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ABSTRACT: Repsol YPF has recently concluded a field pilot, which main goal was to stimulate naturally occurring bacteria in order to increase oil production. This is the first time the company tries this approach. The project was developed in a heavy oil production well located in the Neuquen basin (western Argentina). The basic procedure comprises stimulating the natural bacterial system present at the oil reservoir, through the cyclic incorporation of an aqueous solution of bacteria nutrients. Second stage is a 48 hrs shut-in. The proposed approach is basically different from the conventional MEOR process and was choosen to minimize the impact of adding external bacteria to the original population. The oil from the pilot well is heavy (15º API) and viscous. Several key oil properties were measured and recorded previous and after the nutrients injection. Nitrogen, phosphorus and potassium content of the production water were also carefully monitored. Twelve months after the start of the pilot, some conclusions can be made. Important properties (viscosity, density, molecular weight) showed significant reductions specially during the first months. Most of this reductions remained up to now. Bacterial activity was suspected through the analyisis of nutrients concentrations. Other properties, (i.e interfacial tension and asphaltene content) hasn't shown significant variations. Although well`s productivity seems to have been slightly improved (through decline curve modification) it is still not clear if changes are due to the stimulation.

Keywords: heavy oil, indigenous, MEOR, stimulation

INTRODUCTION:

On late 2001, Repsol YPF E&P Mendoza´s Unit decided to try a new stimulation approach on a low productivity heavy oil field. A single production well (Malal del Medio 84, located in Malal del Medio field, Malargue, southern Argentina) was selected for the pilot. The reservoir is mainly composed of shaly sands from the lower member of Neuquen Group.

METHODS:

Biological approach: A multidisciplinary team was created specifically for the pilot. Mendoza`s Unit Reservoir Group managed the project and monitored well`s productivity. Biological support was provided by the University of Cuyo-BioProcess Group. Fluid properties analysis were performed by the University of Cuyo Liquids Physics and Porous Media Group and by Repsol-YPF Argentina Technology Center (CTA).

Bacteria have been used in several ways in E&P. Surface geochemical techniques use bacteria as an oil indicator. Waterflooding has been improved adding microbes and/or nutrients to the injected water. Recent approaches include plugging watered permeable layers or removing H2S from production gases. However, stimulation of indigenous bacteria is not an usual approach. More popular is injecting at the well pre-selected microbes, combined with nutrient solutions. The proper microbes are choosen by foreign consulting companies. The authors could only find a few references on naturally ocurring bacteria approach [1]. None of them was applied to heavy oil.

The pilot was based on the concept that production of metabolic substances (associated to the growth of microorganisms) depends on the substrates that allow their development. Substrates are added as cultive media and should be balanced with the main macro and micro nutrients that the cells require. The cultive media design should also take into account the energetical and nutritional of the important groups. Main bacterial groups currently found in oil reservoirs are anaerobic. Some anaerobic bacteria produce great amounts of solvents (i.e acetone, butyl alcohol) as well as organic acids (acetic, lactic, butyric), carbon dioxide and methane. Aerobic microbes can produce poly-sacharids and surfactants.

It has been stated that each of this by-products contributes somehow to oil production. Solvents could reduce interfacial tension, acids could dissolve rock carbonates increasing permeability and dissolved gas could reduce oil viscosity. Some papers mention that MEOR process should be thought as an in situ chemical flooding. However, the extent in which each one of the effects contributes in a specific case to an increase of production is still on debate. A recent paper [2] discusses the efficiency of the MEOR process from a reservoir engineering point of view.

A wide variety of microorganisms and its combinations have been studied for MEOR process, i.e: Pseudomona aeruginous (produces surfactants), Enterobacter aerogenes (produces CO2 and other gases), Clostridium sp. (produces acids, alcohols, solvents, gases and surfactants), Clostridium acetobutilicum , Bacillus sp. and Bacillus licheniformis. When dealing with oil recovery the injected nutrients are extremely important, independently from the amount of added microbial mass. It is well known that in most cases there is an abundant indigenous bacterial population at a reservoir. If this population is properly stimulated it can produce direct effects on oil production. Necessary nutrients are salts, (which provide nitrogen, phosphate) as well as vitamins and growing factors. Adding nutrients in a controlled way and low concentrations contributes to the development of useful bacterial populations for oil recovery. However, an excessive concentration of nutrients could certainly generate well plugging by bio-mass.

Pilot design : The team decided that one year long (including baselines) was a reasonable duration for the pilot. The project was divided in 5 steps: well selection, key baselines definitions, nutrients injection, monitoring and results evaluation.

Bio-Process Group selected the following salts and additives for the nutrients: potassium nitrate (26.72 %), acid ammonium phosphate (19.03 %), mono basic potassium phosphate (1.5 %), magnesium chloride (3.02 %), ammonium chloride (30.27 %), ferment extract (8.62 %), malt extract (2.16 %) and water from macerated corn (8.62 %). All percents are in weight.

Nutrients were injected through the annulus four times along the pilot, with a monthly interval. The rest of the pilot was dedicated to analyze the effects on fluid properties, biological changes or oil production. After each injection the well was shut for 48 hours and then put back into production. Nutrients were displaced into the formation using a termination fluid. The operational procedure was similar to the one used for conventional MEOR projects.

Monitoring key parameters included regular production and water cut controls as well as fluid properties measurements in different laboratories. Quite time was invested in selecting the main fluid properties to follow, deciding how to take representative samples and how to measure them. A literature search revealed that usually reported changes in fluid properties were very slight or even undetectable [3,4].In some cases different papers showed opposite effects on a specific property.

From the biological point of view, the following parameters were defined as critical by the bioprocess group.

Nitrogen and phosphate concentration, and pH.

Wellhead aerobic hydrocarbon-degrading microorganisms concentration.

Wellhead aerobic heterotrophic microorganisms concentration

Wellhead anaerobic hydrocarbon-degrading microorganisms concentration.

Wellhead presence of Pseudomonas, clostridium, sulphate reducing bacteria (SRB) and denitrifying bacteria (DNB)

The main fluid properties to be measured were: hydrated and dehydrated oil viscosity, rheological behavior, interfacial tension, API gravity, oil molecular weight, asphaltene content, pour point, sulfur content, gas composition, and oil composition (GC and HPLC).

Well Productiviy Key Parameters: oil and water rates were measured by Repsol YPF staff.

Operational Procedure-Summary: Nutrients injections were performed on July 30, 2002, September 3, 2002, October 8, 2002 and November 12, 2002. Before each injection, demulsifier chemicals were stopped, and wellhead samples were taken, labeled and stored. The well was then shut in and slugs were pumped down (fig. 1). Meanwhile, the nutrients solution was recirculated at the surface to ensure its homogeinity and dissolve it components. Next step is pumping itself, using a 5 m3 front slug of Jet A-1 as cleaner, then 11 m^3 of nutrients solution and final displacement with 9 m^3 of Jet-A1. Well was shut for 48 hours, and then put back into production..

Fig 1

During operations, it was noticed that injection pressure was lower than expected, showing that no advese effect was generated by the solvent (i.e. asphaltene flocculation and precipitation), salts or water impact on shales.

RESULTS AND DISCUSSION

Fluid properties analysis:

Emulsion content of produced water: If bio-surfactants would have been generated at the wellbore, strong emulsification or strong demulsification should be expected (depending of the type of surfactant). None of this effects were detected at two different labs (U.of Cuyo and CTA). The trend of emulsion content is irregular and unstable.

API Gravity: The evolution of dehydrated API gravity is shown in figure 2. Measurements were performed using the same dehydration procedure. Many papers state that a slight increase of API gravity is expected after a production well stimulation. It seems that, when the nutrients injection is stopped, API gravity should return to it original value. Figure 2 shows that along the year the API gravity increased near 3º, very far from method`s experimental accuracy. During post-injection period, two additinal measurements showed that the changes still remained.

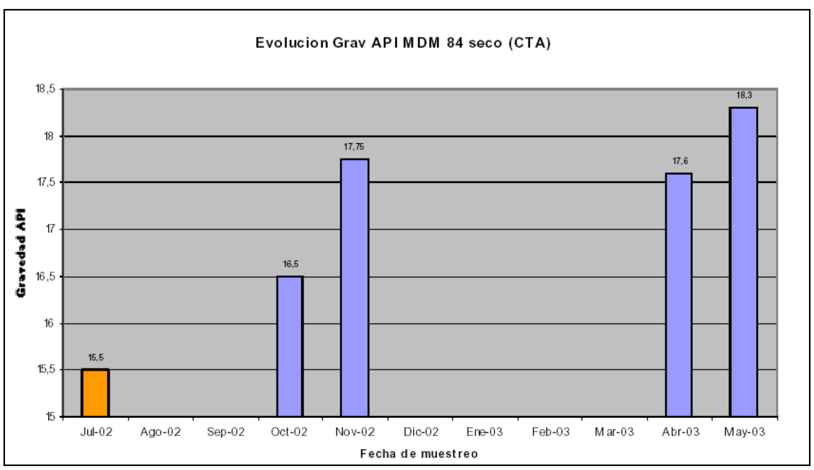


Fig 2

Oil molecular weight: First three measurements showed a significant decrease in the baseline value. The analyzer went out of service after the fourth measurement and it was not possible to analyze the following trend.

Date	30/07/02	8/10/02	12/11/02	20/12/02
Average molecular weight (g/mol)	423±23	304±7	346±3	344±16

GC Analysis : This analysis didn`t show a significant compositional variation between the analyzed samples and the baseline sample.

HPLC Analysis: It was performed on the baseline sample and on nine monthly samples . The accuracy of this method was taken into account in order to try to see any small changes in oil composition. Significant differences were only detected on samples taken on November 11 and January 14. On both cases saturates content decreased. Both samples correspond to the final part of the injection stage, when some effect should appear. However, this effect is the opposite of the one mentioned at reference [4], where saturates content slightly increased (see fig 3).

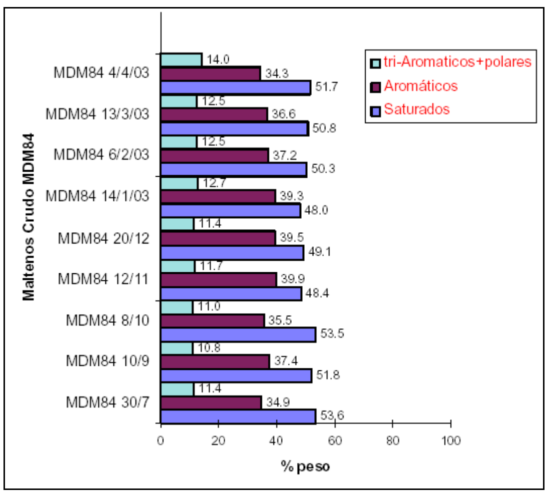
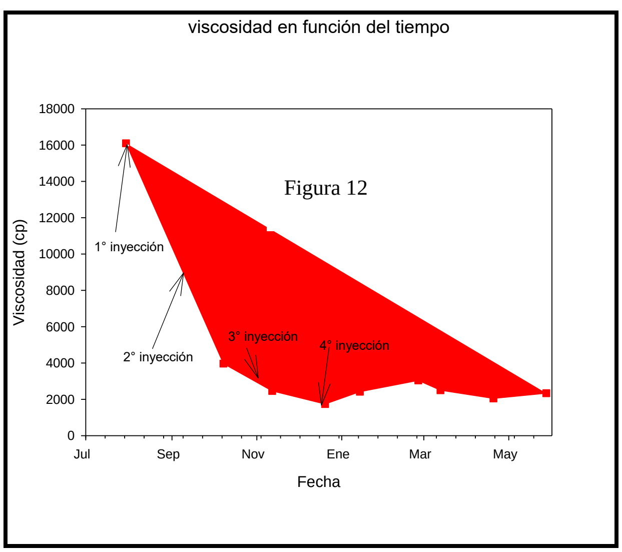


Fig 3

Sulphur and asphaltene: Some investigators reported that during a MEOR process sulphur content should slightly decrease, increasing again at its end. In our case, the sulphur content of dehydrated oil decreased slightly compared with the baseline. A sample taken on april 4, 2003 showed a sulphur content 8 % lower than the baseline. A final sample from May 2003 showed still lower sulphur content. On the other hand, asphaltene content didn`t show a clear evolution. The trend is erratic. At the beginning of the project there was some concern on the feasibility that the displacing fluid (based on oil) could precipitate some asphaltenes. However, no formation permeability reduction was noticed.

Interfacial tension and other tests: Some interfacial tension measurements were affected by the small amount of free water. In spite of a couple of low values, the conclusion of University experts was that no stable reduction effect on interfacial tension was achieved, suggesting that no bio-surfactant was generated in situ. Two additional studies were performed: isotopic measurements of C13 (two samples) didn`t show any significant variation. A biodegradation analysis was also performed by a geochemical expert. No significant changes of biodegradation were found on the oil.

Viscosity and rheological behavior: Oil viscosity is always a key parameter in this kind of treatment. Nearly all references describing succesful pilots mention significant viscosity reductions. In our case, viscosity was the oil property which experienced more and stable changes. The rheological study was performed at the UN Cuyo rheology labs and tests included viscosity curves at reservoir temperature and different shear rates, and viscosity curves at a fixed shear rate and reservoir temperature. The Ostwald non-newtonian index increased during the first two months and then remained nearly constant. The index increase could be related to a lower content of long chain paraffins or a low concentration of asphaltene agglomerates. A dilatant effect was also detected. Above figure its quite important and impressive. It describes the evolution of viscosity at a fixed shear rate, reservoir temperature and all along the pilot duration. As can be seen, a dramatic decrease of viscosity was achieved during the first months. Besides, several months after the injection was stopped the viscosity remain in values that are about 15 % of the baseline values. This behavior is also different from the finding contained in previous reports



Microbiological analysis: Sample bottles containing emulsified oil were sent to the lab and heated to 45 º C for three days to obtain free water. Microorganisms were investigated in this water, using different cultive media and conditions. Determinative method based on STMN Procedure 9215 A was choosen for aerobic and facultatives. Procedure calculates the number of live bacteria in an acqueous media. For anaerobic bacteria a determinative method was applied. All recounts done up to August 2nd were negative for all the media. The media were based on a formation ClNa content of 30 g/l.

When this value was checked at the lab the average value rounded 80 g/l. The media was then corrected. Analytical effort was concentrated in anaerobic hydrocarbon degrading microorganisms, total heterotrophics and SRB. In summary, no significant variation in pH or microorganisms concentration in wellhead water were detected. Although the media was adjusted and positive determinations were made, the final result is that there is no strong or clear evidence that some kind of stimulation of microbial flora was achieved. It seems that wellhead microorganisms determination is not the proper analysis for this type of process, because its not a direct index of the type and number of microbes present at the reservoir.

Phosphorus concentration was always lower than nitrogen one. The design rate between them was fixed as N/P: 3. For last injection, phosfate concentration was increased. There were no negative effects on production or in viscosity, which means that the range of concentrations was not harmful.

Oil Production Control: Measurements were performed at the battery 96 hours after each nutrient injection and once a week during the whole pilot. Some oil increase was noticed inmediately after each injection. However, this increase was not related to microbes effect but the pressure recovery and water and solvent injected volumes. Rates slightly returned to historical ones. Controls (fig 4) were also checked using downhole dinamometer interpretation. There was some concern on the accuracy of water content, so the analysis was based on trends and not in specific points.

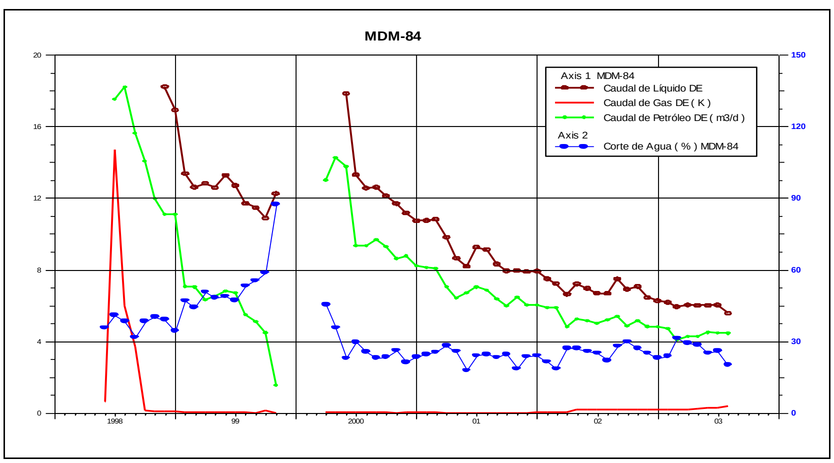


Fig 4

Based on the above figure the treatment didn`t seem to have been succesful in increasing production. However, due to the interesting changes achieved in some fluid properties, a deeper investigation was focused on well decline curves. The original baseline selected for the project showed that the well was declining at a rate of 29 % a.e. Final expected oil recovery was 15.400 m3.

Fig 5 shows in green, the well`s production history. Red points indicate the points taken for calculating decline curve and brown points production estimated from the start of the pilot. All data are based on june 2002.

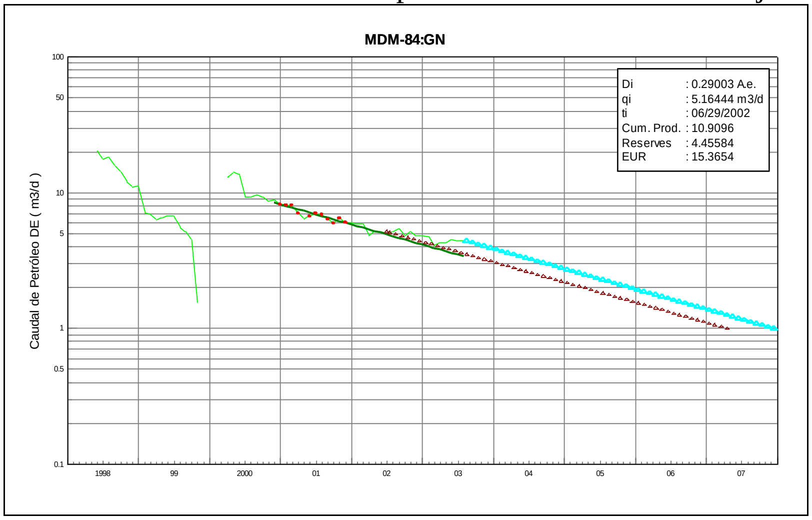


Fig 5

If we analyze the period July-2002 to July-2003 we can see clear changes in the trend of decline curve, reducing the rate to 17 % A.e, which means a total oil expected recovery of 19.500 m^3.

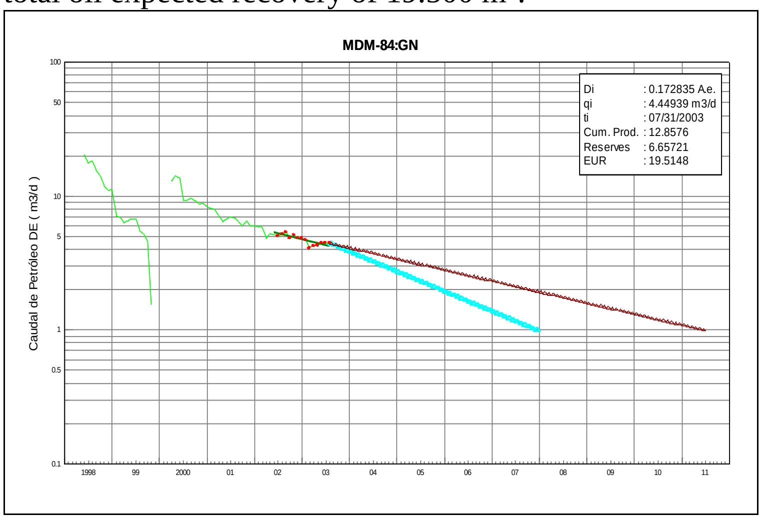


Fig 6

In the above figure we see in light blue the estimation of decline, predicted before the start of the pilot. Brown curve is the estimation predicted after the test. The red zone under the curves and the economic limit, is the acumulated difference of production between both estimations. When the project started, Reservoir area decided not to perform pressure tests due to budget constraints. It was assumed that for poor sands containing heavy oils the possible decrease in viscosity would not be very significant and will be bracketed by measuremnt accuracy. The change should be detected in the decline curve.A simple seudo simulation based on two phase steady state flow was performed to see the extent of the change in viscosity on relative permeabilities. If viscosity is increased ten times in the model, the effect on rate is nearly very hard to see. Other hypothesis (currently being analyzed) deal with the use of different models for fitting decline curves.

CONCLUSIONS

An overall conclusion from this experience is difficult to extract, due to the lack of published papers on this approach, and the contradictory and complex results obtained from well productivity data and from fluid analysis. However, the authors believe that the magnitude of viscosity, density and molecular weight reduction and the fact that some of the changes remained constant for several months are enough to justify to continue investigating on this approach, which seems to be cheaper and less environmentally harmful than the conventional one.

For an hypotetical second field test some aspects must be improved in order to get a deep understand of the results. Some of this aspects are:

- analyze a great number of wells, in order to have more confidence on results
- perform some well testing not only to select the proper well but to evaluate the effects of treatment
- include molecular biology and DNA analysis to find directly which types of bacteria are really present at the reservoir
- take more fluid samples during the baseline period, to analyze natural changes of each property
- dehydrate samples with different procedures to see if changes are basically independent of water removal.

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