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Microbial Enhanced Oil Recovery: Research Studies in the Arabic Area During the Last Ten Years

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Abstract

More than ten strains of bacteria were isolated from Saudi and Egyptian crude oils and formation waters. Experimental investigation was carried out to identify the bacterial isolates, determine the compositions of the appropriate nutrients, conduct surface phenomena measurements. Based on the results obtained, it was found that presence of bacteria affected the solution phase volume, interfacial tension between oil and water, rock wettability, and relative permeability characteristics. These effects depend upon the bacterial type, nutrient type and concentration, salinity, temperature, composition of the crude oil.

A series of microbial displacement laboratory tests were carried out in homogeneous sandpacks and Berea sandstone cores using different types of bacterial solutions of glucose, sucrose and molasses based nutrients. The effects of nutrient type and its concentration, bacterial type, salinity, API, and permeability on oil recovery were investigated. Results show that the greatest oil recovery was obtained from activation of the indigenous bacteria by 1% molasses concentration. Some strains of bacteria were found to produce biogas, biosurfactant and biopolymers which increased oil recovery. The changes in sandpack permeability or API gravity have no effect on oil recovery.

Introduction

During the last ten years scientific and engineering efforts in the laboratories of King Saud University (Saudi Arabia) and Cairo University (Egypt) has established the basic start for Microbial Enhanced Oil Research technology in the Arab World. It is expected that Microbial Enhanced Oil Recovery (MEOR) may recover up to 30% of the residual oil under the Arab reservoir conditions. The actual recovery, however can only be determined through laboratory and pilot tests under field conditions. A new technology should be developed to apply MEOR successfully.

Microbial enhanced oil recovery (MEOR) technology is the process of introducing or stimulating viable microorganisms in an oil reservoir for the purpose of enhancing oil recovery. Although several attempts have been made to describe the MEOR process, no experimental or theoretical model has yet fully incorporated all of the factors that strongly affect the mechanisms of oil displacement, growth and transport of bacteria in porous media.

Many species of microorganisms produce gases such as carbon dioxide, nitrogen, hydrogen and methane that could improve oil recovery by increasing pressure and by reducing the viscosity of the crude oil that improve the mobility ratio. Some other species produce acids that can improve permeability of the reservoir rocks thus improve oil recovery. Microorganisms produce bio-surfactant can decrease surface, and interfacial tension between oil and water, which causes emulsification.

Several research studies in our Laboratory[1-18] have shown, that MEOR is a potentially effective technology for increasing oil recovery through the improvements in interfacial forces, wettability characteristics, displacement tests and modeling of the process.

Role of Microorganisms on Interfacial Forces, Phase Variation and Rock Wettability

Our recent studies[4-7, 10-12] were performed to investigate the effect of biochemical's from microorganisms, originally present in the crude oils, on the interfacial forces, phase variation of oleic/aqueous systems and rock wettability. In some of these studies,[4, 6, 7] it was found that interfacial and surface tension was markedly affected by nutrient type and concentration (see Fig. 1). This effect depends on the temperature at which the tests were carried out. In another studies,[10-12] two Egyptian crude's were used, one of them contained bacteria of *Clostridium* type and the other contained *Bacillus* type. The investigators found that, for each crude oil, the phase variation and interfacial tension was affected not only by the bacterial nutrient type and concentration but also by salinity, temperature and time of contact between the crude oil and the nutrient used. The effect of temperature, as an example, on the phase variation is shown in Figs. 2 and 3. These figures indicate that this effect depends on the type of crude oil used.[10]

The effect of microorganisms on the rock wettability was presented by Sayyouh and Al-Blehed.[5] They found that bacteria obtained from the crude oil (Safaniyah oil field-Saudi Arabia) had an effect on contact angles at both 23 and 50^{0}C. This effect depends on the type of nutrient used, type of rock sample, type of microorganisms and temperature of which the experiments were carried out (see Figs.4-6). During the growth of bacteria, nutrients are consumed and several metabolites such as gases, acids, alcohols, surfactants, polymers, etc. are produced. The type of metabolite depends on the type of bacteria and nutrient used. Therefore, this well affects the rock wettability characteristics. A better understanding of the mechanisms of wettability alteration is necessary for selecting appropriate bacterial strains, thus designing optimal operational procedures.

Effects of Nutrient Type, Bacterial Type, Permeability, API and Salinity on MEOR

Twelve, bacterial strains exist in some Saudi crude oils and formation waters were separated and classified.[6, 7] The effect of nutrient bacterial type, permeability, salinity and API gravity on recovery efficiency of the MEOR process were investigated. Some types of the separated bacterial strains produced gases and surfactants, while some other stains when cultured in sucrose media produced polymers. It was found that the most attractive performance, among different types of nutrients (such as molasses, glucose and sucrose) is the use of commercial molasses. It gives the highest oil recovery and the large oil-water bank (Figs. 7,8). The variation of pressure during the floods is shown in Fig. 9, which indicate the type of microorganisms that product more gases. Also, they found that the change in sandpack permeability or API gravity of the crude oil have no effect on oil recovery. A little variation in oil recovery was obtained by increasing water salinity from 4.2 to 10%. A study on the microbial characteristics and metabolic activity of bacteria for improved oil recovery in the Arabic area was presented by Sayyouh.[14] Results of some laboratory and theoretical studies of MEOR were discussed. These results indicated that some strains of bacteria were found to produce biogas, biosurfactants and biopolymers, which improved recovery efficiency during the MEOR process. It was concluded that although the application of MEOR may be limited due to the high formation salinity of the Arabian area, new biotechnology may solve this problem. In their studies, Abu El Ela *et. al.*[17, 18] showed that presence of 1% molasses concentration increases th relative permeability to oil. This effect depond on the crude oil type and the formation water salinity. Their results were discussed in the light of system phase variation, interfacial forces, wettability characteristics, hydrogen ion concentrations, viscosity effects, and mechanical and mineralogical analysis of the cores.

Modeling of Microbial Enhanced Oil Recovery

In their research, Desouky *et. al.*[8] developed one-dimensional model to simulate the process of enhanced oil recovery by microorganisms. The model involves five components (oil, water, bacteria, nutrient and metabolites), with adsorption, diffusion, chemotaxis, growth and decay of bacteria, nutrient consumption, permeability damage and porosity reduction effects. Comparison between the laboratory and simulated results emphasized the validity of the developed model, which was used to investigate the effects of indigenous bacteria, slug size, incubation time, residual oil saturation, absolute permeability and injection flow rate on oil recovery. The results show that more oil can be recovered by using *Streptococcus* with molasses as a medium. Oil recovery efficiency was sensitive to variation in concentration of injected indigenous bacteria, size of bacterial culture slug, incubation time and residual oil saturation. The change of absolute permeability, or injection flow rate has no effect on oil recover. This work was published in the journal of petroleum Science and Engineering.[9]

Environmental Effects of MEOR

Great effort is being expanded by investigators to understand the complex subsurface environment of a petroleum reservoir in relation to bacterial metabolism. The environmental control of MEOR is of great importance. It is necessary to prevent any adverse effects on the environment when applying this oil recovery method. One of the most important severe effects is the stimulation of indigenous sulfante-reducing bacteria which causes bio-corrosion in the oil fields. The effect of microorganisms, used in MEOR laboratory tests, on the corrosion of surface and subsurface equipment in oil fields was investigated recently.[16] Resulting photographs by binocular microscope show that corrosion may occur under the bacterial growth. This was a function of the bacterial type used. It was found also, that some species of bacteria cause minimum corrosion. Therefore, it was recommended to use certain types of bacteria for MEOR process that their bio product maximize oil recovery and minimize biocorrosion.

Possible Application of MEOR to the Arab Oil Fields

A study of the applicability of MEOR for recovering more oil under the Arab oil field conditions was presented by Sayyouh.[14] Based on the analysis of data obtained from more than 300 formations in seven Arab counties, (Saudi Arabia, Egypt, Kuwait, Qatar, UAE, Iraq and Syria), the possibility of the application of MEOR to the Arabian area was investigated. The basic parameters they studied include formation permeability, reservoir pressure and temperature, crude oil viscosity and API gravity, formation connate water saturation and its salinity (see Figs. 10-12).

It was found that some of the Saudi, Iraqi and Egyptian oil fields can be very good candidates for MEOR processes. Also, depleted oil fields in Egypt and Syria can be activated by injection of microorganisms, which can be beneficial in producing more oil. Recently a state of the art of the MEOR process was presented at the 6th international conference of MPM held in Cairo University.[15] It was concluded that more extensive laboratory and field research should be carried out in order to develop a technology in the area of MEOR under reservoir conditions of temperature, pressure, permeability and formation water salinity.

Conclusions

Extensive research is going on to day at Cairo University to improve the technology of MEOR that can be applied under some Egyptian reservoir condition. Growth of microbes insitu may have a number of potentially important interactions with the inorganic matrix and the oil present in a porous media. Because of the complex interaction among the microorganisms, the reservoir rock, the aqueous phase, and the oil, the complete elucidation of the role of the microbial activities is no simple matter and will probably require intensive research for several years.

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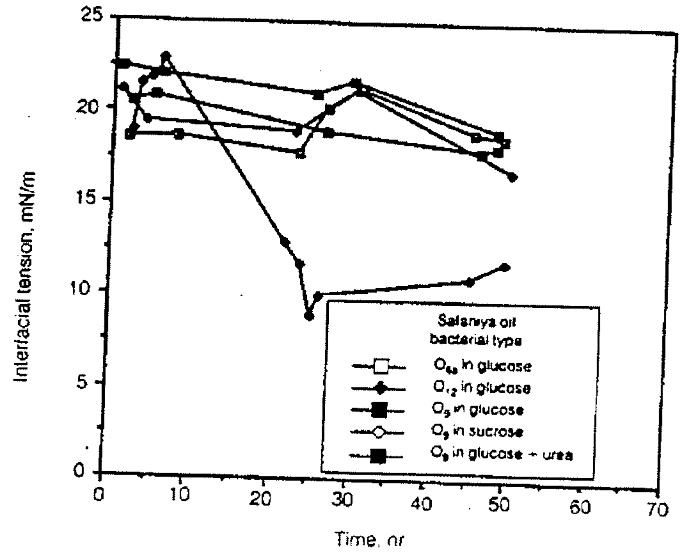

Fig. 1 . Variation of interfacial tension with time for different bacterial types.[7]

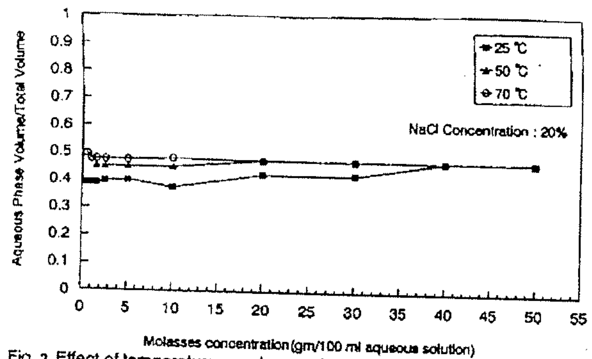

Fig. 2 Effect of temperature on phase volume for molasses solution and crude oil S using 20% NaCl (II)

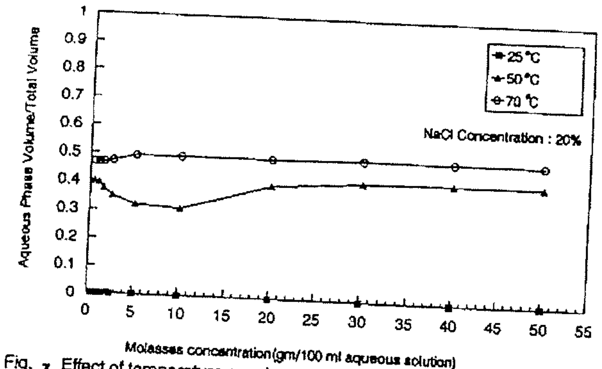

Fig. 3 Effect of temperature on phase volume for molasses solution and crude oil G using 20% NaCl (II)

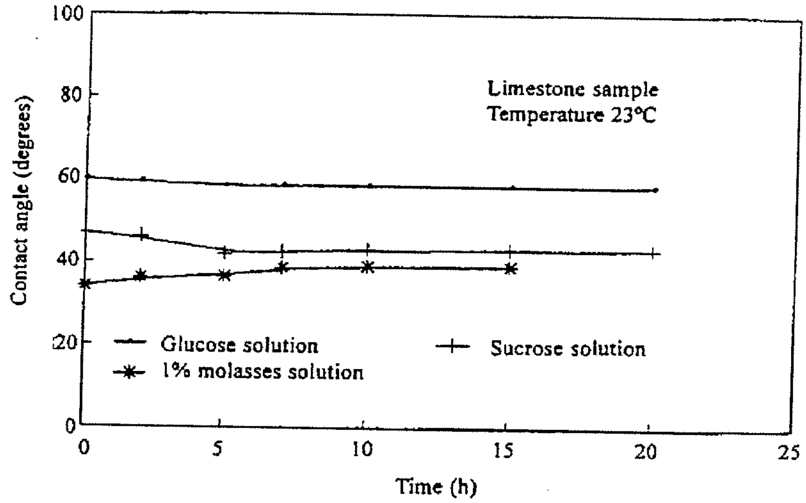

Figure 4. Contact angle vs. time for different nutrients at 23°C.[5]

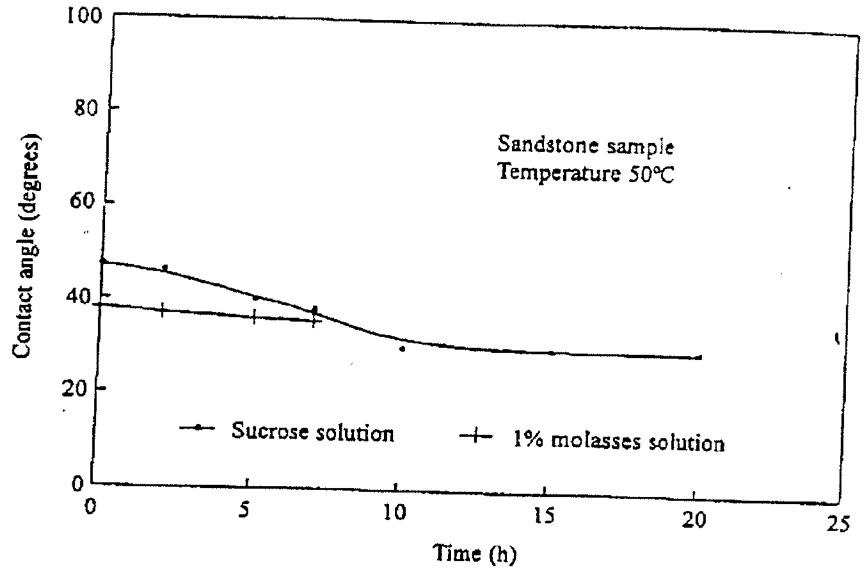

Figure 5. Contact angle vs. time for different nutrients at 50°C.(5)

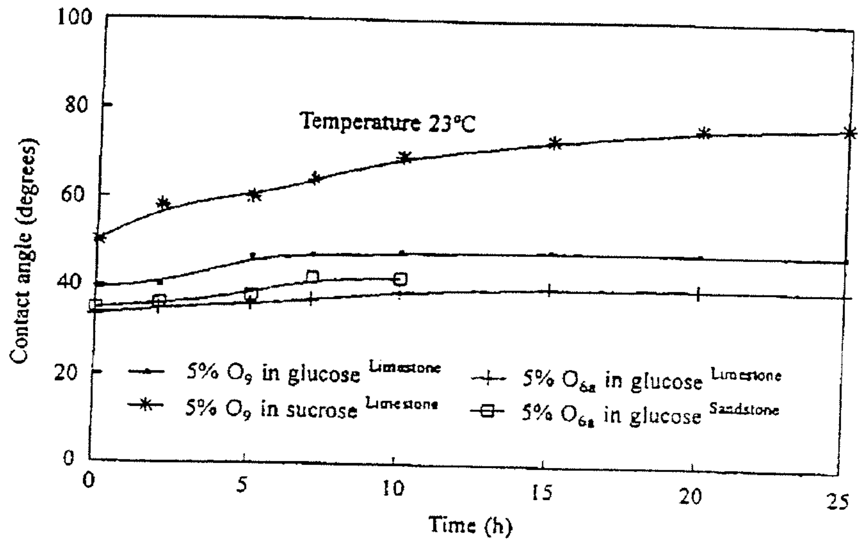

Figure 6. Contact angle vs. time for different bacterial solutions at 23°C.(5)

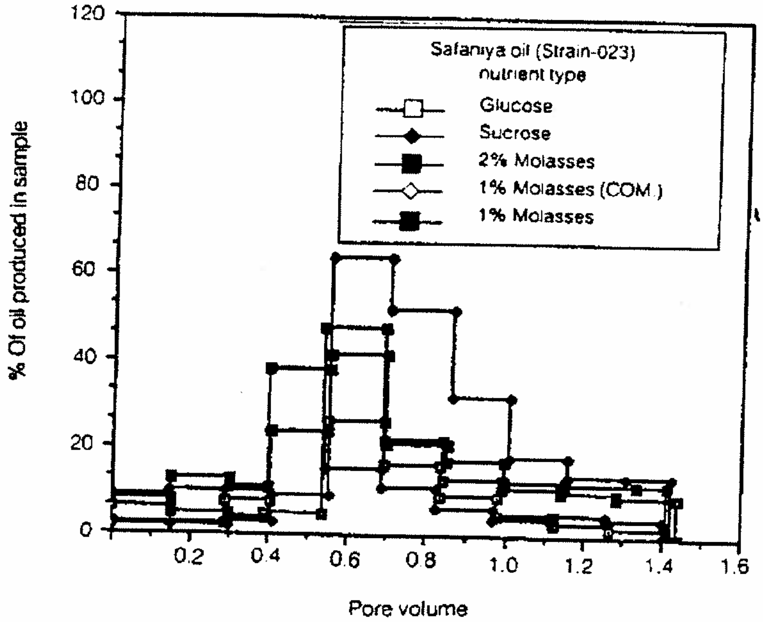

Fig. 7. Effect of nutrient type on % of oil produced in sample.(7)

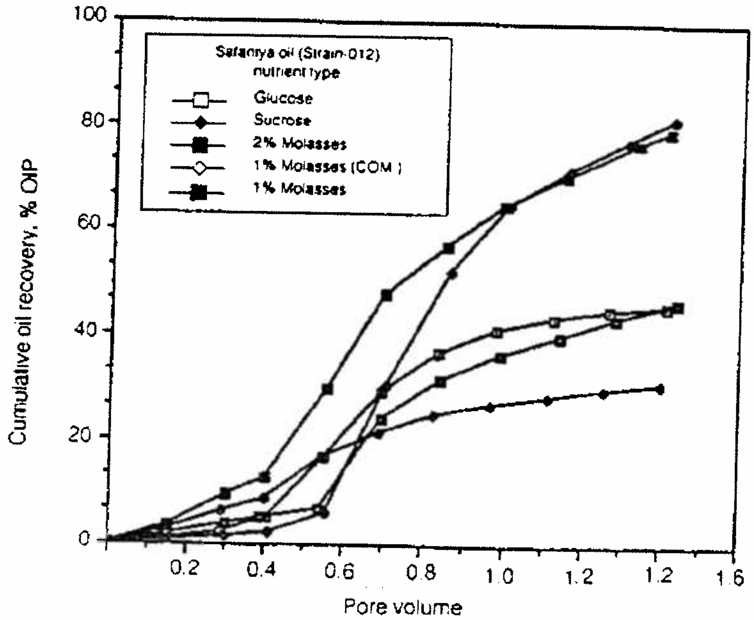

Fig. 8. Effect of nutrient type on cumulative oil recovery.(7)

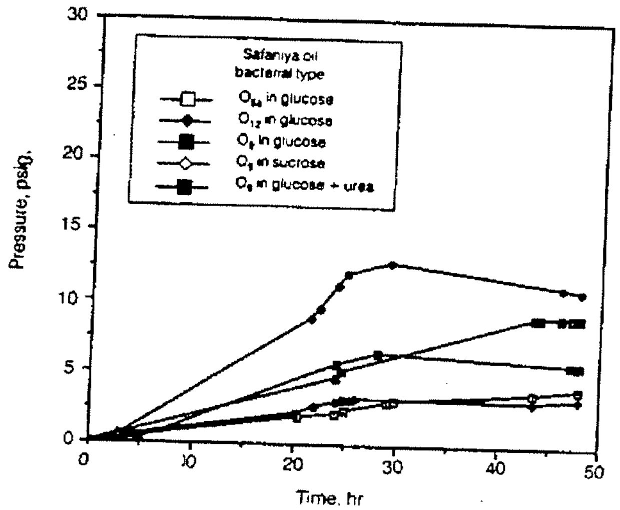

Fig. .9. Variation of model pressure during incubation period with time after injecting different bacterial types. (7)

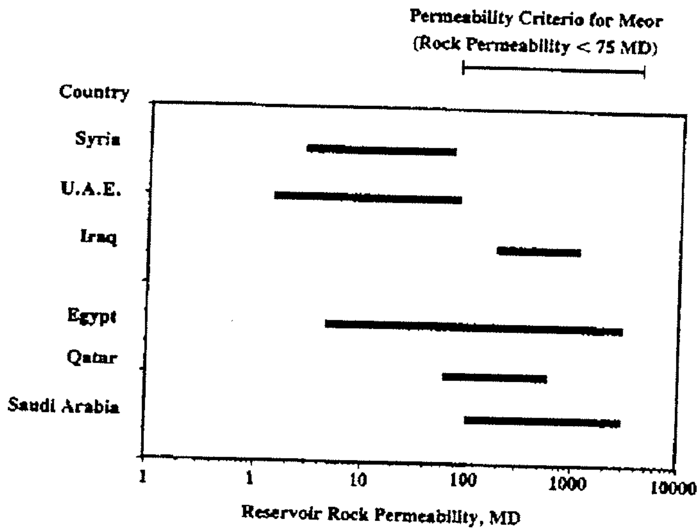

Fig. 10. Rock permeability for different Arab oil reservoirs (3)

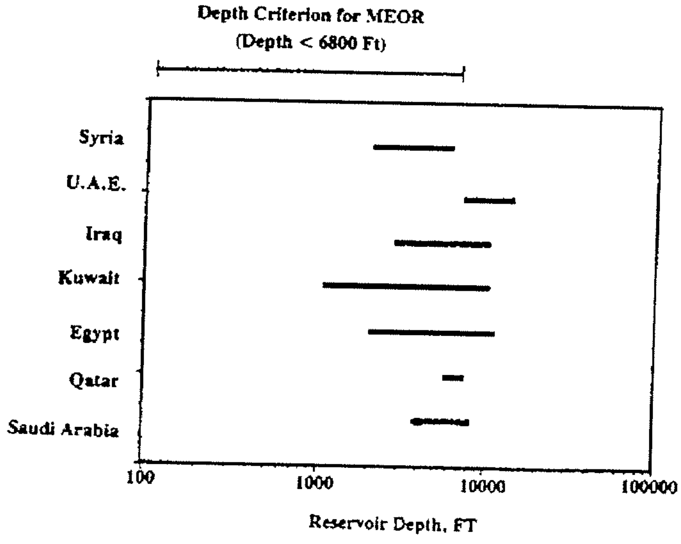

Fig. 11. Depth for different Arab oil reservoirs (3)

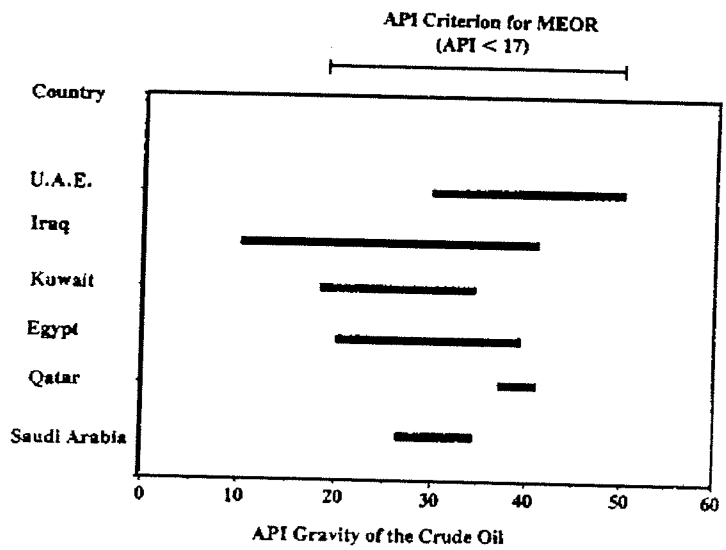

Fig.12. API gravity for different Arab crude oils (3)