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EEOR Success in Mann Field, Myanmar

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Abstract

Oil production increased in two test wells in a mature oil reservoir in Mann Field, Myanmar by successfully applying an enzyme-enhanced oil recovery (EEOR) process, a subset of microbial-enhanced oil recovery. A concentrated, water-soluble enzyme preparation made from DNA-modified proteins released from selected microbes was specifically prepared and injected in oil zones of one well and then recycled and applied in a second well.

Mann Field is a brownfield located in Salin sub-basin of the central basin of Myanmar in Southeast Asia and currently is operated by MOGE, with MPRL E&P Pte Ltd as the contractor for the field operations management. The field began producing in 1970, predominately from Oligocene reservoirs that consist of 26 stacked sandstone payzones. More than 667 wells have been drilled and completed, and 118 million stock tank barrels of oil have been produced. Average porosity of the field is 18% with an average permeability of 10-250 md. Oil gravity is typically 36.5°API, which is paraffinic in certain horizons, and the gas gravity is 0.65.

A test well was treated with four drums of enzyme concentrate diluted to 2% in formation compatible, filtered brine. Pretreatment production was 14 bopd and 2 bwpd. Current production is 18 bopd, and some 530 incremental barrels have been produced in 13 months following treatment. Pretreatment production from the second well was 10 bopd and 109 bwpd. Current production is 16 to 17 bopd, and approximately 1636 barrels of incremental oil has been produced during nine months since the treatment. Additional enzyme treatments are being designed for wells in Mann Field with higher current oil productivities.

There are unlimited targets for EEOR applications, not only in Myanmar, but throughout the world. These successful initial EEOR applications in Mann Field will allow for treatment design improvements in future wells.

Introduction

EEOR, or enzyme-enhanced oil recovery, is an adaptation of MEOR (microbial-enhanced oil recovery), an EOR (enhanced oil recovery) technique. MEOR is an emerging technology that may help recover the 377 billion barrels of oil that are unrecoverable by conventional technologies (Sen, R. 2008).

Enhanced oil recovery, also called improved oil recovery or tertiary recovery (as opposed to primary and secondary recovery), is achieved by gas injection, chemical injection, microbial injection, or thermal recovery (which includes cyclic steam, steam flooding, and fire flooding). Gas reinjection is presently the most-commonly used approach to enhanced recovery. Application of all EOR processes alter the original properties of crude oil and are intended to increase the life of mature oil reservoirs. However, they can actually be initiated at any time during the productive life of an oil reservoir. Their purpose is not only to restore formation pressure but also improve oil displacement or fluid flow in the reservoir to unlock trapped oil (Figure 1).

MEOR from the injection of microorganisms is a biological-based technology that has advanced from laboratory-based studies in the early 1980s to field applications in the 1990s. It consists of manipulating the function or structure, or both, of microbial environments existing in oil reservoirs to improve the recovery of oil entrapped in porous media while increasing economic profits (Lazar, I., Petrisor, I., and Yen, T., 2007). So far, the outcomes of MEOR are explained based on two predominant rationales:

1. **Incremental oil production**. The physical properties and metabolic capabilities of naturally occurring microorganisms alter the interfacial properties of the oil-water-minerals system in the reservoir to improve recovery by affecting:
   - fluidity (viscosity reduction, miscible flooding);
   - displacement efficiency (decrease of interfacial tension, increase of permeability);
   - sweep efficiency (mobility control, selective plugging); and/or
   - driving force (reservoir pressure).

2. **Upgrading**. In this case, microbial activity acts may promote the degradation of heavy oils into lighter ones.

Enzymes, the broad class of protein-based catalysts found in all living matter, are what constitute EEOR. Enzyme are nonliving, which provides EEOR an advantage over MEOR techniques that may require a detailed pretreatment involving the injection of a fermentable carbohydrate nutrient base into the reservoir before the microorganisms. Use of naturally occurring microorganisms may also lead to undesired side effects, such as production of CO_2, biomass, and surfactants; degradation of oil components; and reservoir souring. Additionally, reservoir conditions that restrict MEOR applications are high total salinity (<12%), formation temperatures (above 122°F), and very low permeability. These conditions do not restrict EEOR, which allow for a broader range of well treatment applications.

Successful applications of EEOR have been documented in China, Indonesia, Venezuela, and elsewhere. This paper discusses EEOR trial applications in Mann Field, Myanmar of a specific modified enzyme.

Modified Enzyme Technology

The environment-friendly modified enzyme, a biological catalyst, is a water-soluble formulation made from DNA-modified proteins extracted from hydrophobic microbes in a batch fermentation process (Gray, J., 2008). When diluted in formation-compatible water, it can significantly accelerate (several million reactions per second) release of oil from grain surfaces in an oil reservoir. In addition, it can change rock wettability from oil-wet to water-wet, thus reducing interfacial tension of solids and oil-flow resistance through formation pore spaces. The enzyme works biologically (not chemically or bacterially) in three stages (Figure 2) (Feng, Q., Ma, X., Qin, B., Shao, D., Want, X., and Zhou, L., 2009):

1. Makes attachment;
2. Takes biochemical reactions and creates the enzyme/oil complex; and
3. Decomposes itself into induced fits and particles. The induce fits continuously decompose and release enzyme until oil and enzyme are separated and, consequently, enzyme is restored.

The effectiveness of the modified enzyme releasing oil from sand is shown in a laboratory test. Figure 3 depicts an oil-water-sand mixture treated with 10% modified enzyme compared to the same mixture without. A clean separation of the oil from the sand results from the modified enzyme treatment and there is little oil-sand separation without the modified enzyme treatment.

Theoretically, the enzyme will never be consumed, meaning it can be reapplied unless excessively diluted by produced water. However, its effectiveness will degrade after processing but can be restored by adding surfactants that act as sacrificial agents.

The modified enzyme is ideally suited for sandstone, waterdrive formations with <30º API oil, >20% porosity, and >100-md permeability for single EEOR well treatments, but is not limited to these parameters. Formation pressure, bottomhole temperature, production history, viscosity of crude, and pour point are all factors to consider. Different types of tertiary recovery are factors too. Applications for the modified enzyme fluid could include:

- Heavy oil (cold production)
- Cyclic steam injection
- Waterfloods
- CO_2 or nitrogen injection (WAG or water alternating gas)
- Stripper wells (target >5 bopd)

In laboratory tests, contact angle measurements with a 1% by weight concentration in brine solutions of the modified enzyme indicate more water-wet behavior than other enzymes (Nasiri, H., Skauge, A., and Spildo, K., 2009). This effect can improve relative permeability of the formation to oil, which in turn means greater potential oil production.

Reservoir Characterization

Mann Field is situated at the plunging northern end of the 30 mile long Mann-Minbu structural trend in the proven Salin sub-basin oil province, which is part of the central basin of Myanmar (Maung, P., Nahn, J., Nyein, K., Nyunt, M., Pivnik, D., Smith, G., and Tucker, R., 1998). Oil production comes mainly from sandstone reservoirs of supra-thrust Middle Oligocene and Early Miocene Formations, that deposited under transgressive/regressive marine conditions. The field was discovered in 1970. The peak production of 24,000 bopd was achieved in 1979; the field had already produced over 118 million barrels of oil. Currently, a total of 667 wells have been drilled, of which 335 are producing and the remainders are shut in. Mann Field comprises of 26 oil sands with a total net pay thickness of 535 ft: the field is naturally compartmentalized by four major NE-SW-trending cross-faults with the southern part of the field being characterized by the presence of the west hading thrust, a feature which swings in a NNE direction at the crestal and northern parts of the field. There is a promiently developed series of N-S thrust faults on the western side of the structure with a backwards trend, forming numerous sub compartments (Figure 4). Thus, Mann Field can be described as one of the most geologically complex fields in the world; indeed, the prospects of the sub-thrust and the deeper areas of Middle Oligocene reservoirs are still under evaluation (Anderson, D., Graves, R., Miskimins, J., and Mu, S., 2007).

Production in the Mann Oil Field comes from 26 stacked Oligocene-Miocene sandstones deposited in deltaic to shallow sea environments. The producing sands lie between 300 and 9,400 ft in depth. Porosity varies from 10% to 35%, with permeabilities are in the 1-1,000 md range. The oil composition of Mann varies widely from 25° to 47°API in density and is moderately paraffinic, except for the lighter end hydrocarbon. Oil here is frequently associated with fairly rich gas. The initial formation pressure regime was significantly over-hydrostatic, especially for the deeper reservoirs and in the southernmost compartment of the field. The present pressure regime is under-pressured and the oil is now produced mainly by insert pumps.

Test Well Selection

The Mann field EEOR tests were conducted on Well 395, completed in September 1981, and Well 101, completed in March 1976. Both wells experienced periodic paraffin buildup and have produced 433,500 and 1,384,525 cumulative barrels of oil respectively. They both met the the criteria for a modified enzyme application.

Criteria	**Well 395 – 155 ft Interval**		**Well 101 – 80 ft Interval**	
SFL[1] well above oil zone	Top Perf – 5674 ft	PFL[2] – 5551 ft	Top Perf – 5155 ft	PFL – 5168 ft
BHT[3] ≥36°F above oil pour point	Pour Point – 86°F	BHT – 145°F	Pour Point – 81°F	BHT – 144°F
Average Porosity, φ >20%	24%		27%	

[1]Static fluid level [2]Pumping fluid level [3]Bottomhole temperature

The modified enzyme treatment in Well 395 was preceded by a wellbore clean-out procedure to prevent injecting any wellbore contaminants into the perforations (Figure 5). Then, four drums of modified enzyme concentrate, diluted to 2% in filtered, 2% KCl water, were used to treat Well 395. Injection pressure was maintained below the formation frac pressure and the entire 155 ft interval was open during the treatment with no diversion of fluid. The well was shut-in for four days before returning the well to production. Pretreatment production was 14 bopd and 2 bwpd. Current production is 18 bopd and some 530 incremental barrels have been produced in 13 months following treatment. Figure 6 shows the production history of the well before and after the modified enzyme treatment.

Dilute enzyme recovered from Well 395 was recycled to similarly treat Well 101 (Figure 7). Pretreatment production from the second well was 10 bopd and 109 bwpd. Current production is 16 to 17 bopd, and approximately 1636 barrels of incremental oil has been produced during nine months since the treatment. Figure 8 shows the production history of Well 101 before and after the modified enzyme treatment.

Table 1 summarizes the modified enzyme treatments results on Well 395 and Well 101. To date, more than 2100 barrels of incremental oil resulted from these two applications. Especially note the current “flat” production decine percentage following both treatments. Figure 9 illustrated that the economics for these two treatments are reasonable too.

Additional modified enzyme treatments, using biodegradable ball sealers for diversion, will be conducted in other Mann field wells. Emphasis will be placed on selecting wells with higher oil producing rates that should result in more incremental oil production. Effectively diverting the treatment into multiple zones should enhance results from these future treatments as well.

Conclusions

1. Application of a modified enzyme in Mann field improves oil production.
2. Modified enzyme solution can effectively be recycled into other wells to enhance production.
3. Treating higher impact wells should result in greater profitability.
4. Diverting Modified enzyme treatments into more intervals should improve treatments results.
5. Arresting decline rate after treatment is significant result from this test.
6. Preliminary tests indicate it is more effective in high water cut well.

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Table 1 – Summary of modified enzyme treatment results.

Well Number	Production Decline (%)		Water Cut (%)		Production Rate (avg bopd)	
	Before	After	Before	After	Before	After
395	8.36	flat	17.6	23.8	14	17
101	27.8	flat	90	90.4	10	16

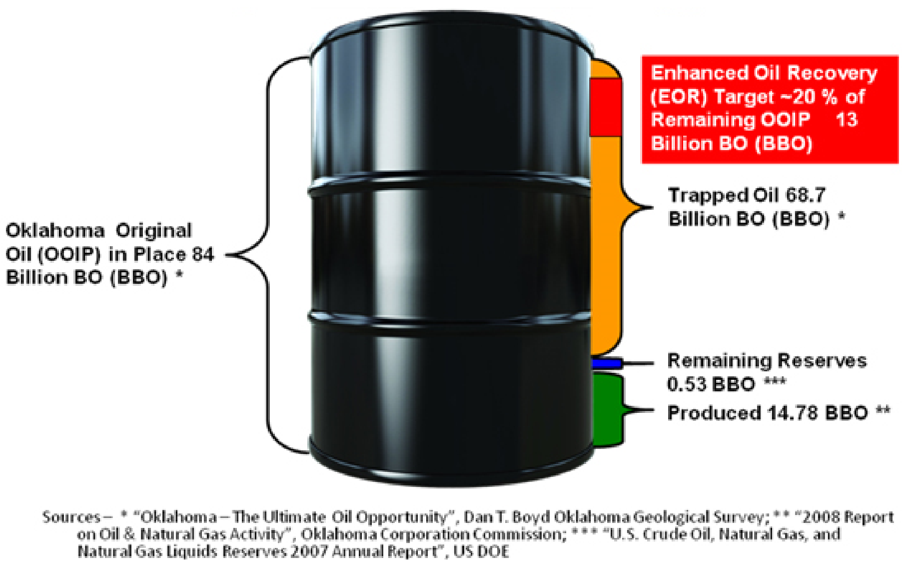

Figure 1 – EOR potential for unlocking trapped oil in Oklahoma USA.

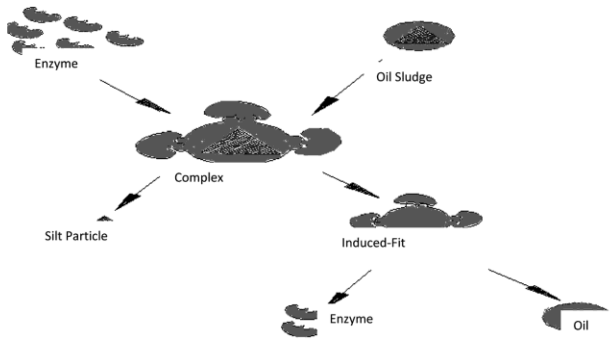

Figure 2 – Schematic of induced-fit of modified enzyme and crude oil.

Figure 3 – Laboratory test comparison of modified enzyme treated (left) and non-treated (right) oil-water-sand mixtures.

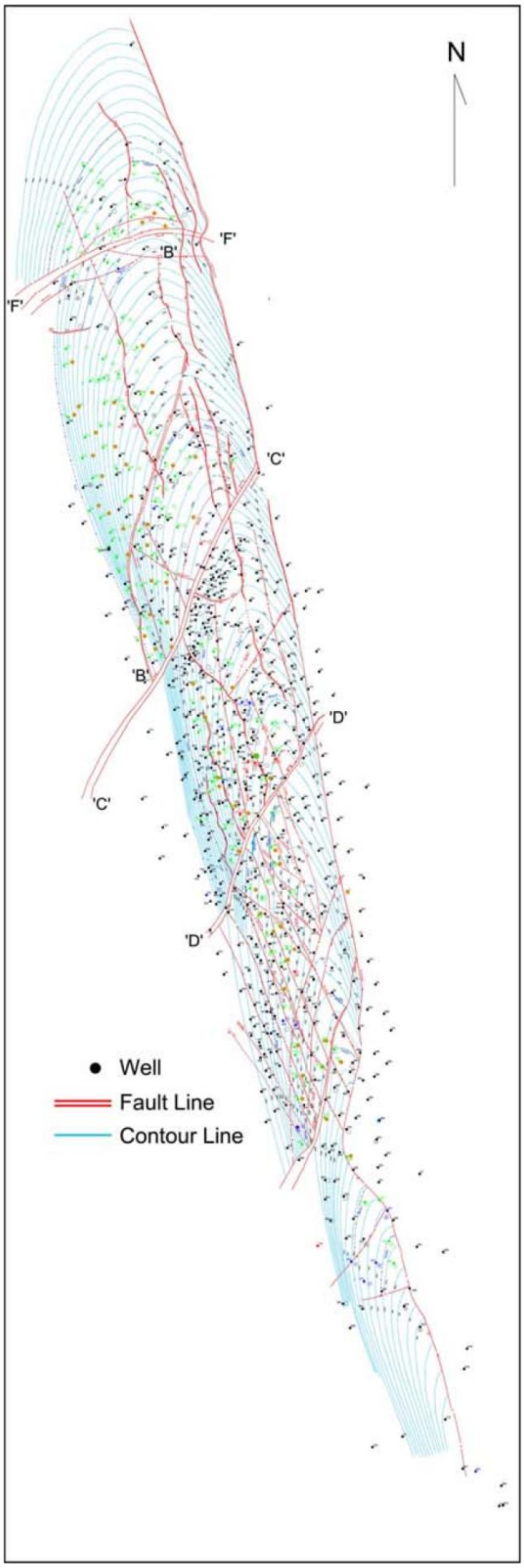

Figure 4 – Structure map of the Mann Field 4500 sand. Note the numberous faults (red) and contour intervals (blue) are 100 ft.

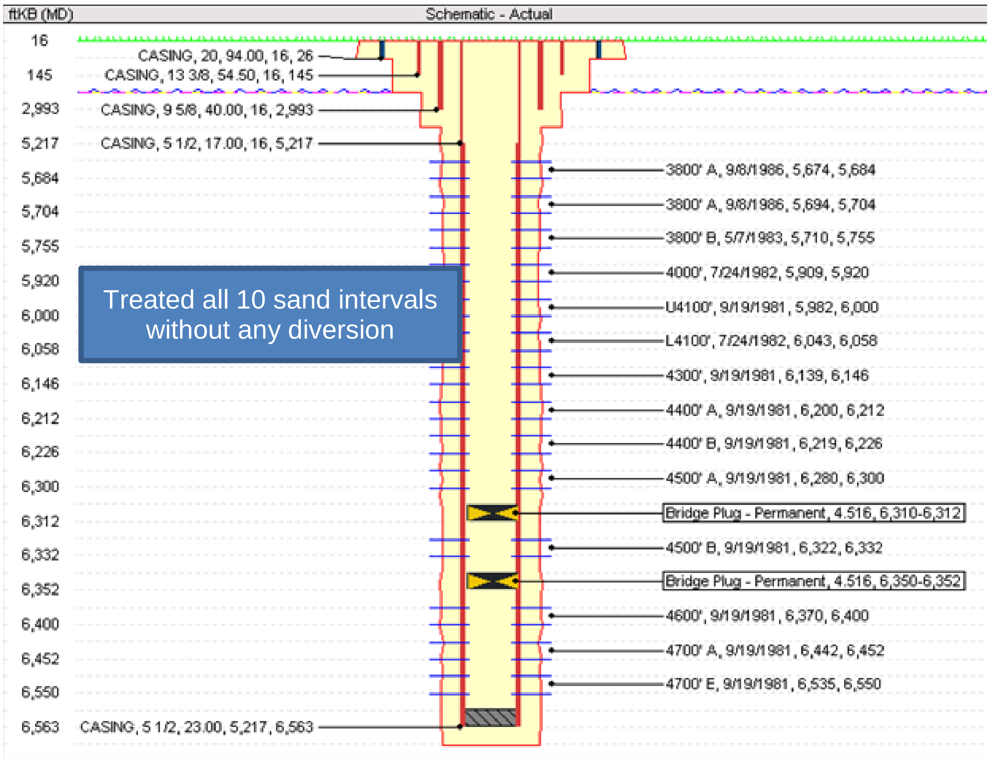

Figure 5 – Well 395 schematic.

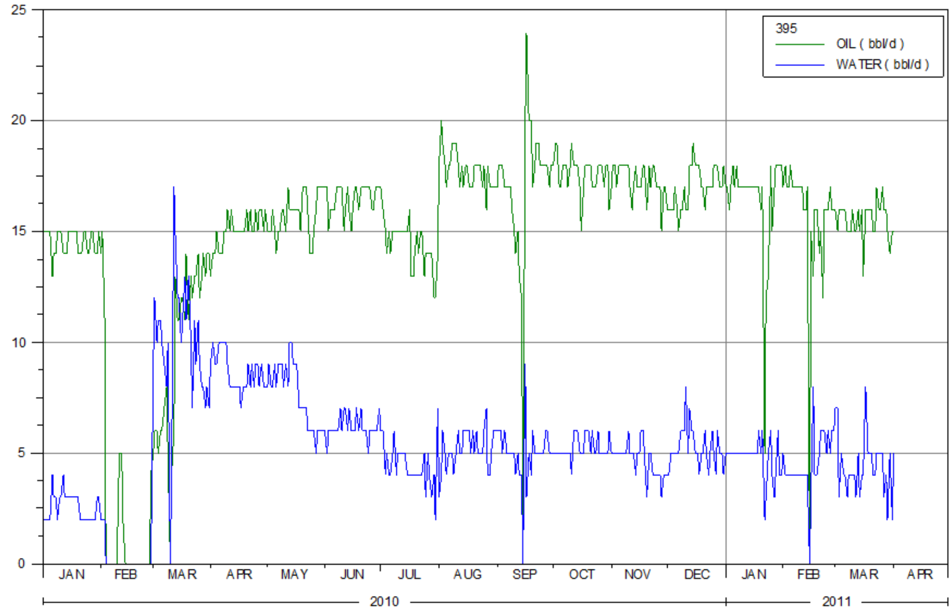

Figure 6 – Well 395 production history before and after modified enzyme treatment.

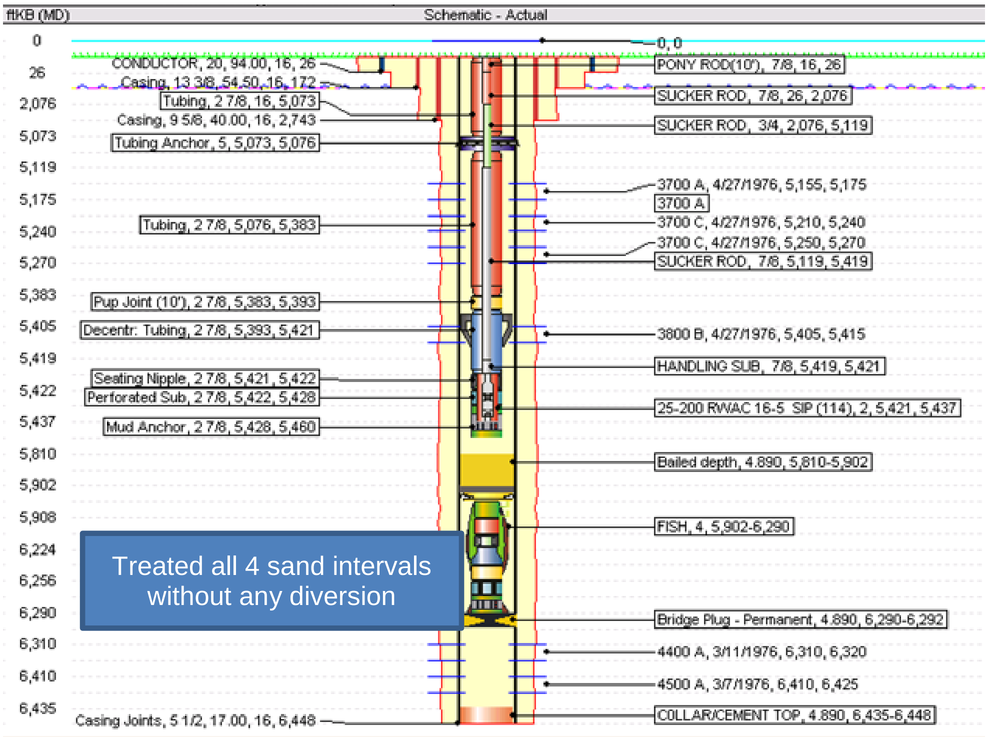

Figure 7 – Well 101 schematic.

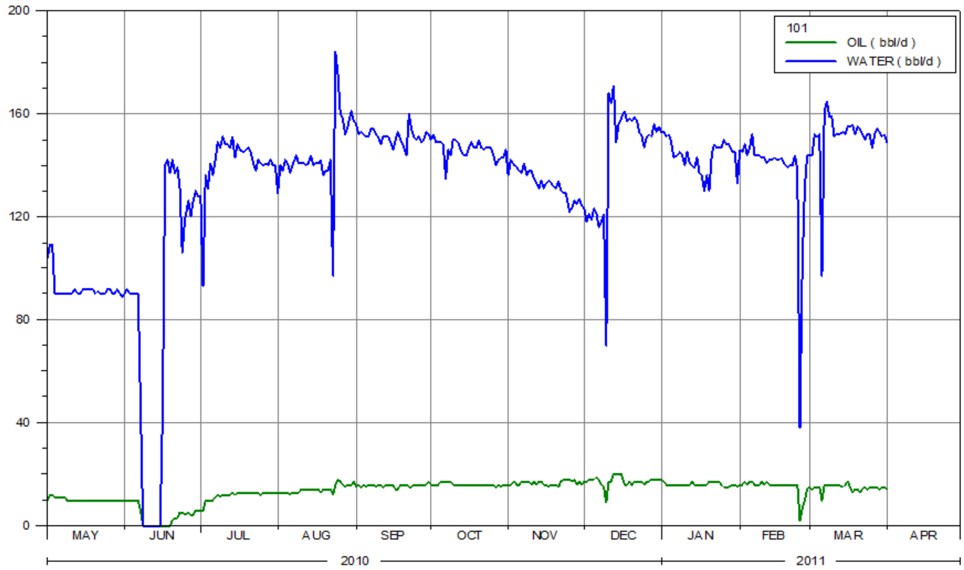

Figure 8 – Well 101 production history before and after recycled modified enzyme treatment from Well 395.

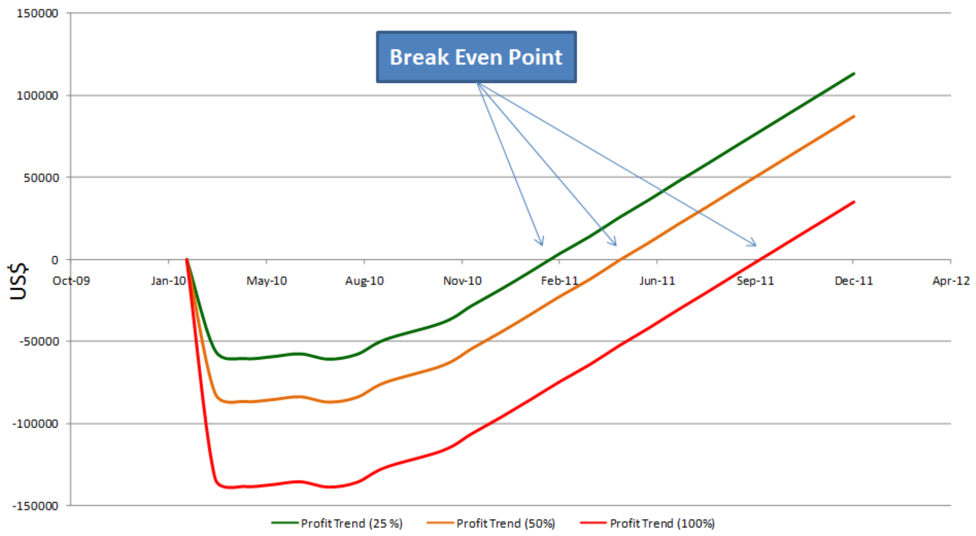

Figure 9 – Short term economic model for modified enzyme treatments on Well 395 and Well 101 combined based on costs and an oil price of US$75 per barrel.