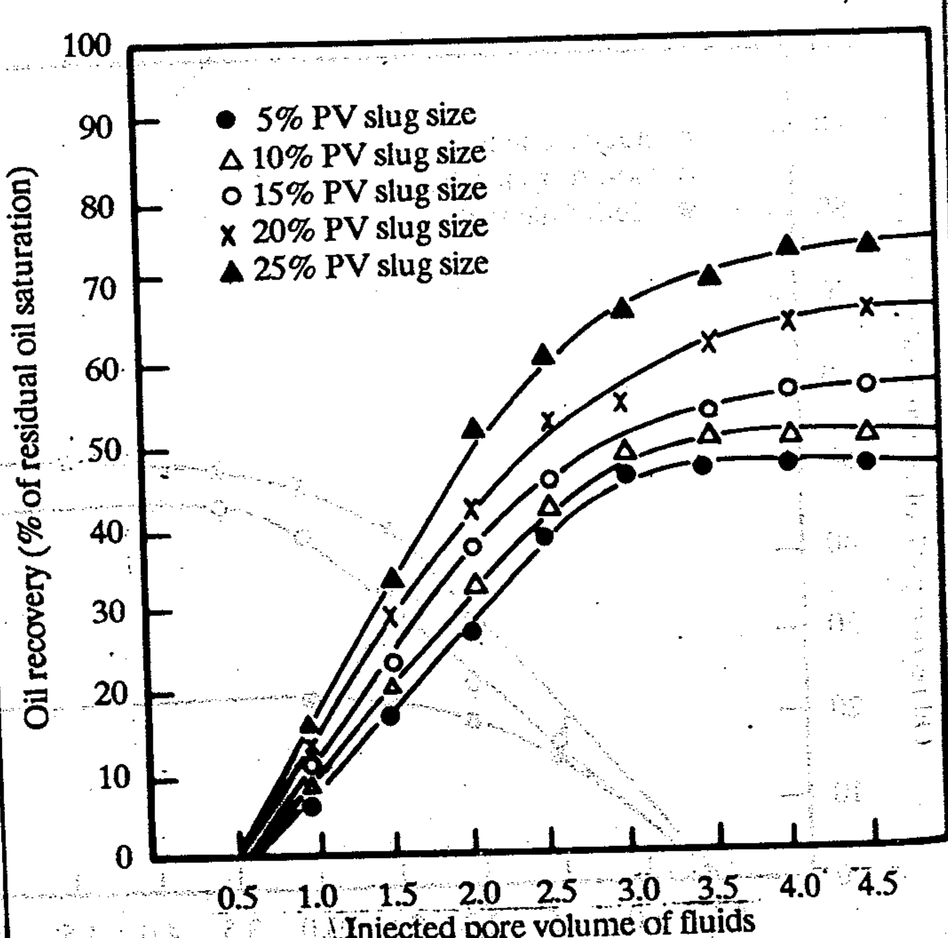

Figure 16— Oil recovery using butyl alcohol.

higher velocity than that of the water phase. However, the cost of butyl alcohol is prohibitive.

The present findings fairly agree with those provided by Latil et al (1980). They indicated that a combination of methyl alchol, isopropyl alcohol and normal butyl alcohol with a total slug volume of about 10% pore volume was required to ensure almost total recovery of the oil. However, due to the high cost of various types of alcohol, this method of miscible displacement has not yet found commercial application.

Finally, for the sake of comparison, thermal recovery processes accounted for 90 percent of all the enhanced recovery oil in the United States in 1975. Thermal methods, especially those involving steam injection, are already proven, and are not technically limited to heavy oils. There are large accumulations of heavy oil amenable to thermal recovery processes in the world. It is anticipated that the rate of production by thermal processes will continue to increase, both in the United States and in the rest of the world. On the other hand, the future of chemical recovery processes will be affected by government policies, such as crude oil price control, taxes and costs of used chemicals.

REMARKS AND CONCLUSIONS

Since the energy crisis of seventies, enhanced oil recovery methods, secondary and tertiary, have found great commercial field applications. Thermal recovery methods are in wide use today, and appear to have good future. Thermal methods constituted 90 percent of all the enhanced recovery oil in U.S.A. in 1975. However, in the U.S.A., the oil production in 1980 using chemical processes accounted for only 0.4 percent of the total enhanced recovery oil. This may be attributed to several factors such as oil prices, chemicals costs, government taxes and size of investment.

In Egypt, a method such as steam injection can be utilized for several oil fields. At the moment, water injection is used for increasing oil recovery in some Egyptian oil fields. Addition of heat by hot water injection or only slugs of alcohol by alcohol slug injection is recommended in the present study for increasing ultimate oil recovery in such fields. It should be noticed, however, that injected water has to be treated to eliminate, for example, anaerobic bacteria, CO_2 and H_2S in order to avoid corrosion of the injection system, swelling of shales, or plugging of the reservoir.

Hot water flooding and alcohol slug injection methods seem to be promising. Figures 5 and 6 reveal that an oil recovery of more than 70% of residual oil saturation may be obtained when hot water at 212 ^{o}F is employed to displace an oil of 4.5 cp viscosity at standard conditions (within the range of experimental measurements).It is shown by Figures 13 and 16 that an oil recovery of about 75% of residual oil saturation can be obtained when butyl alcohol is used with a slug size of 25% of pore volume. These results are fairly confirmed by the findings of Latil et al (1980) who indicated that almost total recovery of oil may be attainable when using alcohol or combinations of alcohol.

Thus, the advantages of the alcohol slug method are evident. One should bear in mind that only small portions of pore volume (slugs) of alcohol are used in the injected liquid.

In this investigation, the available production of commercial alcohols in Egypt is recommended to be extended in order to meet the enhanced oil recovery needs. This may be attained by increasing alcohol production by means of petroleum conglomerates and/or expanding the domestic alcohol fermentation capacity. The capacity of production of alcohols from molasses and other raw materials such as wood and corn starch should be increased. Nevertheless, in addition to the local production, alcohols can be imported from other producing countries.

On the other hand, however, a method such as polymer flooding is not recommended for Gulf of Suez oil fields. This is rather attributed to the spread of shales which may react with polymers and plug the pores of producing formations. Surface active agents are also disadvantageous due to the high loss of surfactant by adsorption on the grain surface of reservoir rock as discussed above.

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