Mature Oil Fields Need Tax Incentives – The Mexican Case

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Mature oil fields, sometimes referred to as ‘brown’ fields, are essentially fields that have past their peak production potential and are on the decline. According to a recent IHS report **[1],** about two-thirds of the world’s crude oil production comes from mature fields, a consequence of reserves depletion. In the case of Mexico the corresponding estimate is near 60%. Continuing to add reserves is the only way to maintain and increase production and the only two sources to replace them are *exploration* and *improved /enhanced oil recovery or IOR/EOR.*

Exploration finds new reserves which often take years to put on stream. IOR/EOR has the potential to generate fresh reserves by complementing the natural energy of the resources already discovered and extending field production for years. Today, development of a new field generally would include IOR (gas or water injection) from start-up, to maintain the pressure of the reservoir. Historically, EOR would come later on to recover an additional 10-20% of the remaining oil in place. This is the technology associated with the exploitation of mature fields. Unfortunately, EOR does not seem to attract a similar level of interest as exploration in many countries. To put this into perspective, the global contribution of exploration has been about 10 billion barrels (Bbo) of new oil reserves per year over the last five years whilst an increase of just 1% per year in recovery factor from EOR could bring 80 Bbo of fresh reserves per year, but only a fraction is being realized.

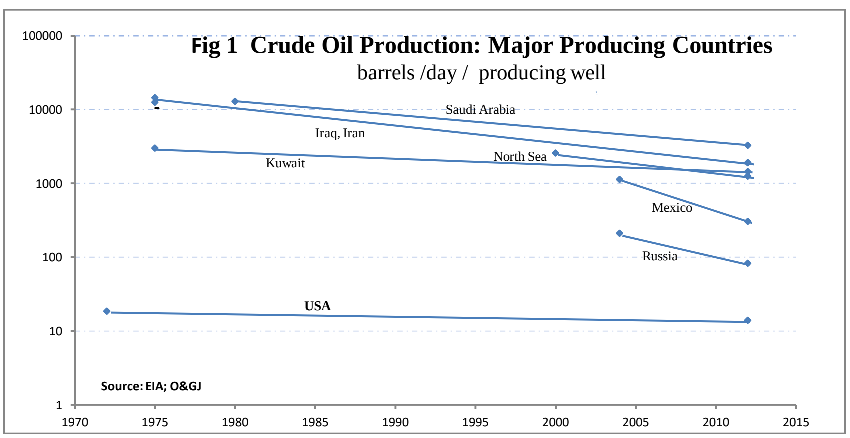

Fig 1 Crude Oil Production: Major Producing Countries
barrels /day / producing well

Production from several major oil producing countries, including Mexico, is on the decline (**Fig. 1**). Six countries (U.S., Venezuela, Canada, China, Trinidad, and Indonesia) already have broad field experience with EOR [**Table 1**] while others (India, Saudi Arabia, Oman, Malaysia, to name a few) are just beginning the cycle. Today, less than 3% of world crude oil production comes from EOR – the U.S. has the highest EOR production, about 12% of its domestic production. Mexico is one of the largest oil producers but has had very limited field experience with EOR – barely one project (CO_2 in Sitio Grande field) so far. However, its recent reforms give strategic importance to developing mature fields.

It is often said that EOR has not been the preferred investment choice of the international oil industry primarily because the economics of finding new reserves, notwithstanding access challenges, versus generating fresh reserves from existing fields have always favored the former. However, global finding and development (F&D) costs for new reserves have been on the increase, doubling from $11 per barrel in the 1990s to about $22 today [**2, 3**]. The high end values refer to deepwater U.S. Gulf of Mexico. On the other hand, capex requirements for implementing EOR are in the range of $3–15 per barrel of fresh reserves.

From a technological point of view, there are three main types of EOR and each has its poster-child (**Table 1**): *Thermal* EOR uses steam as its most popular technology; *Miscible* EOR alternates between CO_2 and natural gas as the preferred injection fluid, depending on availability; and *Chemical* EOR which utilizes principally surfactants. Polymers are generally used as viscosity buffers in water injection projects. Today, steam and miscible gases together account for 86% of all active EOR projects. While interest in chemical EOR is at its lowest point – only three surfactant projects are now active in the U.S. versus more than 200 in the mid 1980s [**4**]. Acceptance of chemical EOR methodologies quickly fell-off because of an inexplicable mix of successes and failures, some even in the same field. The process was not fully understood at that time. We have surpassed that stage and now have a better hold on the DNA of the reservoirs. Nonetheless, industry still remains reticent about the experience. Biological EOR is still in an early stage of field development, and the few active projects are mostly pilot scale.

Table 1 Active Field EOR Projects Worldwide

Thermal		Miscible Gases		Chemical		Biological	
	No. of Projects		No. of Projects		No. of Projects		No. of Projects
Steam	145	CO_2	133	Polymers	24	Microbial	3
Combustion	15	Hydrocarbon	37	Surfactants	3	Nitrates	2
Hot Water	2	Acid Gas	1				
Total	162	Total	171	Total	27	Total	5

Notes: A total of 365 projects across: Argentina (1), Brazil (8), Canada (39), China (36), Colombia (2), Egypt (1), Germany (9), India (3), Indonesia (2), Mexico (1), Netherlands (1), Norway (2), UK (1), Trinidad (11), U.S. (200), and Venezuela (48).

Source 'Worldwide EOR Surveys', Oil and Gas Journal, May 5, 2014.[**4**]

In terms of costs, advanced waterfloods (AWFs) using nitrates, low salinity water, and cyclic surfactants are the lowest, while CO_2 and steam injection are the highest. Opex costs are very important in EOR projects not only because of material costs (CO_2, chemicals, etc.) but, in addition, projects are applied to marginal fields, already nearing their economic limit. These facts are key determinants that need to be addressed in specialized contractual agreements proper to EOR and mature fields so companies/investors can start thinking of making EOR part of their portfolios.

The main objective of EOR is to incorporate fresh reserves from known reservoirs by increasing the recovery factor. Historically, recovery factors have been low across mature fields, with an estimated worldwide average of 22-25%. The North Sea has an average recovery factor nearing 50% while the U.S. average is 40%. In contrast, Mexico's average recovery factor is a low 18%. The North Sea has achieved its high recovery efficiency because of two advances: a) intensive efforts in IOR methods such as: re-injection of stranded gas and waterflooding, both from the *onset* of the development of the fields, and b) the support of well thought-out tax incentives as a consequence of the relatively high cost nature of the operating environment. EOR projects are few in the North Sea, limited to two large miscible natural gas projects and a recently started low salinity-AWF project. These are also the few EOR projects in offshore fields anywhere in the world. Offshore EOR presents complex, expensive logistics.

The Opportunity for Mexico

Mexico is a major oil producing and exporting country. Large scale production started in the early 1900s, peaked at 3.4 million b/d in 2004, subsequently declining at a higher than normal rate of 9% per year (**Fig. 1**). By the end of 2016, production had dropped to a little over 2 million b/d and exports to 1.1 million b/d, with about half going to the U.S. Mexico's production is rapidly approaching a critical juncture. In an effort to brake its decline trend, the country made some sweeping reforms in 2013 that led to the opening of its oil and gas industry to private oil companies and partnering opportunities for Pemex. The declared focus is on boosting offshore exploration and re-vitalizing Mexico's numerous mature offshore and onshore fields, in particular those with original oil-in-place (OOIP) greater than 400 Bbo.

A recent report prepared by the National Commission on Hydrocarbons (CNH) [**5**] states that Mexico has some 700 oil fields containing 250 Bbo of original oil-in-place (OOIP), of which 44 Bbo had been produced by the end of 2016. This gives a low recovery factor nearing 18%. Mexico has been successfully injecting water in several of its fields [**6**] from as far back as 1951 (Poza Rica). However, only 11 other fields have benefited from water injection, among the largest: San Andres (1961), Tamaulipas-Constitucion (1968), Sitio Grande (1977), and Abkatun (1991). Regarding gas injection for pressure maintenance, two world-class nitrogen projects take the stage: Cantarell (2000) and Ku-Maloob-Zaap (2008). The latter is currently the largest producing oil field in the country (**Fig. 2**). Mexico's single EOR project has been miscible CO_2 injection in the Sitio Grande field (2006).

Mexico has several giant oil fields with high quality reservoirs – see the columns of OOIP and RQI in **Table 2**. Inexplicably, the application of IOR/EOR has been limited to only a few fields and this is evident in its overall recovery factor. Case in point is the giant Panuco field [**7**] within the Poza Rica cluster. This heavy oil (11-13 °API) field has an OOIP of 6.8 Bbo with a good reservoir-quality index (RQI) of 4; 1,600-plus wells have been drilled and production peaked at 291,000 b/d in 1924. Recovery factor is 10%. This field should have been a top candidate for huff-and-puff steam injection, an EOR technique in use since the 1940s in Venezuela and the U.S. Nonetheless, it was left to a slow death as production declined slowly, to below 2,000 b/d by 2012.

Table 2 Attributes of Major Oil Fields - Mexico

Fields (1)	Peak Production 1000b/d (year)	Production 1000b/d (2012)	Cumulative Production Bbo 2011	API Gravity	Formation Lithology	Depth (2) feet	Net Thickness feet	Permeability mD	Porosity %	RQI (3)	OOIP Bbo	RF (4) %	Expected EOR Bbo
Cantarell (10)	2,192 (2004)	454	14.0	12-25	Carbonate	115 + 8,423	500	>1,000	10	17	35	40	2.3
Ku-Maloob-Zaap (23)	855 (2012)	855	3.4	12-25	Carbonate	330 + 9,400	1,000	>1,000	10	25	37	9	3.4
Akatum-Pol-Chuc (12)	755 (1995)	266	5.4	28	Carbonate	112 + 9,850	750	>1,000	10	19	15	36	1.0
LitoralTabasco (16).	367 (2015)	319	0.3	39	Carbonate	80 + 10,700	500	150	8	1.5	7.6	4	0.8
Samaria-Luna (8)	653 (1979)	205	3.2	30	Carbonate	0 + 13,120	575	100	6	0.7	10	32	0.7
Bellota-Jujo (5)	440 (1986)	130)	3.0	27-38	Carbonate	0 + 16,000	800	100	5	1.2	6.6	45	0.5
Mascupana-Muspac(4)	409 (1979)	75	1.0	35	Carbonate	0 +.10,000	500	75	8	0.8	3.0	33	0.2
Poza Rica (17)	217 (1970)	68	4.0	32	Carbonate	0 + 7,625	575	100	11	1.6	22	18	1.8
Cinco Presidentes (6)	166 (1972)	96	0.9	35	Sandstone	0 + 9,760	200	200	20	2.0	3.6	25	0.3
Totals (101)		2,518	35								140	25	11

Notes:.
(1) Parentheses indicate the number of active fields in the cluster. Reservoir characteristics correspond to the most representative field.
(2) Depth = water depth + reservoir depth below the seabed.
(3) Reservoir-quality index (RQI) is a measure of reservoir-quality that collates five static geo-parameters: permeability, porosity, net pay, pore-pressure gradient, and heterogeneity into a single number (index) [**8**]. As a guideline, Ghawar's RQI is 9.
(4) Recovery factor (RF) = cumulative production / OOIP.

Source: National Commission on Hydrocarbons (CNH); PEMEX Annual Reports; other reports.

The CNH report considers 101 fields with a total OOIP of 140 Bbo as the most suitable for applying EOR. These fields are grouped in nine clusters (**Table 2**) and had produced 35 Bbo through 2012. The recovery factor for this select group is 25%. This Table provides a quick-look at vital field metrics such as size (OOIP), recovery factor, peak production, oil gravity, reservoir-quality index (RQI) [**8**], and expected fresh reserves to be obtained via EOR. Most likely, these are the fields scheduled to be licensed or farmed-out during the course of this and coming years.

The report further postulates that EOR can recover an additional 10 Bbo of oil which will generate a production potential of 1 million b/d. The report also provides a breakdown of the genres of EOR that they consider will be most applicable for the different fields. In synthesis, miscible gases (CO_2 and hydrocarbon gases) are the dominant choice for all the fields. Additionally, in-situ combustion and alkaline/surfactant/polymer (ASP) slugs pushed along by water injection are secondary choices for the Cinco Presidentes fields. The expected volumes of EOR oil to be recovered for each field are shown in **Table 2**. Cantarell and KMZ together account for half of the 10 Bbo of EOR oil; two-thirds of the expected EOR potential would come from heavy oil in offshore fields, both very high cost settings. Moreover, both natural gas and CO_2 are not readily available in the volumes required which would incur additional costs.

Most of Mexico's main-stay oil fields are aging [**Figs. 2, 3**] and fast becoming economically marginal. Increasing outputs from the KMZ and Litoral Tabasco clusters are the result of new field discoveries. EOR is the last resort to prolonging the life of these existing valuable assets and to recover as much as possible of the large quantities of remaining oil in the ground. This is Mexico's challenge. However, to achieve this lofty EOR goal of 10 Bbo would require huge investments, in the order of $150-200 billion, and this would call for very attractive incentives to shift investors onto this new track.

In addition to the previously mentioned EOR technologies, we would like to highlight three new field-proven technologies that could have a major impact on Mexico: a) *down-hole steam generators* **[9]** that extend the steam injection process to heavy oils well beyond the current depth limit of around 2,500 feet and allow steam to be injected in laterals as long as 10,000 feet; b) *portable on-site nitrate generators* **[10]** using air as input drastically reduce the cost of this chemical; nitrate-AWF generates in-situ surfactants that add 10-plus recovery efficiency points to standard water floods; and c) *huff-and-puff surfactant*s **[11]** that primarily complement ongoing water-injection projects post water-breakthrough. This process has been effective in both light and heavy oil reservoirs, including those with oil as low as 11°API.

Final Remarks

EOR capex is now very competitive with exploration F&D costs. Worldwide, there are more than 1,500 world-class oil fields – those with 100 million barrels or more of reserves – and thousands of smaller fields that are prime EOR candidates. A recent paper [**12**] provides a template-style methodology for screening these potential reservoir candidates for EOR. EOR is no longer an end-of-life recourse. Field experience in the North Sea has shown that early implementation of IOR/EOR produces higher recovery efficiencies.

The stage is all set for EOR to make an impact on future global supplies of crude oil and Mexico has a great opportunity to make it work on a big scale. For investors, it requires significant capex over the long term, with payouts that are characteristically drawn-out for 5-8 years. So how can the producing countries jump-start this effort? The obvious pathway is tax incentives and contracts that specifically address the development of mature fields. In the case of Mexico, permitting of daily operations is an additional important factor. This process is abnormally long and cumbersome.

The best success example of the effects of tax incentives is the current shale gas/tight oil revolution which has extended the gas reserves of the U.S. to 100 years and boosted oil production by 5 million b/d. Tax incentives were put in place in the early 1980s and the results are astounding.

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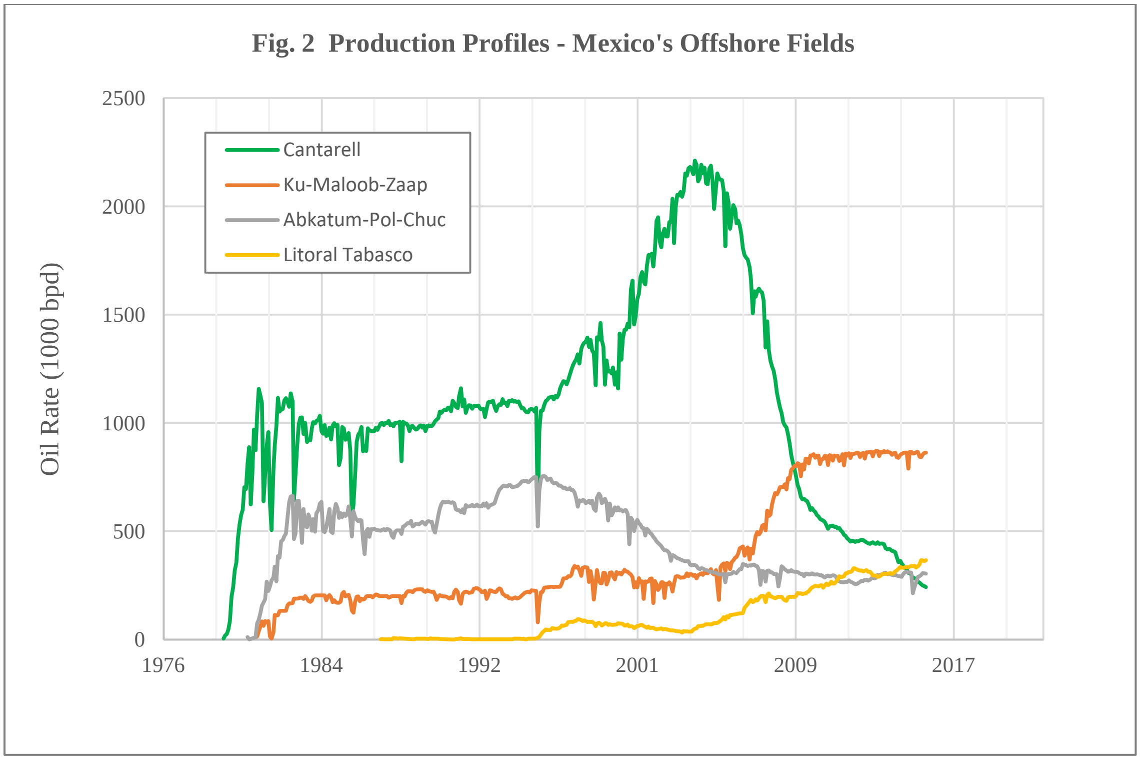
Fig. 2 Production Profiles - Mexico's Offshore Fields
Oil Rate (1000 bpd)
2500
2000
1500
1000
500
0
1976
1984
1992
2001
2009
2017
Cantarell
Ku-Maloob-Zaap
Abkatum-Pol-Chuc
Litoral Tabasco

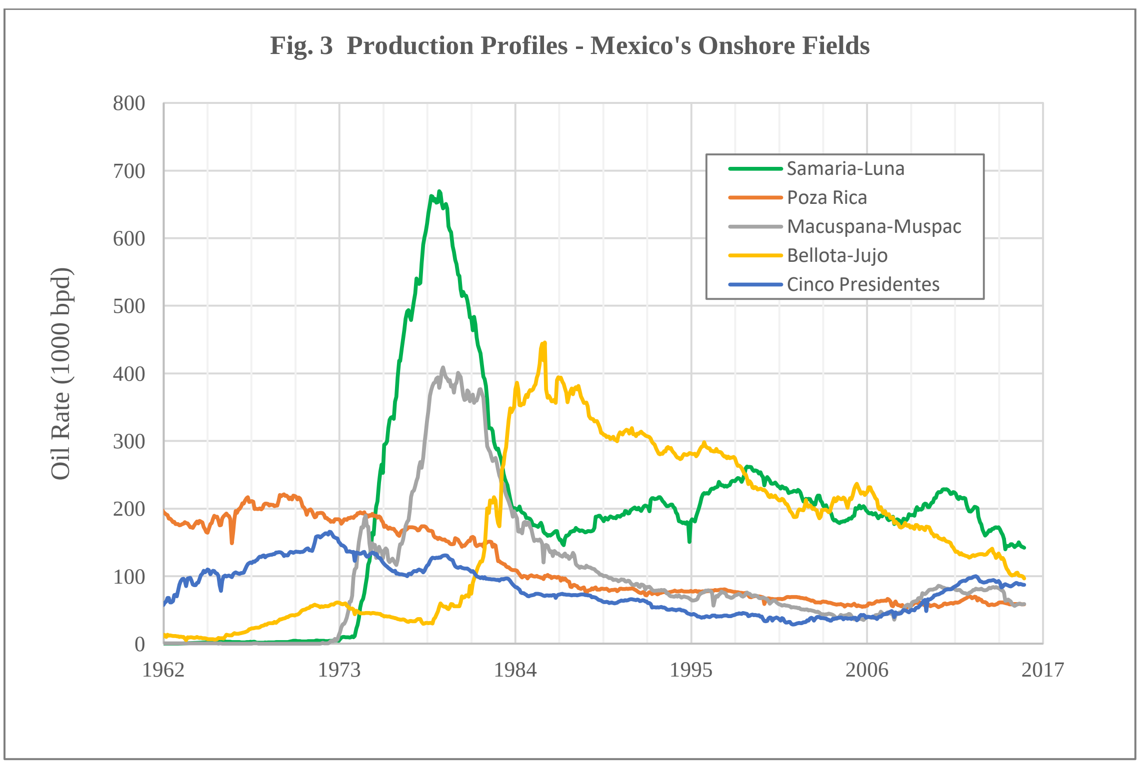
Fig. 3 Production Profiles - Mexico's Onshore Fields
Oil Rate (1000 bpd)
800
700
600
500
400
300
200
100
0
1962
1973
1984
1995
2006
2017
Samaria-Luna
Poza Rica
Macuspana-Muspac
Bellota-Jujo
Cinco Presidentes