Incompatibility of Injection Water with Formation Waters from Different Depths

Mhamed A. Kahrwad, Majeda Erraies and Omar Mkhatresh*

Abstract: This paper aims to evaluate the damage that might occur as a result of incompatibility between injection and reservoir waters under reservoir and surface conditions. The amount of scale formed was determined at surface and reservoir conditions and different mixing ratios for five produced water samples which have been collected from locations DD and EE and tested for parameters of (Temperature, pH, O_2, CO_2 and H_2S) at site and metal content of these water samples (i.e. A, B, C, D, E and produced water) as shown in Table (1). Five water samples (i.e. A, B, C, D, E and produced water) have been tested for water-water compatibility test with different mixing ratios at surface and reservoir temperatures. Each mixture was kept for twenty four hours at desired temperature. The mixtures were filtered through cellulose nitrate filter paper with pore size of 0.45µm. The formed precipitates were collected, dried at 95 ºC and weighed to calculate the amount of deposits. The filtrates were immediately analyzed by Inductively Coupled Plasma (ICP) to determine the cations such as (Ca^{2+}, Sr^{2+}, Ba^{2+} and total Fe) that might react with anions (i.e. SO_4^{2-}, CO_3^{2-} and HCO_3^-) to form mineral scale. These tests demonstrated that $CaCO_3$ and $SrSO_4$ could be precipitated in different amounts depending on mixing ratios and conditions of temperature and pressure. Also, the scale predications have been performed using Multiscale software (7.1) to predict the tendency of scale formation and to compare that with the laboratory work which includes mixing of injection water with formation waters from different depths at surface and reservoir conditions of temperatures & pressures. This prediction covers the type, extent and location of all scale depositions that are expected to form during water injection period. Tests were conducted to identify the main scaling compounds when produced water mixed with the formation water. The basis of positive evidence of scaling encountered in the laboratory tests, a computer simulation program has been carried out to support the incompatibility of these brines when mixed at desired conditions.

Keywords: Water-Water compatibility, mineral scales, scale predictions

INTRODUCTION

The injection of water or gas into the oil-bearing reservoir is to increase the recovery factor and maintain the reservoir pressure. In water flooding, the injected water will react with both the water already in the pore space of the rock (formation water) and with the mineral in the rock itself. This reaction will create scale formation. Sulfate scale (i.e. gypsum $CaSO_4$, anhydrite $CaSO_4.2H_2O$, Celcitie $SrSO_4$, barite $BaSO_4$) may result from changes in temperature and/or pressure while water flows from one location to another, but the major cause of sulfate scale is the chemical incompatibility between the injected water, with high concentration of sulfate ion and formation waters, with high concentrations of calcium, barium and strontium ions. Changes in temperature, pressure, pH and CO2/H2S partial pressure could contribute in forming a scale (Amer Badr, *et al* 2009, Mackay, 2003). Scale also can deposit when two incompatible waters are mixed and super-saturation is reached (Vetter, *et al* 1982). It is important to treat the injection water with a scale preventive chemical to prevent precipitation in the immediate area of the injection wellbore (Charles, 2007).

Water-Water Compatibility Tests: Seven produced water samples have been collected from A and B oilfields and tested for parameters of (Temperature, pH, O_2, CO_2 and H_2S) at laboratories as shown in table (1) The metal content analysis of

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*Production Chemistry Department, Libyan Petroleum Institute (LPI), P.O. Box 6431, Tripoli, Libya. E-mails: oasmkhatresh@gmail.com mhamed_lpi@yahoo.co.uk

Table (1) Water Chemistry of the brines used in the study (mg/L).

	A	B	C	D	E	F	Produced water
Na+	61200	32500	42500	28750	62000	70000	37750
K+	1000	1200	1100	700	2000	200	900
Ca++	7120	2640	4400	2480	5200	4760	4080
Mg++	1507	1118	1458	826	1847	1239	1142
Ba++	<0.0003	<0.0003	0.02	0.14	0.45	0.34	0.25
Sr++	518	125	467	337	1750	412	497
Fe(total)	0.088	3.9	0.1	0.19	0.04	0.04	0.02
CL-	111766	58324	77721	51240	111422	121051	68779
SO4--	480	450	660	550	220	570	720
HCO3-	281	647	317	488	268	244	305
CO3-	0	0	0	0	0	0	0
PH	6.02	6.51	6.4	6.17	6.34	5.91	6.54
Dissolved Solids evap@180Cº	189360	101450	133200	89008	189950	199300	117800

these water samples (i.e. C, D, E, F and produced water) were carried out according to standard methods.

Six water samples (i.e. C, D, E, F and produced water) have been tested for water-water compatibility test with different mixing ratios at surface and reservoir temperatures. Each mixture was kept for twenty four hours at desired temperature. The mixtures were filtered through cellulose nitrate filter paper with pore size of 0.45µm. The formed precipitates were collected, dried at 95 ºC and weighed to calculate the amount of deposits. The filtrates were immediately analyzed by Inductively Coupled Plasma (ICP) to determine the cations such as (Ca^{2+}, Sr^{2+}, Ba^{2+} and Fe) that might react with anions (i.e. SO_4, CO_3 and HCO_3) and form mineral scale.

In this study compatibility tests were performed between produced water which become injection water and mixed with different depths of formation waters (C, D, E, F and produced water) under surface and reservoir conditions. These compatibility tests showed different results based on the operating conditions as follows:

At surface temperature: Fig. 1 shows the amount of scale in (mg/L) as a result of mixing injection water with D formation water under surface temperature. The increasing in the amount of scale as injection water amount increases. This is confirmed in (Fig. 2) where the concentration of calcium increases as injection water increase. In (Fig. 2) blue columns represent calcium content before test and red columns represent calcium content after test. The drop in calcium ions (i.e. difference between blue and red columns) at each mixing ratio is scale based calcium ions. D formation water contains lower TDS (89,008 mg/L) than injection water (117,800mg/L).

E formation water shows high amount of scale which decreases as injection water increases as in (Fig. 3). Fig. 4 confirms the decrease in the calcium concentrations as the volume of injection water increase where the total dissolved solids in injection water is lower than in E.

Figs. 5 & 6 show the results of mixing A water with injection water under surface temperature where the amount of scale and calcium concentrations before and after test are clearly dropped as injection water volume increase (i.e. lower total dissolved solids). In (Figs. 7 & 8) the same trend of F results comparing with E & A waters (i.e. scale amount and calcium ions decreasing as injection water increase).

At reservoir Temperature: Fig. 11 shows scale amount of mixing of E formation water with injection water under reservoir temperature. The amount of scale is decreasing as injection water increase where TDS is lower than formation water. In Fig. 12 a slight decline in calcium concentrations comparing with Figs. (3 & 4).

C and D water shows a slight decrease in the amount of scale at reservoir temperature as injection water volume increase (Figs. 9, 10, 13, 19 and 20). The change in calcium concentration is slightly dropped in Fig. 14 comparing with Fig. 2 at surface temperature.

Observations from Figs. 15, 16, 17 and 18 show no significant effect of temperature on scale formation as compared between surface and reservoir temperatures. Scale amount under reservoir temperature is less than scale amount under surface temperature which strongly affects the scale solubility; also slightly decrease in calcium concentrations comparing with high drop in calcium concentrations at surface temperature.

SCALE PREDICTION

The predictions of scales have been performed using Multiscale software (7.1) under surface and reservoir conditions of temperature and pressure. This prediction calculate the saturation ratio which gives the indication whether scale is likely to form if SR above zero or not. In (Fig. 21) saturation indices as result of mixing of A formation water with injection water under surface conditions. Saturation indices are increasing as A formation water increase where Celestite scale is likely to form associated with Anhydrite & Gypsum. Fig. 22 shows a stable result for sulfate scales as result of mixing of F with injection water. Fig. 23 shows increasing in potential of Celestite as injection water increase (i.e. high TDS). E shows very high potential of celestite to form (i.e. high content of strontium ions in formation water) associated with gypsum and anhydrite (Fig. 24). Fig. 25 shows a slight decrease in saturation ratios as a result of mixing C with injection water.

Under reservoir conditions Fig. 26 shows a slight increase in scale potential where the major scale (Celestite) is associated with gypsum and anhydrite in most cases. Celestite and anhydrite are highly expected to form as F formation water increase (Fig. 27). Fig. 28 E shows very high potential of celestite to form under reservoir conditions of temperature and pressure (i.e. high content of strontium ions in formation water). Gypsum and anhydrite are decreasing as E formation water increase. C under reservoir conditions showed lower potential of saturation ratio than surface conditions (Fig. 29).

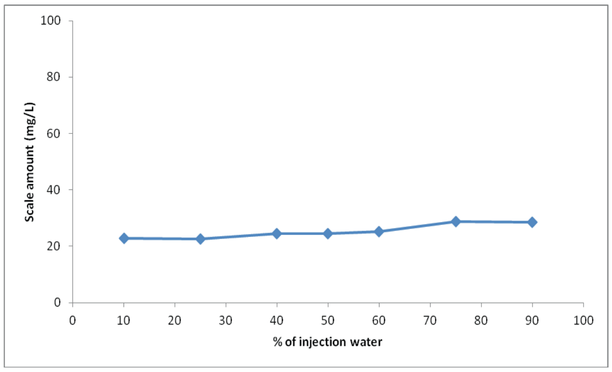

Fig. 1. Scale amount (mg) D mixing ratio at 106 ºF.

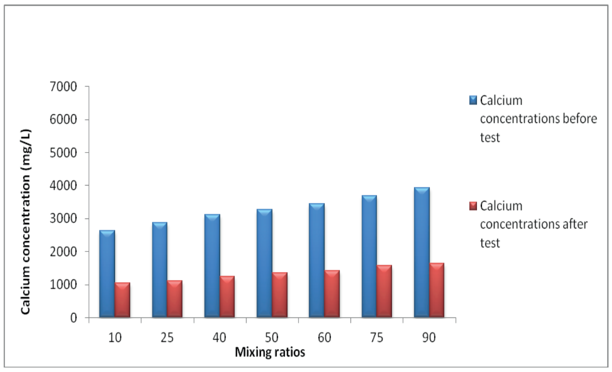

Fig. 2: Calcium concentration (mg/L) in filtrate for D after test at 106ºF.

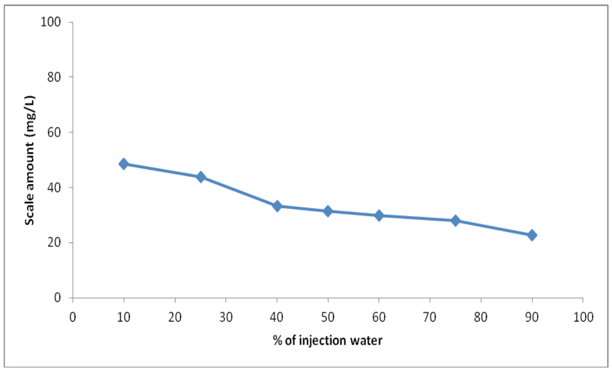

Fig. 3. Scale amount (mg) of E mixing ratio at 113 ºF.

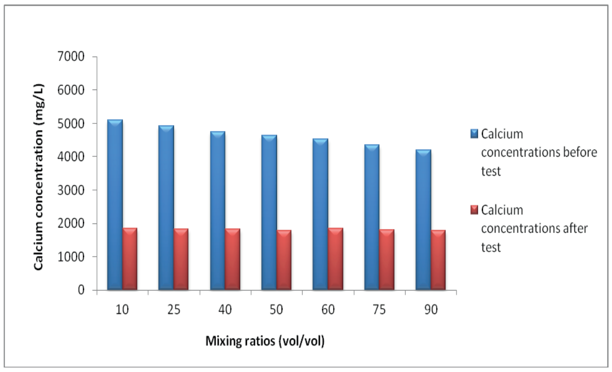

Fig. 4. Calcium concentration (mg/L) in filtrate for E after test at 113º

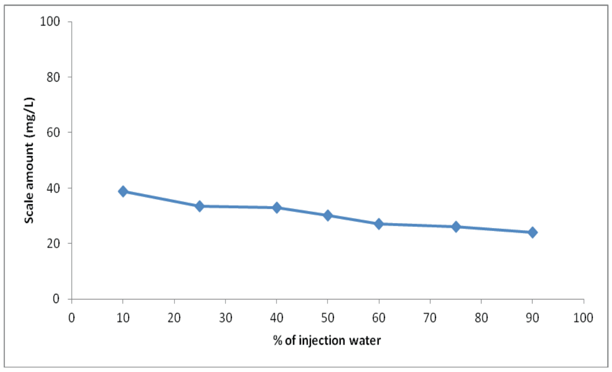

Fig. 5. Scale amount (mg) of A mixing ratio at 136ºF.

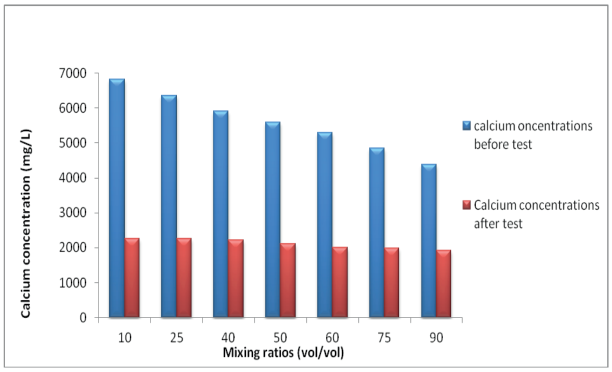

Fig. 6. Calcium concentration (mg/L) in filtrate for A after test at 136ºF.

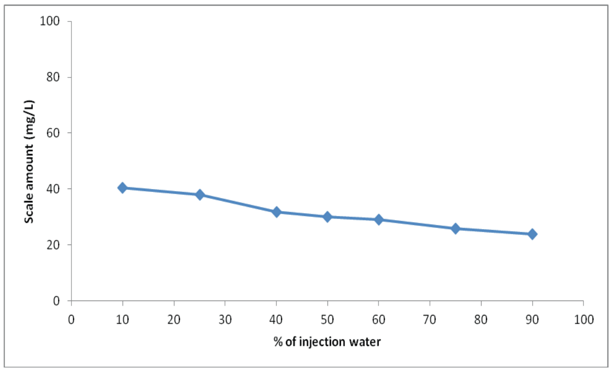

Fig. 7. Scale amount (mg) of F mixing ratio at 149 ºF.

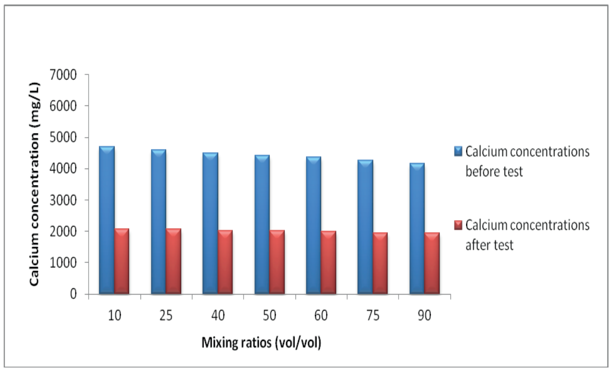

Fig. 8. Calcium concentration (mg/L) in filtrate for F after test at 149ºF.

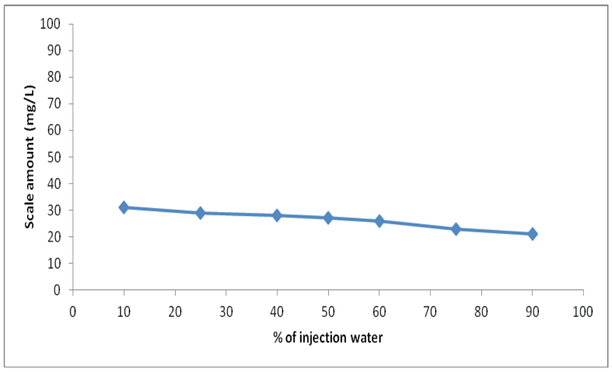

Fig. 9. Scale amount (mg) of C mixing ratio at 154 ºF.

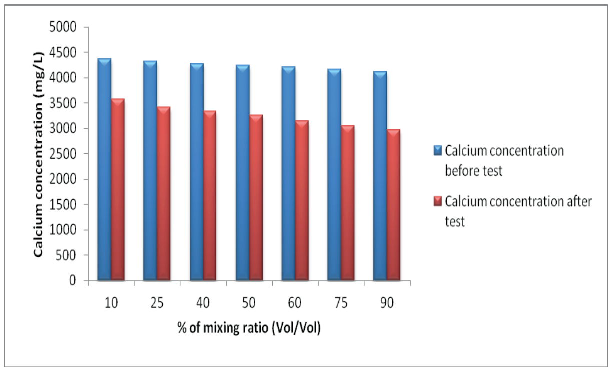

Fig. 10. Calcium concentration (mg/L) in filtrate for C after test at 154ºF.

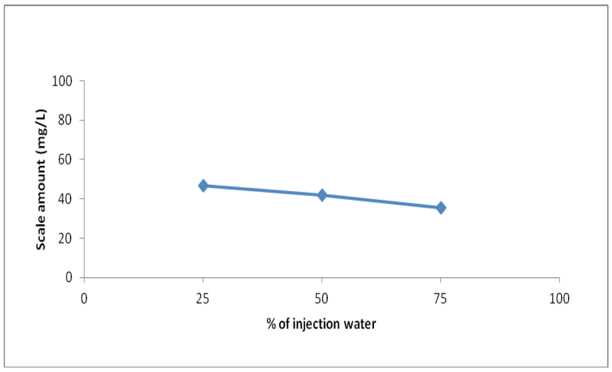

Fig. 11. Scale amount (mg) of E mixing ratio at 197ºF.

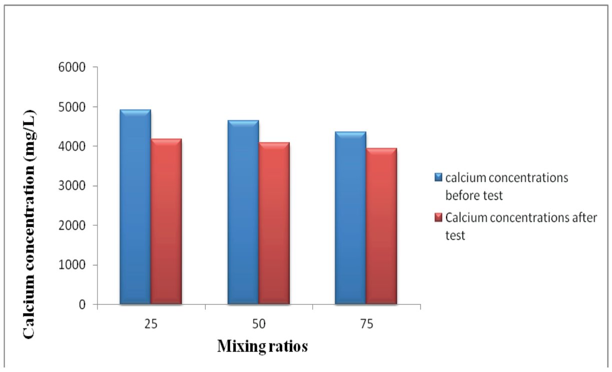

Fig. 12. Change in Calcium concentrations (mg/L) in filtrate for E before & after test at 197ºF.

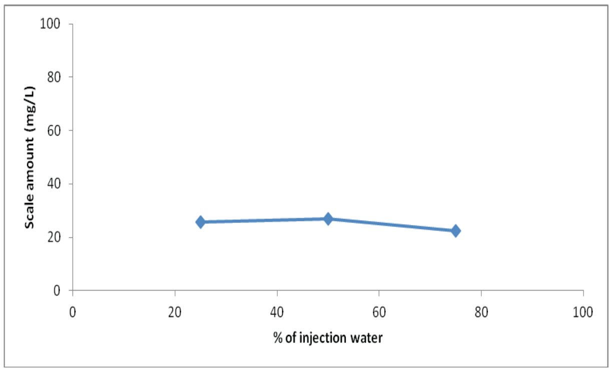

Fig. 13. Scale amount (mg) of D mixing ratio at 165ºF.

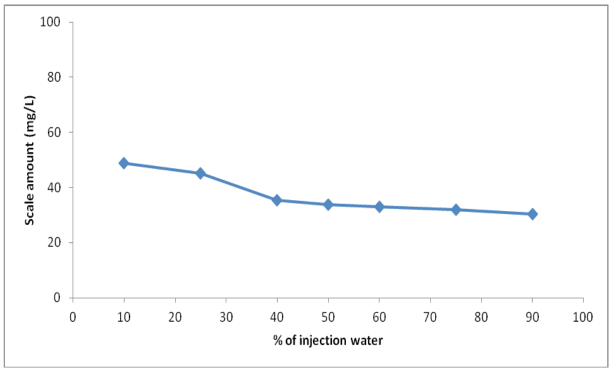

Fig. 17. Scale amount (mg) of A mixing ratio at 226 ºF.

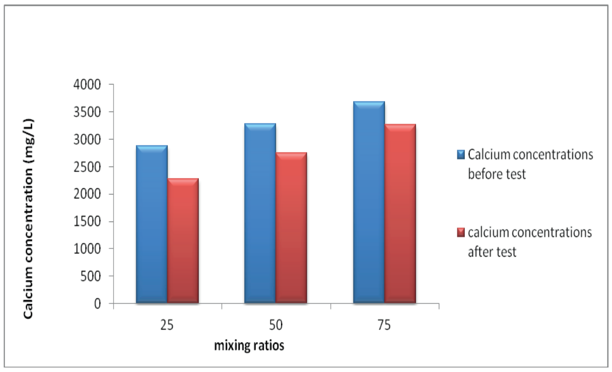

Fig. 14. Calcium concentration (mg/L) in filtrate for D mixing ratio at 165ºF.

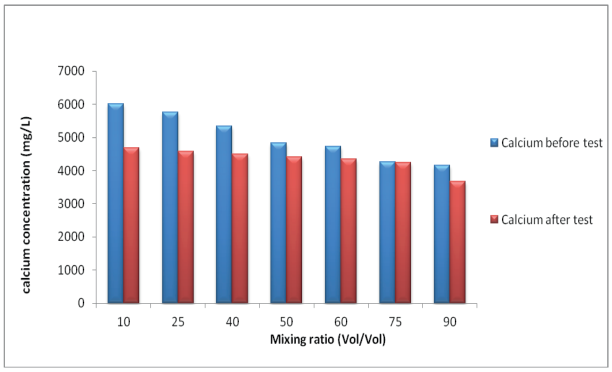

Fig. 18. Calcium concentration (mg/L) in filtrate for A mixing ratio at after test at 226ºF.

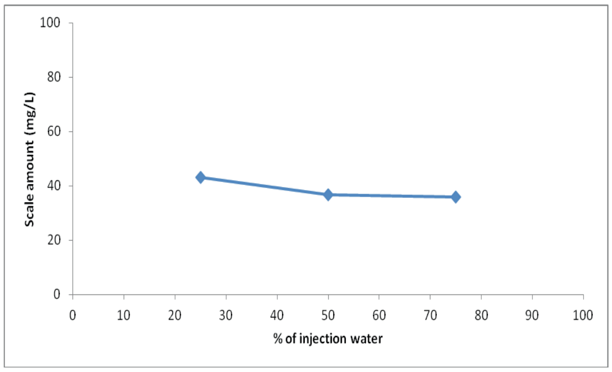

Fig. 15. Scale amount (mg) of F mixing ratio at 215ºF.

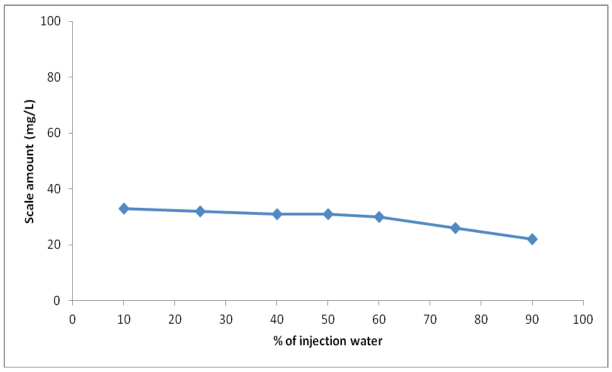

Fig. 19. Scale amount (mg) of C mixing ratio at 162ºF.

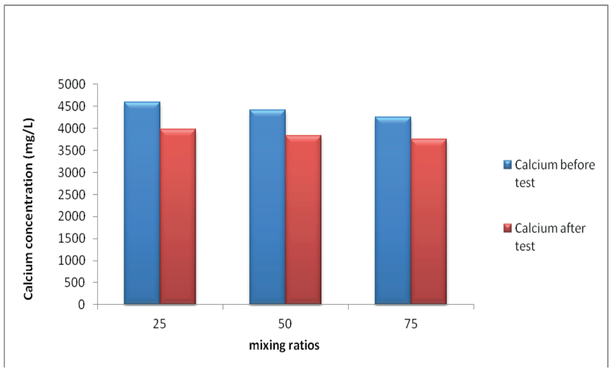

Fig. 16. Calcium concentration (mg/L) in filtrate for F mixing ratio at after test at 215ºF.

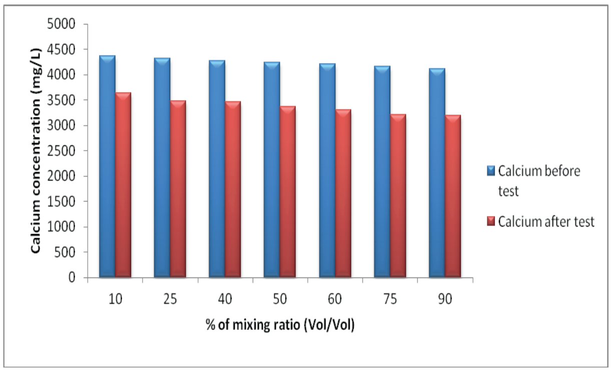

Fig. 20. Calcium concentration (mg/L) in filtrate for C mixing ratio at after test at 162ºF.

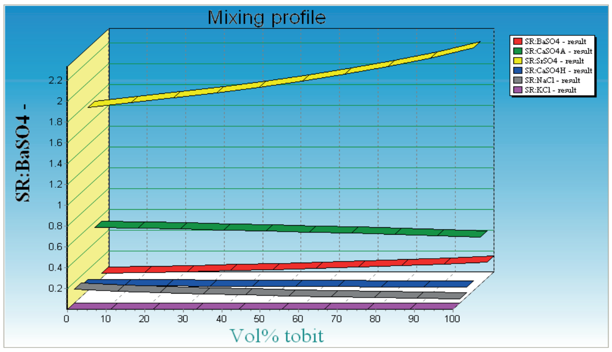

Fig. 21. Saturation indices for sulfate scales at surface conditions of temperature and pressure (A).

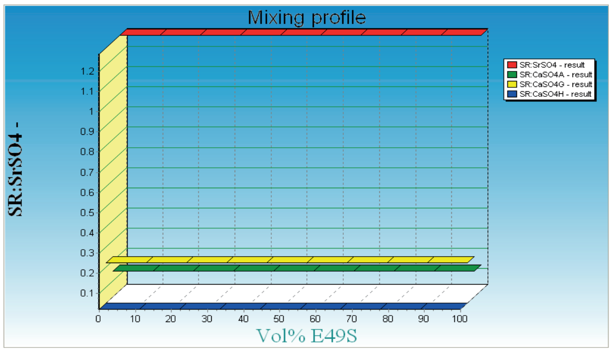

Fig. 22. Saturation indices for sulfate scales at surface conditions of temperature and pressure.(F).

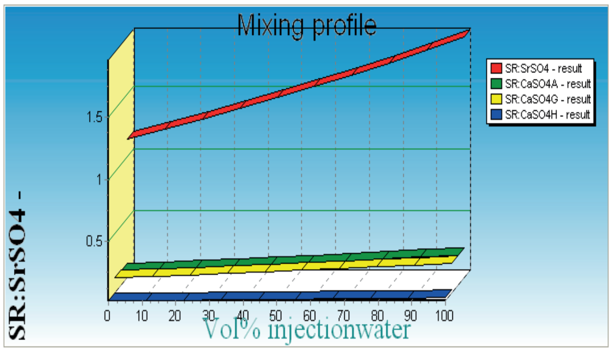

Fig. 23. Saturation indices for sulfate scales at surface conditions of temperature and pressure.(D).

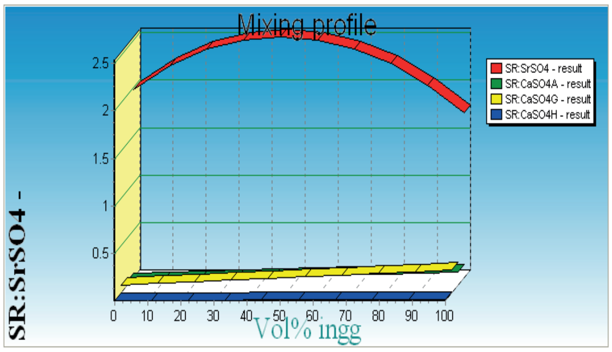

Fig. 24. Saturation indices for sulfate scales at surface conditions of temperature and pressure.(E).

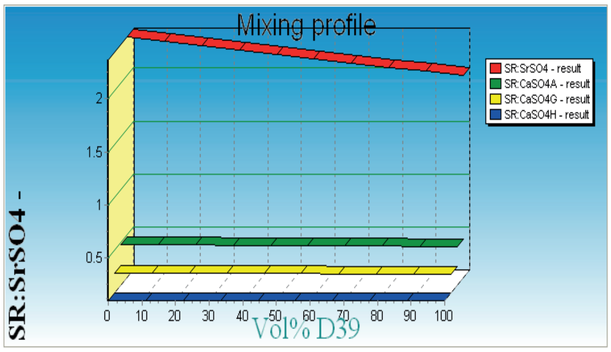

Fig. 25. Saturation indices for sulfate scales at surface conditions of temperature and pressure.(C) Under reservoir conditions.

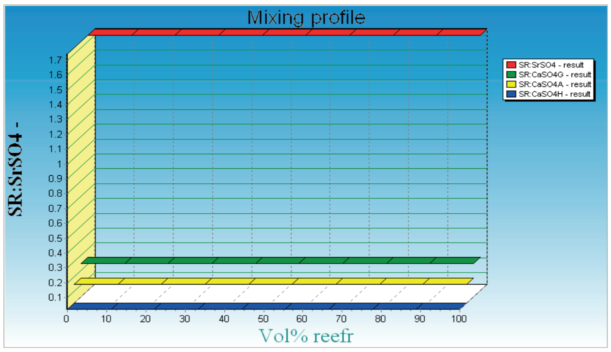

Fig. 26. Saturation indices for sulfate scales at reservoir conditions of temperature and pressure(A).

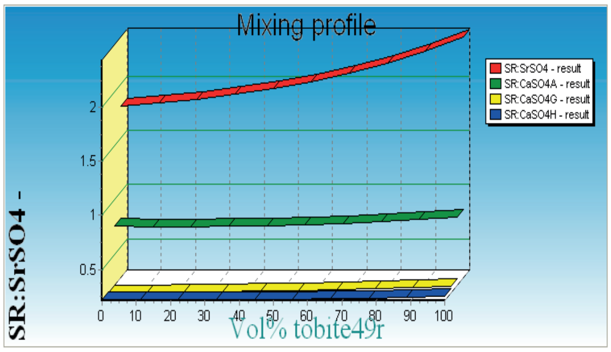

Fig. 27. Saturation indices for sulfate scales at reservoir conditions of temperature and pressure (F).

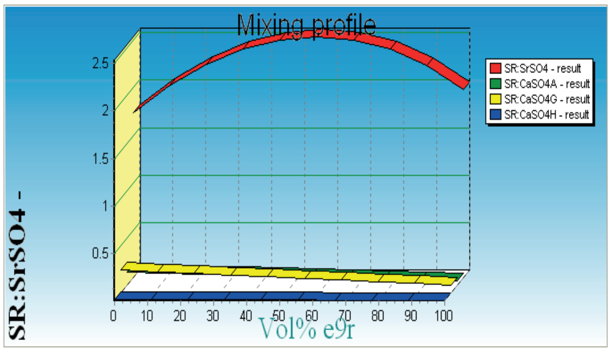

Fig. 28. Saturation indices for sulfate scales at reservoir conditions of temperature and pressure (E).

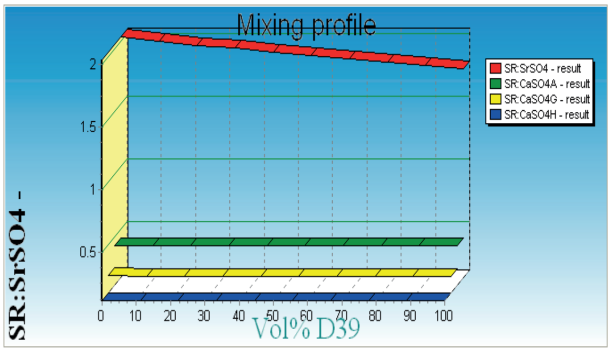

Fig. 29. Saturation indices for sulfate scales at reservoir conditions of temperature and pressure.(C).

CONCLUSIONS

Tests were conducted to identify the main scaling compounds when produced water mixed with the formation water. These tests demonstrated that $CaCO_3$ and $SrSO_4$ could be precipitated in different amounts depending on mixing ratios and conditions of temperature and pressure. On the basis of positive evidence of scaling encountered in the laboratory tests, a computer simulation program has been carried out to support the incompatibility of these brines when mixed at desired conditions.

a. The effect of temperature is observed on amount of scale for all mixing ratios where the amount of different types of scales are higher under surface conditions than reservoir conditions

b. A complex scale was observed under surface conditions as Celestite, Anhydrite and Gypsum.

c. Under reservoir conditions Carbonate and Celestite are most likely to occur.

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