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Enhanced Oil Recovery Techniques Miscible and Immiscible Flooding

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Abstract: The shortage of oil products in the recent years has evidently proved that Enhanced Oil Recovery (EOR) technologies require great attention in order to offer solutions to the impending energy demands in the coming years. This present study shows the details survey of EOR techniques of oil recovery processes and the possibility of producing more oil at a very cost effective manner in oil reservoirs. More specifically, this study deliberated on EOR techniques for offshore fields. The comparisons between miscible and Immiscible CO_2-EOR techniques and the general preview of CO_2 will be discussed.

Key words: Enhanced oil recovery, miscible and immiscible, CO_2 injection, reservoir

INTRODUCTION

Petroleum has supplied the world's energy demand during the last century and nowadays, the main concern of many countries and authorities is increasing the oil recovery from the ancient resources which is obviously increasing consumption of worldwide from the oil. Moreover, the amount of reserved oil products was based on the new discoveries which have constantly decreased in the last century, so the extent at which the recovery element of primary and secondary techniques from development fields will attract much attention to the energy demands in future.

TECHNIQUES OF OIL RECOVERY

During the long time of oil reservoirs, some of the common EOR techniques are usually applied in two phases or three phases, primary recovery which is typically implemented at the first stage of oil production using the nature energy to drive the oil to well, from then to the surface and recovered only 5-25% OOIP (original oil in place) (Thomas, 2008). In addition, it completed when the pressure is too low and the production rate is no longer economical (Ibid). Secondary recovery, it is applied when the primary no more effective and economical and the fluid, generally water injection, natural gas injection and gas lift are being employed (Ibid). The recovery factor of operations ranges from 6-30% OOIP rely on the oil and reservoir characteristics. Tertiary recovery also called (Enhanced Oil Recovery) it is applied in oil fields when they approached to end their life and it can produce 45-60% OOIP for the light and medium oil reservoirs but lower in the heavy oil reservoir (Ibid).

EOR processes consist of thermal recovery, chemical methods and gas injections. Microbial recovery the screening criteria for EOR selection are reported in the Table 1.

ENHANCED OIL RECOVERY METHODS THERMAL RECOVERY

Steam injection which is effective in recovering heavy viscous oil by adding heat into the reservoir in order to reduce the viscosity and this method can be implemented in shallow reservoirs (>1,500 m) of the heavy oil deposits which no effective to produce economically with primary or secondary recovery. In the situ combustion, the process application with light oil reservoir (>30 API^{O}). During thermal methods in 2008 the EOR production was around1, 252,000 bpd (1,0016,000 bpd prediction in 2010), therefore the best methods is the formal methods for the heavy oil and sands reservoir (Thomas, 2008).

Chemical recovery: Thomas (2008) stated that enhanced polymer flooding or surfactant flooding are injected to improve effectiveness of the recover efficiency, reduce the interfacial tension and increasing the water viscosity. The economic effect of crude oil sales in the world market has so much impact on EOR projects, thus the sustainability of EOR projects rely on the readiness and

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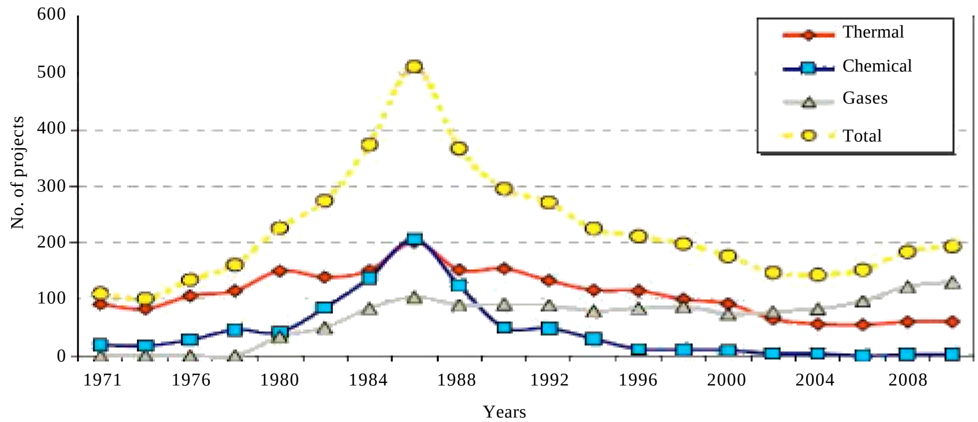

Fig. 1: EOR projects growth period in the United States. Oil and Gas Journal EOR (1976-2010)

Table 1: Enhanced oil recovery screening criteria functions of reservoir characteristics (Taber *et al*., 1997)

	Reservoir characteristics				
EOT process	Oil saturation (pore volume %)	Type of formation	Permeability (mD)	Depth (m)	Temperature (°C)
Steam flooding	>40	High porosity and permeability sandstones	>200	>1,500	Not critical
In situ combustion	>50	Sandstones with high porosity	>60	>3,833	>60
Gel treatment/polmer flooding	>50	Sandstones preferred can be used for carbonate	>10	>3,000	>90
Alkali surfactant polymer, alkali flooding	>35	Sandstones preferred	>10	>3,000	>90
CO_2 flooding	>20	Sandstones carbonate	Not critical if sufficient injection rate can be maintained	Appropriate to allow injection pressure> than MMP, which increase with temperature	
Hydrocarbon	>30	Sandstones, carbonates with minimum fractures	Not critical if uniform	>1,333	T can have significant effect on MMP
N_2, flue gas	>40	Sandstones, carbonate with few fractures	Not critical	>2,000	Not critical

eagerness of investors to deal with risks associated with EOR technologies and the stringent economic factors in order to have possibilities of having more chances and ability to entice investors.

It has been reported in US from the middle of 1980's to 2005 that EOR thermal and chemical projects steadily depreciates as it is illustrated in Fig. 1, so it is necessary to note that the efficiency of analysis on EOR has been impeded and usually hidden as a result it becomes unrecorded. The application of CO_2 gas injection technique as the main factor of EOR project has been experienced with significant increases from mid 1980's down to the year 2000, so this showed the efficacy and great potential of EOR technologies.

The first time in the most three recent years, starting from 2002 the number of EOR gas injection increases in the thermal projects. Since 2004 in the light oil reservoir and the High Pressure Air Injection (HPAI) increasing, however the thermal projects growing little at the same year. In fact, the recorded in 2008 that oil companies not give concern to EOR Chemical Methods not more than two projects (Stokka *et al*., 2005; Moritis, 2008). In other hand, the EOR chemical projects in U.S compared to overseas which is still not be recorded in the literature for various reasons which will be deliberate later on in this study.

OFFSHORE ENHANCED OIL RECOVERY

EOR techniques in offshore fields take less opportunity than onshores; the main barrier is pressure maintenance through water and gas flooding. The oil recovery data in North Sea illustrated in Fig. 3 (Zhou *et al*., 2007; Awan *et al*., 2008), as well as available options of EOR in offshore Malaysia (Hamdan *et al*., 2005). The rate of growth in EOR gas injection techniques indicates to widely resource and the costing less of CO_2 flooding from natural sources, also the pipeline of CO_2

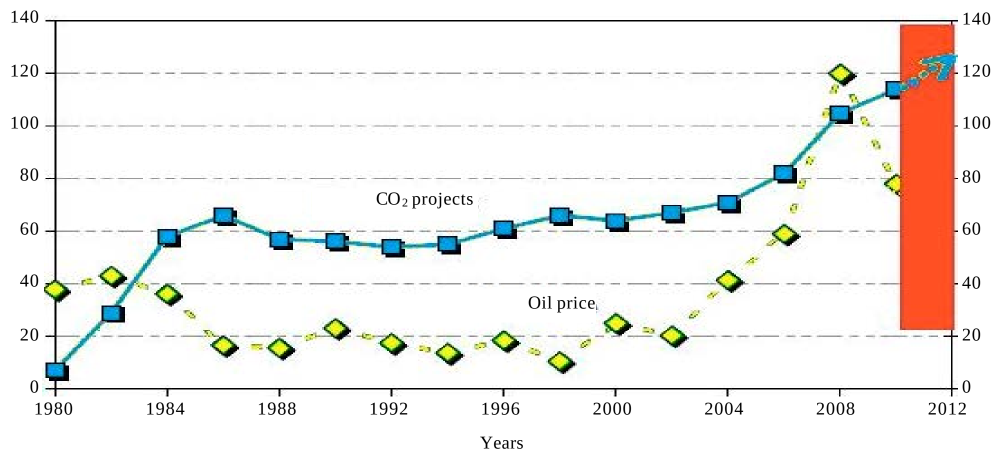

Fig. 2: CO_2 projects, oil prices evolutions in U.S and U.S. EIA 2010. Oil and Gas Journal EOR surveys (1980-2010)

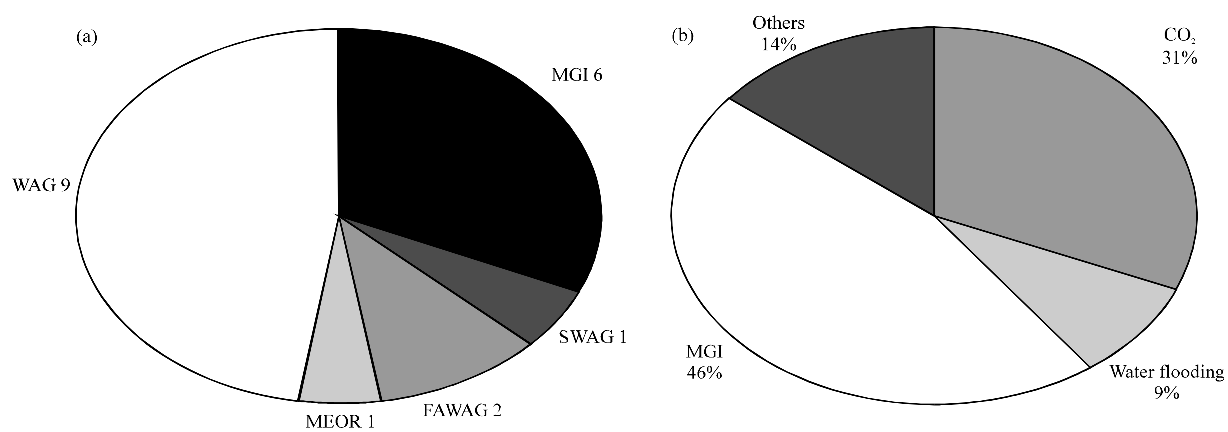

Fig. 3(a-b): EOR examples in offshore fields, (a) North Sea EOR (Awan *et al*., 2011) and (b) Malaysia EOR (Thomas, 2008)

ready to use in order to create EOR projects effective with less cost to be 20$US for barrel (Manrique *et al*., 2007). Despite of CO_2 pipeline system was established in 30 years (1975-2005), still noted to be necessary by time running whereas the tax, duty free and the cost of oil were interesting enough to guarantee prompt official system of the major drivers in the currently recorded (Hustad, 2009). However, competitive advantage is one of the factors militating against the privately owned pipelines, it is difficult to ascertain the potential benefits or contributions of the privates against the public owned of CO_2 pipeline in the coming years CO_2-EOR or storage market.

The average cost of crude oil during 28 years and the CO_2 projects in U.S evaluation in the Fig. 2. Crude Oil Price (2010) stated that the crude oil gained was recorded by Energy Information Administration and the advantage of oil price is to use as domestic crude oil refiner.As reference, the usage of crude oil prices in Fig. 2 was selected without delay for all months of June except that 2010 year (Crude Oil Price, 2010) March 2010.

Since 1990 to 2013 prediction, the oil recovery in U.S Gulf of Mexico (GOM) in deep and shallow waters showed in Fig. 4. The oil recovery in the Gulf of Mexico usually used whether water flooding or gas flooding. (Harun *et al*., 2008). In spite of forecasting which related to the area like (hurricane seasons), the Gulf of Mexico where it anticipated to keep on producing in deep water which depend on recovery processes instead of EOR projects (Close *et al*., 2008).

Closed the last examples, maximize the oil recovery and field production in offshore is under

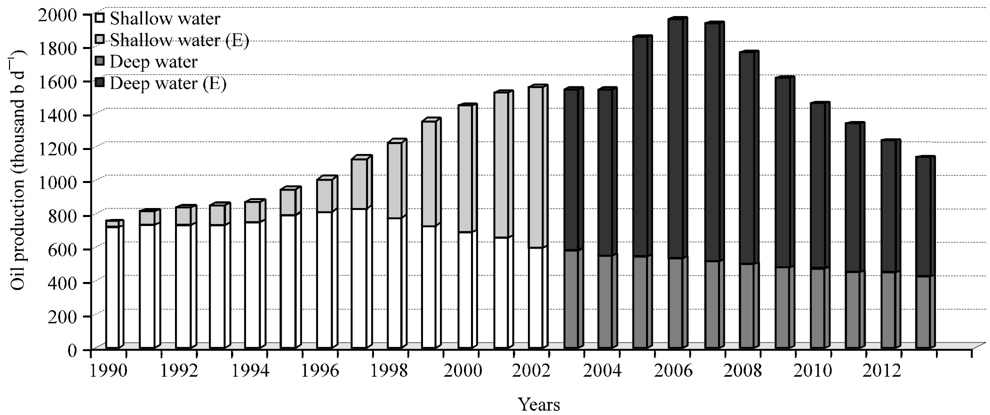

Fig. 4: Rates of oil production in U.S Gulf of Mexico in both shallow and deep water projects (Mineral Management Services, 2005)

Table 2: Comparison between miscible and immiscible CO_2-EOR methods (Stokka *et al*., 2005)

Projects	CO_2 miscible	CO_2 immiscible
Project start	Before or after water flooding	After water flooding
Project duration	Short (<20 y)	Long (>10 y)
Project scale	Small	Large
Oil production	Early (1-3y)	Late (>5-8 y)
Oil recovery potential	Lower (4-12% OOIP)	Higher (up to 18% OOIP)
Recovery mechanism	Complex	Simple
Recycling of CO_2 injected	Unavoidable	Avoidable
CO_2 storage potential	Low (0.3 tonn/bbl)	High (up to 1 tonn/bbl)
Experience	Significant	Limited

continuous improving the planes of water and gas flooding (Daltaban *et al*., 2008). Here below there are some tests of EOR methods for offshore and cases listed below:

- EOR/CO_2 reserve has been planed through the pervious short age (Hustad, 2009). Malaysia reported in Dulang Field EOR/CO_2 floods tested with produced gas (Spildo *et al*., 2009)
- The storage of CO_2-EOR in offshore fields depends on two ways, the anthropogenic sources which captured by produced gas or through CO_2 pipeline of offshore facilities, despite of high-pressure air injection (HPAI) in Ekofisk, North Sea but still does not test because of economical and technical causes (Stokka *et al*., 2005)
- In Mexico offshore fields, the possibility of air injection has been proposed (Bortolotti *et al*., 2009)

Even though the EOR chemical flooding in reported less in offshore fields in literatures, below are some examples:

- Norwegian North Sea reported that chemical flooding was tested in Snorre Field to optimize the gas mobility using FAWAG (Foam Assisted WAG) (ORME, 2009)
- Venezuela also reported that in Lagomar Field, Maracaibo Lake, the single-well partitioning tracers has been combined with Alkali-Surfactant-Polymer (ASP) before and after the injection of ASP and it has been worked (Manrique *et al*., 2007)
- Malaysia actually reported in Terengganu, Angsi offshore Field, the Alkali-surfactant (AS) that the evaluation succeeded by combining single-well partitioning tracers with injecting AS before and after the process (Othman *et al*., 2007). The offshore EOR implements obtained current concern in polymer method contain Colloidal Dispersion Gels injection or CDG (Moritis, 2008) here below few examples for test of polymer flooding test:
  - Polymer flooding reported in California offshore, Dos Cuadras Field (Dovan *et al*., 1990)

Implements of EOR in offshore field, the majority still in the beginning stages or with recent technology not economic enough. For that reason, the applications of EOR techniques are commercially foreseen to have no significant part at most one or two decades. Several barriers become the main obstacle faced the EOR applications in offshore fields like environmental regulations (e.g., chemical adds for EOR) or the surface facility (Table 2).

Some common issues with offshore EOR projects which makes less in energy markets, the high risk related to this kind of project, also the decreasing in the potential of the applications. There by the Water Alternative Gas (WAG) the combination of gas and water flooding in conjunction with injection gas or water shut-off (foams, gels).

CO_2-EOR METHODS MISCIBLE AND IMMISCIBLE

Researches still going on CO_2 miscible and immiscible techniques in the last decades, particularly the CO_2 flooding (Lake, 1998). ECL Technology (2001) reported that EOR can use CO_2 flooding miscible and immiscible displacement which will be obtained under certain pressure and temperature oil characteristics. To achieve the miscible flooding, under the reservoir good conditions (<1,200 m) and oil density (>22°API), both CO_2 injected and oil will mix completely inside the reservoir, in addition reduces the interfacial tension between the two material near to zero (from 2-3 N m^{-2}), this is due to the low viscosity of the fluid and convenient in transporting and production as well.The range of OOIP from 4 to 12% of OOIP.

However, in immiscible method, the CO_2 injected does not mix with the oil, the pressure will be too low, the density is too high, it acts for swelling the oil, its density decrease, improving in mobility, thereby the recovery will be growth, although the extra and heavy oil Reservoir comes from different fluid phase. The recovery range attains 18% OOIP. In EOR projects, miscible displacements are more popular than immiscible; despite of immiscible displacements could be more effective and significant if CO_2 potential is high at immiscible process with great level whereas in miscible is not implemented (Stokka *et al*., 2005).

However, there is some concern about the possibility of having asphaltene precipitation during CO_2 miscible flooding which believed to have a plug in well pore and decline in oil recovery, that is why it is necessary to investigate the condition of asphaltene precipitation for the oil-CO_2 system (Stokka *et al*., 2005).

Miscible and immiscible CO_2 projects: The recent study in Oil and Gas Journal (Koottungal, 2010) it was observed that EOR techniques have more important part among the oil production, particularly in the United States of America.

The recovery factor boosts reserves of the crude oil, the rate of reserves of 70 billion barrels. In 2010, the projects of EOR overseas are 316, the recovery of oil production is 1,627,000 bpd which means 2% form world total oil production today (84 million bpd) in detail:

- In US (+9 above 2008) reported 193 projects out of 316, the oil production 666, 000bpd (-17,000 bpd above 2008)
- Canada actually reports 40 projects (-9 above 2008), producing 356,000 bpd (-49,000 bpd above 2008)
- The production is much the same in 2008 605,000 bpd and the 83 projects reported in remaining worldwide (-7 above 2008). Despite of CO_2 projects are completely 124 in 2010, 303,000 bpd (+33,000) which is almost same for 2008, in consideration of 2008, 0.36% of the oil recovery universe and 19% of EOR

There are 114 projects announced in United States of America (+9 above in 2008), also in Canada were 6 projects, others remain in Brazil, Turkey and Trinidad, but more 21 projects in 2010 were decided, 12 of them using CO_2 projects of EOR-CO_2 usually depend on miscible technique (7 of 124), however, there was less interest in immiscible CO_2 technique, just (7 of 124) and the only great project in 2010 was in Turkey and produced 7,000 bpd.

The amount of EOR-CO_2 projects steadily rising since 1986 as it listed in Fig. 2. Although, its large amount in 2008 for immiscible EOR-CO_2 considering to the last trend which decreases in 2010. Even though the immiscible EOR-CO_2 is produced, treatment operation still high in 2010 and limited, it is about 19,200 bpd of 303,000 bpd from the total of EOR-CO_2 production which not similar in 2008.The initial attempt for CO_2 flooding improved in 70s in Texas, (Permian Basin), done it by Chevron.

In SACROC unit 22 mile distance, this unit use to recover the CO_2 via flue gas with employing four gas plant to dehydrate and transfer it. In the present time 31 project work by Oxy (Occidental Petroleum Corp.), started 28 in 2008, also the Denbury Resources effective (13 in 2008) with CO_2-EOR (Fig. 5).

In fact, recently Wasson Denver field with 25,274 bpd high production of CO_2 in Oxy project, whereas in the EU, no activation of EOR-CO_2 applications. The reason for this is the economical cost of CO_2, besides, the source with cost less at the injection location. Comparing to CO_2 implement in Texas such as Permian Basin recently, where in 2009 (83% of CO_2 comes from a natural source and transfer for treatment of EOR. Particularly, the applications of CO_2 are not cost effective in offshore work (Doll *et al*., 2009).

Canada reported CO_2 in Weyburn project, captured form gasification plant site in North Dakota and supplied via pipeline to Weyburn where EOR used. The present oil production is 16,500 bpd with 1,600 Keaton/year of CO_2

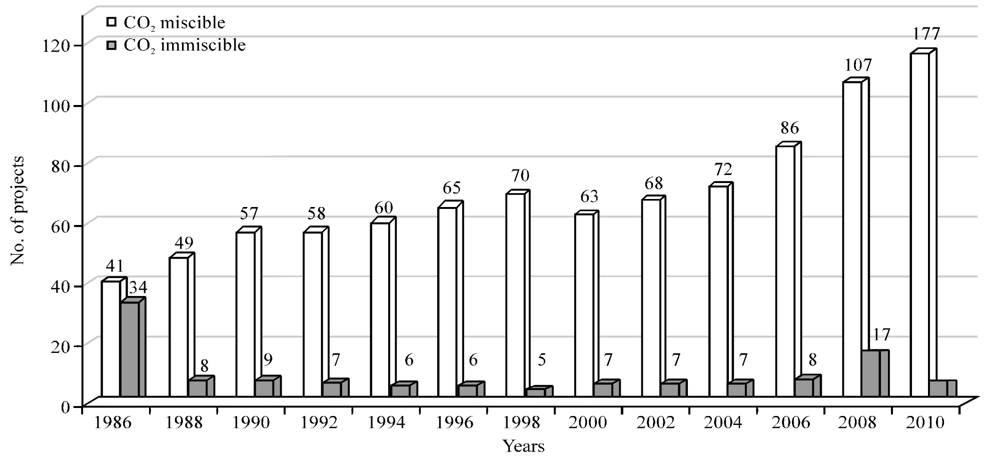

Fig. 5: EOR-CO_2 projects miscible and immiscible (1986-2010) (Koottungal, 2010)

reserve in the reservoir and the injected rate is 67%, moreover it expected to recover 122 million bales additional oil and expand the life of the field by 20-25 years, thereby the recovery increasing to 34%.

CONCLUSION

A CO_2-EOR proposed interesting chance for upstream and downstream strategy for all businesses, however they achieve deployment needs good study to secure CO_2 locations which depend on geological knowledge of formations. Currently there are only plans but no applications for CO_2-EOR in Europe which conduct to have lack in sources of CO_2 with low cost. Thermal recovery, with steam injection considers as a preferred EOR method for heavy oil reservoirs, nevertheless, in North and South Dakota, still the HPAI field projects focus on the low permeability of the rock in Montana formation. The major reason for the deployment and understanding of information base on the design of HPAI and risk reduction which act the number of cases dissemination in full field projects, although of achievement in recent projects. CO_2-flooding (continuous or WAG mode), continues to be the efficient oil recovery process offshore field preferred in gas condensate reservoirs or rural locations which no opportunity to reach gas market easily.

The EOR projects with N_2 injection look to be decreased excluded Mexico in Campeche Bay Area due to large instated of N_2 capacity production. Chemical EOR methods during recent time in recovering crude oil in the world, like China has been developed with high production; however the planning of SP and ASP implement in Canada and US with pilot scale. Polymer flooding application in Canada with heavy crude oil and offshore fields, but the chemical is anticipated to have a high effect of oil production in the world at the recent time whereas if it is at commercial standard. Chemical EOR flooding technologies such as SP or ASP are beginning to have a high interest from the operators in South America like Argentina in El Tordillo Field successful experience. As a result, projects on chemical methods are not expected to have a global effect on oil production in the future.

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