EXOTHERMIC CHEMICAL TREATMENT (ECT), TOWARDS OPTIMIZING HEAVY CRUDE PRODUCTION OF AL HARAM FIELD, CONCESSION 47, SIRT BASIN, LIBYA, USING ECT TECHNOLOGY

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Abstract: In today's oil and gas world, there is an ongoing demand for Enhanced Oil Recovery Techniques (EOR). Operators look for the best available solutions to optimize production from heavy crude fields which were not put on production due to lack of technologies suitable for the individual field nature, type of reservoir, pressure and most important of all, technologies that are economically feasible and environmentally friendly. Libya's capability to boost its oil production is strongly dependent on innovative extraction technologies. Particularly in the case of the 1billion barrel Al Haram Field. Many years of scientific research and technical innovation gave birth to the Exothermic Chemical Treatment (ECT) by New Oil Generation (NOG). This EOR technology is a modern method for thermal stimulation of oil reservoirs containing crude oil ranging from 10 to 30 API. ECT uses Binary Mixtures of Chemicals, containing non-explosive and non-hazardous aqueous solutions, injected to the wellbore into the pay zone within the production or injection well to stimulate the reservoir. Chemical reaction generates three key components: heat, nitrogen and pressure, which leads to increasing reservoir pressure and lowers the viscosity of heavy oil. Thus, ECT achieves rapid improvement of oil production. On line monitoring and controlling system of temperature and pressure in the reaction zone, provides efficiency coefficient of Binary Mixtures reaction that are close to 1. Successful application of ECT in Russia and USA, proved the technology as the most cost- effective method at the present day. Comparing the geology and nature of reservoirs of the case histories on which ECT was applied, they are found to be very similar to those of the Al Haram Field. That makes ECT the most invaluable technology to assist Libya in boosting its heavy crude oil production in the safest and most economical way.

Keywords: Binary mixture, exothermic chemical treatment, oil well stimulation, enhanced oil recovery, case study.

INTRODUCTION

The one billion barrel Al Haram Field in Libya (Fig. 1) has been a challenging one for heavy crude production since many years. It is not only containing heavy crudes which are difficult to produce using conventional production methods, moreover, these heavy crudes are of a waxy nature causing them to jam when transported through production lines and when is under room temperatures.

Charged by Sirte Shale, main reservoirs at the Al Haram Field are Rachmat Carbonate, and Bahi/Hufrah clastics and Hufrah quartzites. Source rocks of lacustrine nature are thought to be the main cause for the waxy oils at Al Haram, with critical times at Eocene to Oligocene (Hallet and Clark-Lawes, 2016).

Arabian Gulf Oil Company (AGOCO), one of Libya's major National Oil Corporation Exploration and Production Companies was looking for an Enhanced Oil Recovery method suitable for the field nature. Reservoir conditions and simultaneously an economically feasible method to extract heavy oils in the field with minimum cost, and in light of the today's world of rapidly changing oil prices. In the past, Libya has applied basic forms of EOR on most of the pressure declined fields which are no longer capable to maintain production on the prevailing conditions. These forms of EOR as the so called primary Enhanced Oil Recovery Techniques or methods such as Water Injection, gas injection and sometimes pumps were deployed in Libya and Particularly in Concession 103 Intisar D reef which is part of the prolific Sirt Basin where water flooding and gas injection were used.

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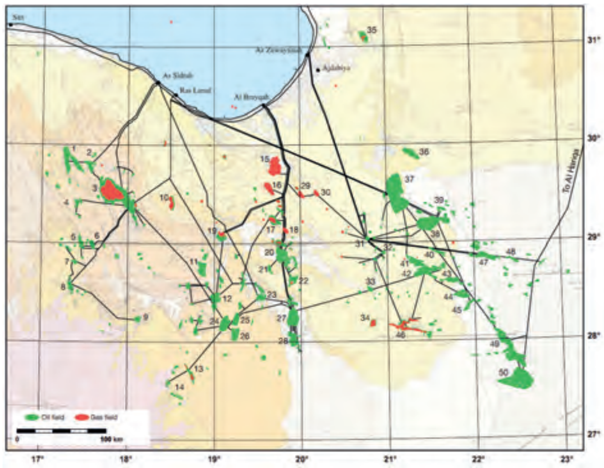

Fig. 1. Location map of the Al Haram Field among the neighbouring fields in Libya. Highlighted with a blue square and numbered 11 on the map (Source: Nubian Consulting Ltd., Geological map of Libya, 1985).

Nowadays, the Al Haram Field requires a more sophisticated technological innovation to produce the waxy heavy oils and maintain production rates at the field. This is where Exothermic Chemical Treatment (ECT) proved to be the most viable solution. Taking into account the nature of the Carbonate reservoir which is very similar to both Oil Field in Turkey and Tatarstan which undergone successful ECT application in recent years. (ECT) is offering a new technology of EOR, which brings the adequate response to production improvement, where issues encountered by operators are dealt with such in the case of production drop.

Important economy driver of the ECT is the high efficiency of impact combined with low costs in comparison with other EOR methods. The time needed for deployment of EOR system in the field is counted in weeks only. However, the effect is instantaneous and tangible improvement of production is immediately noticed.

The technology is often referred to as Binary Mixture-Technology (BM-Technology) which stimulates oil reservoirs by producing heat and pressure and by an oil combustion chemical reaction (oxidizing process with the oil). Therefore, it is a multiple stage enhanced oil recovery technology. In combination with high pressure generated during the chemical reactions and heat in the reservoir, the viscosity of oil is lowered and oil flow is increased in productive wells or renewed in non-productive or stripper wells. Hence, ECT solution is very effective in old wells where they could be rejuvenated putting back on production. The technology was developed and tested in Russia and Europe for more than 15 years. The method and technology itself have been patented globally.

Single EOR treatment could be done during the standard service works on the well to spare the time of a workover rig and shorten the service time when the borehole is unproductive as much as possible. Table 1 shows the range of use of the ECT method that combines effects of three other EOR methods. ECT as a thermal EOR method is comparable primarily with steam stimulation. Table 2 shows comparison between ECT and CSS EOR method especially in terms of energy consumption and harmful gases (greenhouse gas) emission.

Theory of Exothermic Chemical Treatment

Principle of the Exothermic Chemical Treatment (ECT) technology is based on a chemical reaction called Binary Mixture (BM). Binary Mixtures are special designed water solutions of the chemicals in specific concentrations. The composition of these chemicals has been tested for a long period to maximize the energy efficiency of the components on the oil reservoir taking into consideration preserving the economy and using available chemicals in conventional chemicals markets. Through the reaction of Binary Mixtures in the production well or injection well, high amount of heat, gas and pressure are generated. One of these chemicals acts as fuel in this process and the second chemical as an oxidizer. Additional heating proceeds due to the fact that oxygen produced in a heated bed oxidizes the fraction of oil within the formation.

TESTS AND PROCEDURES

The initial laboratory tests of reaction of Binary Mixtures were performed in Russia and in the field in 2007. Operating formulations and 1st generation of the system of continuous monitoring and optimization of BM reaction in the wells has been developed and were then successfully applied in the fields of the Perm region and the Komi Republic - Usinsk deposit oil field. It has also been granted permission to pump BM into the well without limiting its mass. In 2014, an experimental study was conducted of the conditions of exothermic reaction of BM and its effect of reaction products on oil at high temperatures and pressures. This study includes experimental laboratory tests in a specially designed, high pressure chamber, where reservoir conditions were simulated during the BM reaction in the oil formation. The study also dealt with the

Table 1. The range of the ECT method.

Thermal EOR	Gas EOR	Chemical EOR	Hydrodynamic EOR
• Steam treatment (cycling injection or continuos steam injection) • In situ combustion • Hot water flooding • Cyclingsteam treatment	• Air injection • Light hydrocarbons injection • Carbon dioxide injection • Nitrogen, flue, and others gases injection	• Surfactant flooding (including foam) • Polymer displacement • Alkaline displacement • Acid displacement • Chemicalreagents displacement (includingmicellar polymer flood, etc.) • Microbiological treatment	• Surfactant flooding (including foam) • Polymer displacement • Alkaline displacement • Acid displacement • Chemical reagents displacement (including micellar polymer flood, etc.) • Microbiological treatment

ECT

corrosion effect of components and reaction products where an assessment of safety and environmental risks was made with a proposal to minimize them. The basic components of BM are chemicals that are used by ECT technology on oil well stimulation which are essentially in aqueous solution. Due to the specific characteristics of BM chemicals, safety regulations for handling BM Chemicals were elaborated clearly. The produced document has been prepared by a specialized company, which provides the industrial safety assessments. Moreover, due to the possible corrosive effects of BM on metal well completion components, extensive BM tests were performed at certain pressure and temperature.

Used Equipment

ECT technology is designed to stimulate heavy oil wells by Huff & Puff or Injection / Production method. The basis of this technology is pumping two aqueous solutions of chemicals into the well through separate channels (tubing in tubing) and their reaction bellow the packer in special designed (NOG) Injection Spearhead, generating heat, gas and pressure. Specific proportions of Binary Mixtures are pumped simultaneously into the well. After pumping all the chemicals, minimal amount of water is used to remove all chemicals from tubing. The used equipment is divided into two parts:

Table 2. Comparison of ECT technology and CSS stimulation.

Parameter	CSS	ECT	Unit
Oil Production	1	1	m^3 / day
Water consumption	3,05	0,08	m^3 / day
Fuel consumption for 1 m^3 of oil	8-10	0,4	GJ / m^3
SOR	3	0,08	m^3 / m^3
Water losses in reservoir (10%)	0, 3	0	m^3 / day
CO_2 Emission	0,6	0	kg / day
SO_2 Emission	0,01	0	kg / day
NO_x Emission	0,08	0	kg / day
Water recycling	85	90	%

NOG Surface Equipment:

- Compact mobile high pressure pumping system.
- Quick and safe connection to tanks with chemicals and well through the NOG Interface.
- Electronic monitoring and controlling system – SW and HW tools for the process management, real time data collection from downhole pressure and temperature sensors and pumping control.

NOG Bottom Hole Assembly (BHA):

- Mechanical set packer integrated with NOG Data Concentrator.
- NOG Injection Spearhead.
- Pressure and temperature sensors above the packer.
- Pressure and temperature sensors below the packer.
- Temperature sensor in reaction zone.

Operator contributions are work over rig, tubing, wellhead and ESP cable.

Conducted Technology Tests

The technology was tested in laboratory conditions and in real downhole conditions during the first pilot tests. The laboratory tests were mentioned above. After every downhole application, the state of technology was thoroughly assessed and all technology parts were evaluated in terms of mechanical wear and the influence of high pressure and temperature and also corrosive effect.

Equipment Evaluation

Based on this technology field test, the technology was developed and a compact mobile high pressure pumping system with electronic monitoring and controlling system accompanied the evolution of technology. Real time data collection from downhole pressure, temperature sensors and pumping control including specially integrated bottom hole assembly were evolved and approved too. Technology has been recently successfully tested on heavy oil fields in Turkey, USA and Russia in the year of 2012-2017 and assisted in elevating production rates effectively.

RESULTS

The typical pilot of ECT oil well stimulation is prepared in four steps:

1. Data collecting: Gatehering all reservoir and well available data.
2. NOG analysis: The well treatment programme is prepared including the expected effect on increased oil production.
3. NOG on location: NOG team together with engineer and geologist will consult and agree on the "treatment issues" and finally approve the progress of the work and submit the treatment documentation.
4. NOG conduct ECT: Treatment on the oil well according to the agreed procedure, following that NOG submits the final report on the application with a proposal for further potential stimulation.

Of the previously implemented applications we have chosen stimulation performed on the deposits of similar type to the Al Haram Heavy Oil Field, the main field of the Kotlah Graben, with Rachmat Carbonate. These two ECT stimulation were performed on Oil Filed in Turkey and in Russia. In Table 3 we provide basic stratigraphic data about oil reservoirs. Reservoir in Lower Carboniferous, the chosen case history reservoirs mentioned earlier, have characteristics relatively well comparable with Al Haram Field reservoirs. Garzan Limestone in Turjey has a reefal origin and a fractured, vuggy character. Average porosity of 18% and is mainly vugular and fissured in type. Average matrix permeability determined from cores is -16mD. Well tests indicate 200 to 500mD effective permeabilities, confirming the contribution of secondary porosity. The layer of Tournai Series is composed of fractured and cevernous-porous limestone. Separate interlayers are dolomitized with stylolite sutures. Average porosity is 16 % and is mainly porous and fissured in type. Average matrix permeability is determined from cores to be -70mD. Well tests Effective permeabilities from well test vary from 100 to 180 mD. Basic reservoir characteristic are given in Table 4.

Al Haram Field was discovered in the early1960s. First exploration well was D1 in Concession 47 and S1 was the first development

Table 3. Basic Stratigraphic Data.

System / Period	Epoch	Formation	Lithology	Reservoir
Upper Cretaceous	**Mastrictian**	**Garzan**	**Limestone**	**Turkey**
	Camoanian	**Rakhmat**	**Carbonates**	**Haram**
	Santonian			
	Conician			
	Turonian			
Jurassic				
Triassic				
Permian				
Lower Carboniferous	**Tournaisian**	**Tournai Series**	**Limestones**	**Russia**

Table 4. Basic Reservoir Characteristics of Oil Fields.

Reservoir	Turkey	Russia
Type of reservoir	Oil Saturated	Oil Saturated
Net Pay (m)	40	8
Depth (m)	1300	1380
Reservoir temperature (^oC)	65	26
Reservoir pressure (MPa)	12,4	10,3
oAPI	12	22
GOR (m3/m3)	5	8
Porosity (%)	21	16
Permeability (mD)	60	70
Oil Saturation (%)	76	74
Gas Saturation (%)	11	12
Water Saturation (%)	13	14
WOC	6	5
Initial Oil Production	12,5	14

well which was drilled 3 years later than D1 well. Two years later more wells were drilled. The field was never put on production due to the at the time uneconolical nature of the heavy crudes within. High viscosity of (27cp at reservoir temperature of 81 and 380cp at `38), 21.9oAPI and a pour point of 21. The OOIP for Haram Oil Field is estimated as high as 950 MMSTB. All these put the Al Haram Field on hold for production until a new technology arises and a change in the industry takes place enabling successful production at reasonable production costs. The field consists of three reservoir horizons, starting with Gargaf at the bottom and the oldest in age. These three horizons are:

1. The Gragaf Group which is a fractured quartizite and is of (Cambro-Ordovician) age.
2. Bahi Formation is a quartzitic sandstone comprising the middle reservoir unit or horizon and is (Upper Cretaceous) in age.
3. The Haram Members (Tagrifet) are bioclastic limestones which are (Upper Cretaceous) in age as well and which the field was named after.

Haram reservoir is very similar in characteristics to the case histroy reservoirs in Turkey and in Russia. This is a very encouraging factor in deploying ECT in the Al Haram Field as it will definatly give great results and will boost and maintain commercial production rates. There are two assumptions as for the origin of the waxy heavy crudes in terms of occurance which are thermal maturity and biodegradation. Having the Al Haram Field at shallower depth than the neighbouring fields within Concession 47 gives favor to the first assumption of decreased thermal maturity and depth of burial of the kichens. That led to the waxy heavy crudes in addition to the lacustrine deposits (Source rocks) out of which the the hydrocarbons had formed.

As shown in the tables parameters of the treated oil fields are similar to those of the Al Haram Oil Field, therefore, we consider the Al Haram Oil Field appropriate for the pilot test. To support this assumption, we further outline the case study results of ECT application on oil field in Russia. The pilot test was performed in 2016. The total duration of the test, including well completions for applications and putting back into production lasted 7 days. This application achieved all treatment objectives with regards to temperature and pressure profiles as well as treatment duration profiles. Overall, it was concluded that the test was performed successfully within the parameters defined. only standard oil well operator equipment workover rig, hook load 40t, pump track, geophysical log truck, swabbing unit work over rig crew and the service facilities were used for the treatment: low and high pressure chemicals pumps, downhole pressure and temperature sensors, control unit, bottom hole assembly-packer, injection spearhead and BM chemicals. The volume of 33tons of BM was pumped into the well in 55 hours and these maximum values of temperature and pressure were reached in the reaction zone-temperature 278^oC and pressure 17.6MPa. Two breaks were made during the application. Firstly, in order to check reaction control-immediate stop of reaction and restart-with successful results. Secondly, the reaction was stopped due to surface tubing valve leakage, tubing valve leakages were fixed quickly by the well operator and the reaction started again successfully. After the application, the downhole parameters were monitored and then the bottomhole assembly was pulled out of hole and the well was completed by PCP pump and put back to production. In (Fig. 2) treatment measured data is shown. In this case, 64 GJ of heat energy was released, 550 m3 of gas. The Production was increased up to 10 times from 1.5 to 15m3/day. The effect of production increasing lasted 107 days.

Fig. 2. Treatment Measured Data.

CONCLUSIONS

- Good results were achieved on carbonate reservoir oil fields with production rates enhanced substantially.
- All performed processes and procedures achieved major treatment objectives with regard to temperature and pressure profiles as well as treatment duration profiles.
- Theoretically, predicted parameters during the application and the results were obtained and confirmed with the production history after stimulation.
- During application, there were no difficulties or system failures detected and the whole system were found to be reliable, safe and encouraging to be deployed in other similar parameter oil fields.
- Oil production increased from heavy / medium oil reservoirs and was 6 – 10 times confirmed increase.
- When the heavy oil field in Turkey was treated, significant contribution of gas was seen generated during ECT increasing oil production. The field had experienced large scale applied CO^2 flooding reservoir stimulation.
- Al Haram Heavy Oil Field exhibits very similar petroleum system. This makes it a suitable candidate field for ECT technology deployment capable of lifting and mobilizing crudes with magnificent amounts which cannot be obtained otherwise.
- The three reservoir horizons of fractured quartizites, quartzitic sandstone and bioclastic limestones are favourable for ECT application. Fractures here communicate chemicals between layers and aid in the overall thermal heating of the heavy crudes and thus, increase production.

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