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Effect of acidizing rate on enhanced oil recovery for Eocene Thebes limestone, Eastern of the Gulf of Suez, Egypt

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Thebes Limestone of Eocene age contributes to oil producing reservoir of Abu Rudeis Field. Acidizing process has been applied successfully for many years to increase the productivity of petroleum wells in carbonate formations, consequently demands of application acidizing techniques are increasing. Carbonate acidizing differs than that occurs in sandstone because the reactive nature of a carbonate rock, as a result of this, carbonate acidizing causes formation of large flow channels in some portions of the rock comparing with the original pore size distrubution, in addition enlarging of some aspects as diameters, areas and volumes of original pores. This study investigated that the presence of oil slows reaction rate of HCL acid with a carbonate reservoir rock, where the treatment of carbonate reservoir rock with high concentrated HCL acid speeds up the acidizing rate, decreases the effect of oil within the rock and creates much new channels that facilitate injectivity and productivity of oil wells. The effects of acidizing on carbonate rocks at various conditions were different and obvious, consequently help us to improve the oil recovery from reservoir rocks.

[**Keywords:** Carbonate Reservoir; Acidizing; Slow Rate]

Introduction

The acidizing technique was patented in 1895, where the first successful acid job was performed in 1932 on a limestone formation in Michigan. Acidizing has remained an important part of petroleum engineering, especially in secondary and tertiary oil recovery. The acidizing process involves injection of certain acid such as hydrochloric acid (which is the primary acid used to treat carbonate formations) into a well bore to dissolve some of the surrounding formation rocks and change the pore dimensions of the reservoir rock. This dissolution allows better outflow of formation fluids, easier injection of completion fluids and easier injection during secondary recovery. Most carbonate acidizing today are performed using hydraulic acid (HCL) plus a mixture of corrosion inhibitors, penetration fluids, and other chemical additives. HCL is a strong acid penetration fluid; also other chemical additives with different types of acids can be used for enhancement oil and gas production wells[2] and to improve water injection wells and disposal wells[3,4].

The main objective of stimulation treatments is to increase the well productivity or injectivity. In most carbonate-stimulation treatments, HCL was used to be the main stimulation fluid and it is better than another type. The reaction between HCL and mineral composition such as calcite is fast, and reaction rate is going faster with higher downhole temperatures, which results in rapid HCL spending and failure of the treatment[5,6]. HCL is strong acid that has limited mass-transfer in its reaction with limestone at temperature above 32^{o}F (15.6^{o}C). Also the rate of acid spending is a function of the rate of injection, so at small injection rates, the acid penetrates only a limited depth before consumption. In this turn, it causes excessive dissolution near the well bore and prevents deep stimulation. The most obvious solution to exceed this problem seems to be the injection of acid with high rates. Pressure limitations sometimes prevent the high injection rates. Fracture acid stimulation is usually carried out on carbonate reservoirs which have lower permeability. It can be used either to remove formation damage or stimulate undamaged formations to create conductive channels through the fracture where oil and gas can migrate[7].

In case of carbonate rock, concentration of HCL is typically 15.0 wt%, but can be as high as 28.0 wt%, (where commercial HCL is usually 37.0 wt% aqueous solution). Lower concentrations can be used as pickling acids to clean up the well in a pre-flush (to remove scale and rust) or after-flush. In high temperature applications, HCL does not produce acceptable stimulation results due to its fast reaction that leads to lack of penetration. Organic acids, like formic or acetic acids, can be used to offer a slower-reaction and thus deeper stimulating acid[8].

It is important to understand how acid solution injection affects the microstructures and pore characteristics such as pore diameter, pore shape and pore area, those can be changed when dissolving carbonate minerals, in addition to how acid solution affects minerals like clays, quartz or organic matter. The well productivity would continue to benefit from path ways of the fluids provided by the acid injection. Acid fracturing can be a potential method for improving the oil productivity of the microstructures in shaly carbonate rock[9].

Abu Rudeis oil field is a one of the oldest oil fields occurred on the Eastern Coast of the Gulf of Suez; North of Belayim Land Field, to the Southeast of October Field. The location of Abu Rudeis Field in Sinai Area is displayed (Fig. 1). The concession was discovered in 1957 and the oil was found in the Nukhul Formation of the Lower Miocene. The exploration activity in Pre-Miocene started in 1978, by the drilling of ARS-1 well. The Abu Rudeis oil Field produces mostly from the Nukhul reservoir, with contributions from the Thebes Limestone, Matulla, Turonian and Nubia Sandstone. The Raha and Nubia Sandstone is a producing zone in Ras Budran Field while, in October Field the oil production is mainly from the Nubia Sandstone, Matulla and Nukhul.

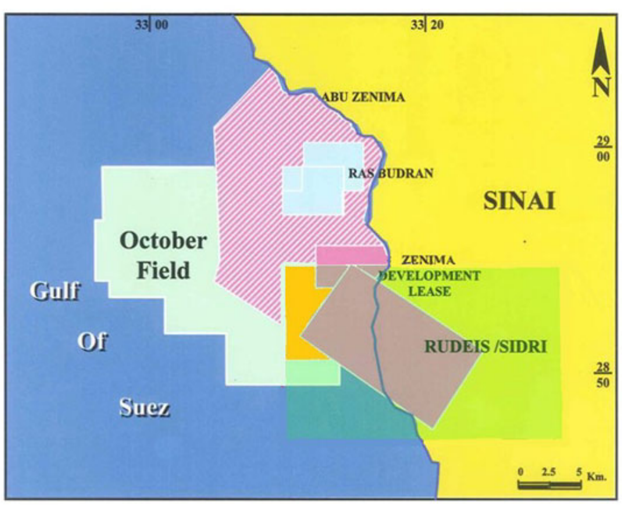

Fig. 1 — Location map of Abu Rudeis Field (after)[1]

The ideal geologic succession in the central part of the Gulf of Suez is represented by the stratigraphic sequence in Abu Rudeis Field. This succession is observed in both the surface outcrops and subsurface drilled wells at the different locations in the eastern side of the Gulf of Suez and also in the drilled wells scattered in the area.

The stratigraphic column of the study area ranges in age from Paleozoic to Recent without erosional hiatuses, (Fig. 2). The Paleozoic to Lower Cretaceous succession (Nubia D, C, B and A at the top) is unconformably underlain by the Pre-Cambrian basement. Most wells in Ras Budran Field is partially penetrated the Paleozoic Nubia sandstones (Nubia D, C, and B units), but in Abu Rudeis-Sidri and Abu Zenima Fields the Paleozoic is not penetrated by any well.

Nubia Sandstone (A) top Member (Fig. 2) represents the most interesting reservoir in the central part of the Gulf of Suez between Belayim, Abu Rudeis, October and Ras Budran Fields. The Thebes Limestone of Eocene age contributes to oil producing reservoir of Abu Rudeis Field with small percentage, the acidizing technique was used to enhance its contribution.

For this study, fourteen oil saturated carbonate cuttings that represent Thebes Limestone of Eocene age were obtained from a certain well of Abu Rudies oil Field. Three similar groups of the studied samples were prepared, where they subjected to different acid

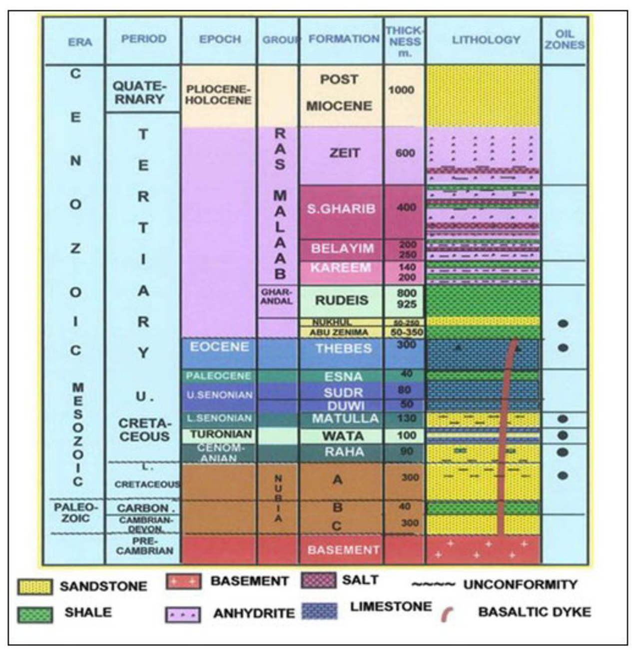

Fig. 2 — Schematic stratigraphic column of Rudeis-Sidri area, Gulf of Suez (after) [1]

treatments. The aim of this study is to know the response of carbonate reservoir samples when treating them with acid through three runs of different conditions. Knowledge of maximum response of carbonate reservoir rocks toward acid at certain conditions helps and facilitates oil production from carbonate reservoir rocks. The first run involves the treatment of oil saturated cuttings with 15% concentration HCL for a time of (24 hour). The second run involves the treatment of oil saturated cuttings with 37% concentration HCL for a time of (24 hour). Afterwards, a comparison will be made to show the cuttings sensitivity toward acid concentrations at the same time interval.

The effect of oil absence on acidizing rate with carbonate reservoir was investigated, where the third run involves the treatment of oil-free clean cuttings with 37% HCL for a time (24 hour).

Materials and methods

The samples those obtained from a well of Rudies oil Field for this study were investigated mineralogically by X–ray diffraction (XRD). As previously mentioned, the studied samples were repeated into three groups. The oil saturated samples of the first group were immersed in 15% HCL for a time of (24 hours), where the oil saturated samples of the second group were immersed in 37% HCL for a time of (24 hour). The samples of the third group were cleaned from hydrocabon using tolouen solvent and dried, then the cuttings were soaked in 37% HCL for a time of (24 hours) to show the reservoir cutting sensitivity without oil content toward the acid.

Results and discussion

A-Mineral composition

Bulk minerals and clays of the samples were analyzed using the method of X-ray diffraction. The results are illustrated (Table 1 and Fig. 3), where the composition of bulk minerals are mainly carbonates (calcite) that ranges from 42.0% to 88.0% with an average of 61.0%, K-feldspar ranges from 1.0% to 14.0% with an average of 4.0% and quartz ranges from 2.0% to 11.0% with an average of 6.0%. Smectite constitutes the highest percent of clay minerals (average 18.0%), the content of illite ranges from 1.0% to 10.0% with an average of 3.0%, where kaolinite ranges from 2.0% to 15.0% with an average of 6.0%. Due to the large surface area of kaolinite, it is easily eroded with flooding fluids than other minerals, like quartz.

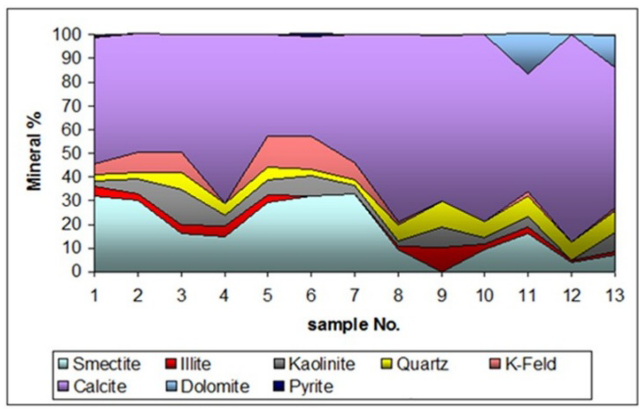

Fig. 3 — Graphical representation of XRD results shows mineral composition of the studied rock samples

Table 1 — XRD results show the mineral composition of the cutting rock samples

Cutting no.	Clay mineral contents, (%)				Bulk mineral contents, (%)						Total minerals
	Smectite	Illite	kaolinite	Total clays	Quartz	K-Feldspar	Plagioclase	Calcite	Dolomite	Pyrite	
1	32	4	2	38	3	5	0	53	0	0	62
2	30	3	6	39	3	8	0	50	0	0	61
3	16	4	15	35	8	8	0	49	0	0	65
4	15	4	5	24	5	0	0	71	0	0	76
5	29	3	6	38	5	13	0	44	0	0	62
6	32	0	8	40	3	14	0	42	0	1	60
7	33	0	4	37	2	7	0	54	0	0	63
8	9	2	2	13	7	1	0	79	0	0	87
9	0	10	9	19	11	0	0	70	0	0	81
10	9	2	3	14	7	0	0	79	0	0	86
11	16	3	5	24	8	0	1	50	17	0	76
12	4	1	0	5	7	0	0	88	0	0	95
13	7	1	9	17	9	1	0	59	14	0	83
14	17	3	6	26	6	4	1	61	2	0	74

B-Solubility of cuttings in acid

Reservoir acid sensitivity appears when injecting an acid into the reservoir that make a reaction with acid sensitive mineral to release precipitation or particulates which reduce permeability, or increase permeability when pickling reservoir layers[10].

Calcium carbonate shares the typical properties of other carbonates. It reacts with strong acids, releasing carbon dioxide. The dissolution of calcite ($CaCO_3$) in acids is of interest to many fields of sciences, and the equilibrium relationships in the calcite-carbonic acid-water system have been studied extensively[11]. The dissolution rate of calcite in acids has been measured for purposes as the acidizing of petroleum wells.
The reaction between limestone and HCl can be represented by Equation (1)[12]:

$$CaCO_3(s)+2\ HCl\ (aq) \rightarrow CaCl_2\ (aq)+CO_2(g)+H_2O\ (l)$$

The solubility of carbonates both limestone and dolomite in HCL depends on many factors such as the acid concentration, temperature and mineralogy of the rock itself.

The reactivity between the samples and HCL of different concentration was tested, where acid concentrations were 15% and 37%. The tests was performed at room temperature on the oil saturated and oil free-clean samples. The samples were installed in beakers filled with an amount of acid about 20 times the weight of the piece used in the test. The sample pieces were weighed before the reaction. After certain time of reaction (24 hours), the samples were removed from the acid, rinsed by di-ionized water, dried and weighed to calculate the solubility of the rock (percent of soluble carbonate).

The weight loss of the tested samples as a function of acid concentration is shown (Table 2 and Fig. 4) which show solubilty of cutting samples after treatment with acid at different conditions, where the weight loss for oil saturated samples is lower than that of oil free-clean samples, upon contact with 37% acid for a time of (24 hours) as shown as in Fig. 4. The weight losses of the treated rock samples using 15% acid were not high like those treated using 37% acid.

From these static simple measurements, it is clear that the oil saturated cutting samples under study exhibits lower solubility than oil free-clean cuttings at the same time, while the tests were performed at room temperature.

In addition, at high bottom hole temperatures, the reaction will be very quick causing acid spending resulting in face dissolution, and the efficiency of the treatment will be low. So it is recommended to use one of the retarding acid systems to stimulate wells drilled in deep carbonate reservoir (high bottom hole temperature).

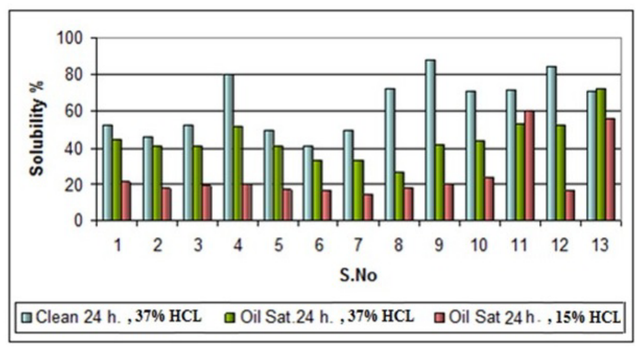

Fig. 4 — Solubility % result of the carbonate cutting rock at different conditions

Table 2 — Acid solubility % results of the oil saturated and clean cutting samples

Cutting no.	Solubility % of oil satuated cuttings, after 24 hours, 15% acid	Solubility % of oil satuated cuttings, after 24 hours, 37% acid	Solubility % of clean cuttings, after 24 hours, 37% acid
1	21.5	45.0	52.7
2	17.5	41.0	46.2
3	19.0	41.0	52.7
4	20.0	52.0	80.0
5	17.0	41.0	49.8
6	16.1	33.0	41.7
7	14.3	33.0	49.7
8	17.6	26.0	72.0
9	19.9	42.0	87.8
10	23.3	44.0	70.9
11	53.6	60.6	71.8
12	16.3	52.5	84.2
13	55.7	72.0	80.6

Conclusion

Carbonate acidizing is vey different from the process that occurs in sandstone, because the reactive nature of a carbonate rock, as a result, carbonate acidizing causes the formation of large flow channels in some portions of the rock comparing with the original pore size distrubution, while other portions are unaffected. This type of dissolution is extremely heterogeneous. Because of their macroscopic sizes, these flow channels are highly conductive to fluid, thus increase the permeability of the porous medium. The present study showed that the presence of oil slows reaction rate of HCL acid with carbonate reservoir rock. The use of high concentration acid overcomes slowing effect of oil, hence increases solubility of carbonate rocks or acidizing rate and this will enhance oil recovery through creation of much connected flow channels which affect positively oil productivity during fluids injection of secondary recovery.

Case history

In west Texas, six wells were producing at less than optimum performance, only 1.5 to 2 MMcf/D. BHTs ranged from 180 to 200°F while BHPs ranged from 2,500 to 2,800 psi. For these six wells, treatment volumes ranged from 12,000 to 15,000 gal. Post-treatment production ranged from 2.0 to 7.5 MMcf/D for an average 4.1 MMcf/D-over twice the production before treatment. Approximately 30 additional wells were treated and produced similar results for a total economic value of over $50 million per year.

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Refrences

1 Zahra, H. S. and Nakhla, A. M. 2016 “Structural interpretation of seismic data of Abu Rudeis-Sidri area, Northern Central Gulf of Suez, Egypt,” *NRIAG Journal of Astronomy and Geophysics, 5, 435–450*.

2 Kasza, P., Dziadkiewicz, M. and Czupski, M. 2006 “From Laboratory Research to Successful Practice: A Case Study of Carbonate Formation Emulsified Acid Treatments,” *Paper SPE 98261 presented at the International Symposium on Formation Damage Control held in Lafayette, LA, 15-17 February*.

3 Mohamed, S.K., Nasr-El-Din, H.A. and Al-Furaidan, Y.A. 1999 “Acid Stimulation of Power Water Injectors and Saltwater Disposal Wells in a Carbonate Reservoir in Saudi Arabia: Laboratory Testing and Field Results,” *Paper SPE 56533 presented at the SPE Annual Technical Meeting, Houston, TX, 3-6 October*.

4 Nasr-El-Din, H.A., Al-Anazi, H.A. and Mohamed, S.K. 2000 “Stimulation of Water Disposal Wells Using Acid-in-Diesel Emulsions - Case Histories,” *SPEPF 15(3): 176-182*.

5 Allen, T.O., and Roberts, A.P. 1989 ”Production Operations: Volume1 & 2,” *Penn Well Books, Tulsa, OK.*

6 Nasr-El-Din, H.A., Al-Driweesh, S., Al-Muntasheri, G.A., Marcinew, R., Daniels, J., and Samuel, M. 2003 ”Acid Fracturing HT/HP Gas Wells Using a Novel Surfactant Based Fluid System,” *Paper SPE 84516 presented at the SPE Annual Technical Conference and Exhibition, Denver, Colorado, 5-8 October.B.B*.

7 Williams, J.L. Gidley, and R.S. Schecter, "Acidizing Fundamentals'; Monograph Series, vol. 6, Dallas: *Society of Petroleum Engineers, 1979*.

8 M. Buijse, P. de Boer, M. Klos, and G.Burgos, "Organic acids in carbonate acidizing: *SPE 82211, 2003*.

9 Nianyina, L., Jinxina, D., Jianhuib, L., Fengjunc, B., Pinglia, L. and Zhifeng L. (2016) “Application status and research progress of shale reservoirs acid treatment technology” *Natural Gas Industry B3 (2016) 165-172*.

10 Tang, H.; Meng, Y. (2002) “Scale prediction and analysis in ASP combination flooding in Daqing Oilfield. *Driuing Fluid and Completion Fluid* ”.

11 Lund, K., Fogler, H.S., McCune, C.C. and Ault, J. W. 1975 “Acidization-II: The Dissolution of Calcite in Hydrochloric Acid,” *Chem. Eng. Sci.30(8): 825- 835*.

12 “Candidate Selection and Acidizing Process for Optimized Production from Carbonate Reservoirs,” Carbonate 20/20SM Acidizing Service, Halliburton’s “*Technical Briefing on Carbonate Acidizing” Production Optimization (2005)*.