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Overview of Air Injection Potential for PEMEX

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Abstract

Air injection has proven successful in applications to non-fractured reservoirs and its use, in the 1990's, was extended beyond its original heavy oil applications to include light oil reservoirs having high reservoir temperatures and appropriate oil compositions. No studies or field applications of this technology in naturally fractured reservoirs have, however, been documented in the literature.

Since most of Mexico's current oil production and reserves, about 97 and 91 percent respectively, come from naturally fractured carbonate reservoirs; a means for obtaining high recovery in these reservoirs is needed. Water is limited in availability and nitrogen and other injectants can be quite expensive, so it was decided to assess the potential of air injection technology in such applications to Mexican naturally fractured reservoirs. An overview of the potential of this process is presented in this paper, as well as an analysis of the impact that air injection could have when compared to alternative secondary and enhanced oil recovery technologies currently feasible for application in Mexico.

Details are also presented of an ongoing project that aims first to investigate, through experimental, theoretical and numerical simulation work, the feasibility of injecting air in naturally fractured carbonate reservoirs. This comprises selecting a reservoir for evaluation, preparing a thorough reservoir description, including a description of the fracture system, and developing a concept by which gravity forces can mitigate the effects of the fractures. This paper will also describe plans to implement, monitor, and evaluate a pilot test in a Mexican reservoir if the process looks feasible.

Introduction.

Air injection, AI, was extended beyond in-situ combustion heavy-oil applications to include light-oil reservoirs[1] having high temperatures and appropriate oil compositions. The principle difference between in-situ combustion and light oil air injection is that in the latter, the combination of high temperature and appropriate oil compositions leads to autoignition when the air contacts the oil. This has safety implications and leads to a more robust process that propagates well in the reservoir and insures that all of the oxygen injected is consumed.

Detailed experimental studies[2,3] on air injection conducted in the 1990's, due to the renewed interest brought by successful applications of this technology in light-oil reservoirs, yielded a better understanding of the process and its applications. In light of this new knowledge, it is possible to design and operate successful air injection projects.

Evaluation of air injection as a technique for a particular reservoir involves answering two questions: 1) if air is injected, will the crude autoignite and the oxygen therefore be consumed? and 2) if air is injected, will oil be produced from the wells that are available? The first question is answered in the laboratory by two laboratory tests: the combustion tube test and the accelerating rate calorimeter test. However the second question depends on the ability to sweep a significant portion of the reservoir and to get that oil to a production well. In the case of highly fractured reservoirs, this becomes problematic.

Assessment of Air Injection Potential for México.

Target Oil for Secondary and Enhanced Oil Recovery.

Naturally fractured reservoirs, NFR, in Mexico currently account for about 91 and 97 percent of Mexico's proven oil reserves and production, respectively. Almost all of the NFR are located in the Southeast Basins: Chiapas-Tabasco, onshore, Litoral de Tabasco and Sonda de Campeche, offshore, and produce from carbonate formations of Mesozoic age, discovered in the early seventies, late seventies and mid eighties respectively.

Table 1 provides information on the original oil in place[4], OOIP, oil production and reserves as of beginning 2004, for each of the Southeast basins and amounts corresponding to the NFR are given. It can be seen from this table that there were 95.2 billion stock tank barrels, BSTB OOIP and with cumulative oil production of 23.8 BSTB and proven remaining reserves of 12.8 BSTB, the target oil for secondary and enhanced oil recovery, S&EOR, would be 58.6 BSTB.

Main features of the naturally fractured reservoirs of the Southeast basins.

Main features and properties of the Southeast basins reservoirs[5] are given in Table 2. The distribution of the S&EOR target oil in these basins, in terms of API gravity is provided in Table 3. These tables indicate that depths of the naturally fractured carbonate reservoirs vary from 1000 up to 6500 meters below sea level, mBSL, as we move from the Sonda de Campeche into the other two basins. Reservoir thickness and structural relief are in general moderate to high. Fracture permeability of the offshore basins reservoirs is in general high; these features, favor gravity segregated flow in these reservoirs. The permeability of the fractures in Chiapas-Tabasco reservoirs and in some reservoirs of Litoral de Tabasco is relatively low; matrix permeability is also in general low. Total porosities, fractures plus matrix, are moderate in most of the offshore. In some of the onshore reservoirs, such as the Chiapas-Tabasco basin, it is about 3-4%.

Most of the S&EOR target oil is in the Sonda de Campeche and Chiapas-Tabasco basins, 68 and 29% respectively, see Table 2. In **Sonda de Campeche**, 8% of the oil is heavy-oil with 12 °API gravity, 79% is medium, with an average gravity of 23 °API and 13% is light with 33 °API, see Table 3. In **Litoral de Tabasco**, with only 3% of the total target oil, 46% is medium gravity oil with 25 °API gravity, and 54%, is light, averaging 36 °API. In **Chiapas-Tabasco** all of the target oil is light-oil with an average gravity of 35 °API. Most of the NFR in México that are candidates for the application of S&EOR processes contain medium to light oils and could be regarded as high pressure and high temperature reservoirs according to air injection operation standards[6].

Screening Criteria for Air Injection Projects.

Screening parameters developed for heavy oil in-situ combustion projects[7] do not apply to the reservoirs considered here. Even more, screening criteria recently presented for light-oil AI, prospects[6,8,9] do not fully apply to NFR. Such criteria, however, provide useful guides for screening reservoirs such as those found in the Southeast basins and will be reviewed here.

The air injection process can operate in one of two oxygen-oil reaction modes as defined by testing samples of the oil and reservoir rock in the accelerating rate calorimeter: Low temperature oxidation (LTO) and high temperature oxidation (HTO). In HTO, all the reactions lead to bond scission and conversion primarily to CO_2 and water. However, in the LTO mode, reactions can result in either bond scission or oxygen addition, depending primarily on oxygen flux. The oxygen addition reactions do not yield as much heat of reaction as bond scission and produce oxygenated products which can act as surfactants causing emulsion problems. Moore et Al.[9] indicate that the key to success is to design the process for operation in the bond scission mode and point out that for many high-pressure light-oil reservoirs, the process tends to operate in this mode if given enough oxygen flux. They also indicate that successful operations for heavier oils require that combustion reactions develop in the high-temperature-oxidation mode, HTO, more than 450°C because the heat is a necessary component of the displacement process which is often not the case with light oils. Sufficiency of operation in the LTO mode for light- and medium-gravity oils is also indicated elsewhere[3,6,10].

The reaction mode is clearly determined in the accelerating rate calorimeter and the combustion tube experiments but can be different in the reservoir due to differences in oxygen flux, as the combustion zone propagates away from the injection well, and to heat transfer to the porous medium. Which mode will be in evidence is difficult to predict in fractured reservoirs because of the difficulty of knowing the exact fracture geometry and therefore rates of flux of the injected air. However, analysis of the produced gases and fluids can be used to identify the mode of operation that was actually taking place in the reservoir. Laboratory screening[6,9,10,11] of potential candidates, under reservoir pressure and temperature conditions, is therefore required. Lab screening also provides kinetic data of the oxidation for use in the numerical simulation of the process, and parameters that are important for a preliminary assessment of the economics of field projects, such as air requirements and air/oil ratios.

Turta and Singhal[8] give insights on the expected effects of very pronounced heterogeneities, such as natural fractures, in the reservoirs. They indicate that operations under gravity-aided vertical flooding may be the viable option for reservoirs with extensive fracturing. Benefits of vertical air flooding in homogeneous formations are documented elsewhere.[3,12] High structural relief or thickness and appropriate vertical permeability[6] are desirable features in the reservoirs for implementation of this mode of operation.

Potential of air injection in the naturally fractured Mexican reservoirs.

Nelson has categorized fractured reservoirs into four types.[13]

-Type I: Fractures provide the essential storage capacity and permeability in a reservoir. The matrix has little porosity or permeability.

-Type II: Rock matrix provides the essential storage capacity and fractures provide the essential permeability in a reservoir. The rock matrix has low permeability, but may have low, moderate, or even high porosity.

-Type III: Fractures provide a permeability assist in an already economically producible reservoir that has good matrix porosity and permeability.

-Type IV: Fractures do not provide significant additional storage capacity or permeability in an already producible reservoir, but instead create anisotropy.

Initially, reservoirs were sought that would exhibit Type II or greater behavior and the plan was to try and design a process that would recover oil from the matrix using gravity drainage to ameliorate the effects of the fractures. However, upon examination of cores from candidate reservoirs and production characteristics, it was found that most of the reservoirs in the Chiapas-

Tabasco basin exhibited Type I-II behavior. This means that essentially all of the remaining producible oil is in the fractures and that the recovery process will need to be designed to deal with that fact.

Estimated benefits of AI.

The expected recovery from air injection can be bound by two processes and the actual results are expected to lie somewhere between the two. For immiscible flooding and the LTO mode of the process, the expected oil recovery would be at least as much as that expected from nitrogen injection and can be simulated in that way. Benefits of air injection then would be at least the savings in nitrogen separation costs.

Additional oil recovery would be expected however, as the result of the induced thermal process. As reservoir pressure increases either partial or total miscibility of the flue gases with the oil may develop, with the corresponding oil recovery benefits. However, the benefits of miscibility may be offset by the costs of compression as the reservoir pressure increases. This is also true if nitrogen injection is intended under miscible conditions.

Feasibility Study on Injecting Air in NFR for EOR.

Since no studies, or field experiences on air injection in NFR have been documented, PEMEX Exploration and Production, PEP, and BP launched a joint technology project aiming at proving the feasibility of using air injection as an EOR process in these reservoirs.

Main objectives of the project are to develop the understanding of the technological requirements for the application of air injection technology to fractured reservoirs and to carry out studies that can bring about the most effective and efficient recovery of hydrocarbons using air injection technologies. Activities considered in the project are:

1) Reservoir screening: based on characteristics, infrastructure and reserves.
2) Laboratory testing, theoretical and numerical analysis
3) Static and dynamic reservoir characterization.
4) Reservoir project design, including prediction of additional oil recovery.
5) Facilities project design, including injection and production side considerations to ensure safe operations.
6) Field test: implementation, safety, operations, monitoring and evaluation.

The field test will be implemented if the laboratory and simulation results show it is technically and economically justifiable.

As mentioned above, the monitoring of the field test will be important both to evaluate the results of the test and to insure safe operations. A monitoring program is being designed that will use analyses of the produced fluids to diagnose the operation of the combustion process as well as to ensure that oxygen does not find its way into production facilities.

Status of the PEP-BP Joint Technology Project.

The project initiated in October 2002 with the screening of reservoirs. The Cárdenas field, located in the South Region of the Chiapas-Tabasco basin, was selected. It is a faulted structure producing from two carbonate fractured formations of Jurassic and Cretaceous ages. The Southwest Block, in the Upper Jurassic Kimmeridgian formation, was selected for possible pilot testing. OOIP and cumulative production are 863 and 230 MMSTB respectively. Depth of reservoir top is 5,090 mBSL and structural relief is high. The average thickness of the formation is 420 m and total porosity is 5%; fracture and matrix permeability are 10-100 and 0.1-1 md respectively. Reservoir temperature is145°C and initial, bubble point and current pressures are 649, 308 and 350 Kg/cm2 respectively. The gravity of the reservoir oil is 40.1 °API. Laboratory testing, ARC and Combustion Tube tests, were carried out at the U. of Calgary: the spontaneous ignition capability of the reservoir oil was confirmed. The static characterization of the reservoir was completed and dynamic characterization is underway.

Conclusions.

1. Target oil for S&EOR in naturally fractured Reservoirs in México is 58.6 BSTB.
2. Most of the target oil is in the Sonda de Campeche and Chiapas-Tabasco basins: 94% of the oil is medium and light-oil. Reservoirs could be regarded as high pressure and high temperature reservoirs, according to air injection project standards.
3. Air injection in naturally fractured reservoirs seems appealing and feasible as S&EOR method in medium and light-oil reservoirs.
4. Expected outputs of AI in medium and light-oil NFR are: Oil recovery would be at least as much as that expected from nitrogen injection. Benefits would be at least the savings in nitrogen separation costs. Additional oil recovery would be expected from the induced thermal process.
5. No studies or field experiences have been documented on AI in NFR. The joint technology project launched by PEP and BP aims at understanding the technological requirements for the application of AI technology to NFR and establishing the most effective and efficient recovery of hydrocarbons using this technology.
6. To date results of the PEP-BP joint technology project are encouraging.

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Table 1. S&EOR Target oil in naturally fractured reservoirs of the Southeast basins

Basin	**Original Oil in Place (MMSTB)**		**Cummulative Oil production, (MMSTB)**		**Proven Oil Reserves, (MMSTB)**		**S&EOR Target Oil in NFR, (MMSTB)**
	Total	**NFR**	**Total**	**NFR**	**Total**	**NFR**	
Sonda de Campeche	64,386	63,320	16,624	16,511	9,217	9,097	37,713
Litoral de Tabasco	2,640	2,640	183	183	566	566	1,892
Chiapas Tabasco	36,430	29,264	8,785	7,126	3,377	3,097	19,041
TOTALS	**103,457**	**95,225**	**25,592**	**23,819**	**13,160**	**12,760**	**58,646**

Table 2. Main features of reservoirs in the Southeast basins

Basin	**Depth, (mBSL)**	**h, (m)**	**Struct. Relief**	**Secondary Porosity Features**	**f Total (%)**	**K Fracs (md)**	**K Matrix (md)**	**Initial Pressure (Kg/cm^2)**	**Oil Gravity°API**	**Reservoir Temp. (°C)**
Sonda de Campeche	1000 to 4400	200 to 1200	High, up to 2000m	Highly fractured	8 to 12	2000 to 5000	1 to 10	270 to 700	12 to 36	95 to 160
Litoral de Tabasco	4400 to 6200	60 to 200	Moderate	Moderate to highly fractured	5 to 11	30 to 1500	1 to 10	650 to 1000	25 to 41	134 to 161
Chiapas - Tabasco	4500 to 6500	150 to 900	High, up to 2000m	Moderate to low fractured	3 to 7	30 to 175	0.1 to 5	370 to 995	30 to 44	123 to 165

Table 3. Distribution of Volumes of Target Oil by API Gravity

Oil Gravity (°API)	**Sonda de Campeche**		**Litoral de Tabasco**		**Chiapas Tabasco**	
	Volume (MMSTB)	**Average Weighted API**	**Volume (MMSTB)**	**Average Weighted API**	**Volume (MMSTB)**	**Average Weighted API**
Less than 15	3292.3	12	0		0	
15-30	29634.9	23	737.1	25	0	
30-45	4733.7	33	850.4	36	16052.6	35