# Estimation of $H_2S$ Produced from Reservoir Souring

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## Abstract:

The increase of the produce $H_2S$ due to water injection is known as reservoir souring. The sulfate reduced bacteria (SRB) which may be exist in the injected water reduces the sulfate which already existing in the reservoir. This study includes prediction of $H_2S$ for Mauddud reservoir in the Ahdeb oilfield by using specialized reservoir numerical simulator. Reservoir souring modeling utilized to enable operations to make better decisions for remedial actions to either prevent souring or to mitigate its impact. The aim of this study is to estimate the probability and timing of the start of $H_2S$ production in produced fluids. The results showed that the maximum concentration of $H_2S$ in the prediction production well was reached to 2.9 Ibm/day which occurs after 180 days this carry out when the SRB concentration was about 2000 ppm .The SRB concentration is increasing in areas where the sulfate is in high concentration and also there is a direct relationship between the SRB concentration and the $H_2S$ concentration.

**Key word:** Reservoir souring, Sulfate Reducing Bacteria, Modeling, Prediction.

## الخلاصة:

زيادة انتاج كبريتيد الهايدروجين بسبب حقن الماء تعرف بحموضة المكامن، ان البكتريا المختزلة للكبريتات (SRB) تعمل على اختزال الكبريتات المتوفره في ماء الحقن. تشمل هذه الدراسة بناء موديل مكمني ثنائي الابعاد لمكمن مودود

باستخدام برنامج المحاكاة المكمني (Reveal) من اجل التنبأ بكمية كبريتيد الهيدروجين المنتج لنفط مكمن مودود في حقل الاحدب وكذلك معرفة العوامل التي توثر على زيادة البكتريا المختزلة للكبريتات (SRB) . الموديل المكمني يمكن المشغلين من اتخاذ افضل القرارات سواء كانت للحماية من انتاج كبريتيد الهايدروجين او للتقليل من تأثيره.

الهدف من هذه الدراسة هو تخمين احتمالة ومعرفة وقت بدء انتاج كبريتيد الهيدروجين في السوائل المنتجة، وأظهرت النتائج أن اعلى تركيز يصل اليه كبريتيد الهيدروجين($H_2S$) في بئر الانتاج التوقعي بعد 180 يوم هو 2.9 باوند / يوم عندما يكون تركيز البكتريا المختزلة للكبريتات حوالي 2000 جزء في المليون. تركيز البكتريا المختزلة للكبريتات (SRB) تزداد بالمناطق التي يتوفر بها وفرة من الكبريتات و كذلك توجد علاقة مباشرة بين تركيز SRB وتركيز $H_2S$.

## Introduction:

The popular secondary recovery method is water injection. The water injection into a reservoir is carried out with two objectives: to maintain pressure and to sweep oil towards producing wells [1]. The side effects of water injection in many reservoirs are the hydrogen sulfide ($H_2S$) generation. Nowadays, the widely accepted mechanism of reservoir souring is the microbial activities in the reservoir. The reservoir souring is interfered by sulfate reducing bacteria (SRB) which reduce the sulfate and generate $H_2S$ [2, 3]. Bastin et al. presented the first indication of SRB activity in oil reservoirs in 1926 [4]. The production of $H_2S$ in the reservoirs causes numerous of problems such as toxicity to humans, corrosion of production facilities, reduces the quality of produced hydrocarbon and plugging of injection wells [5, 6].

There are three mathematical models that describe the reservoir souring. The first mathematical model was a mixing model [1] assumed that reaction occurs in a mixing zone between the injected water and the formation water where all of the requirements are available for SRB activity. The injected water is normally rich of sulfate (i.e., electron acceptor) and the formation water which rich with fatty acids and other organic compounds (i.e., substrates) because of the contacted with the oil phase. The next mathematical model is the biofilm model [2]. The main approach of this model is that $H_2S$ production due to SRB growth in a biofilm in the formation rock close to the well of injection. Therefore, $H_2S$ is generated in this area and transported toward the producers. The third mathematical model for reservoir souring prediction is the Thermal Viability Shell (TVS) [7]. TVS emphasizes the temperature and pressure effect on SRB activity. This model is used when injecting low-temperature water to the high-temperature reservoir, the region became with a suitable temperature for the SRB growth and $H_2S$ would be produced.

The modeling of reservoir souring is used to predict the onset and the scope of reservoir souring for preparing development and treatment plans. The operators can plan for possible treatment options by the knowledge of timing, amount of souring, and the wells that are prospective to $H_2S$ production. Also, operators would like to know if the water injection could cause reservoir souring [6, 8].

The object of the present work is to design a 2D souring module for the Mauddud formation in Ahdeb oilfield by using Reveal Reservoir Simulation Software in order to study the decrease of hydrogen sulfide ($H_2S$) production in the oilfields.

## Methodology:

Oilfields contain a big collection of anaerobic bacteria which called Sulfate Reducing Bacteria (SRB). These bacteria reduce sulfate to hydrogen sulfide (H2S) in the existence of an energy and electron source as well as a carbon source [9, 10]

Sulfate reducing bacteria isolated and enumerated by using Most Probable Number (MPN) technique from the injection and produced water of Ahdeb oilfield in Iraq. The medium that used to isolation these bacteria was American Petroleum Institute (API) medium [11]. The composition of this medium was mentioned in the Table (1).

**Table (1) The chemical composition of the API medium for SRB growth [11].**

| Chemical ingredient | Amount (g/L) |
|---|---|
| yeast extract | 1 |
| $MgSO_4.7H_2O$ | 0.2 |
| $Fe(SO_4)_2(NH_4)_2.6H_2O$ | 0.2 |
| NaCl | 10 |
| $KH_2PO_4$ | 0.01 |
| Sodium lactate | 0.15 |
| Ascorbic acid | 0.1 |

In order to ensure that SRB is a producer of sulfide, the laboratory experiments work was performed by using spectrophotometer method [12] and also determined the energy source that consumed by these bacteria by using high-performance liquid chromatography (HPLC) system which used sodium lactate as energy source [13].

The results showed that the numbers of bacteria in injection water were higher than the number in produced water while the result of sulfide production by SRB showed that inversely correlated to the concentration of sodium lactate [8] as shown in Figures (1 and 2). Also, there is a direct relationship between SRB concentration and sulfide production.

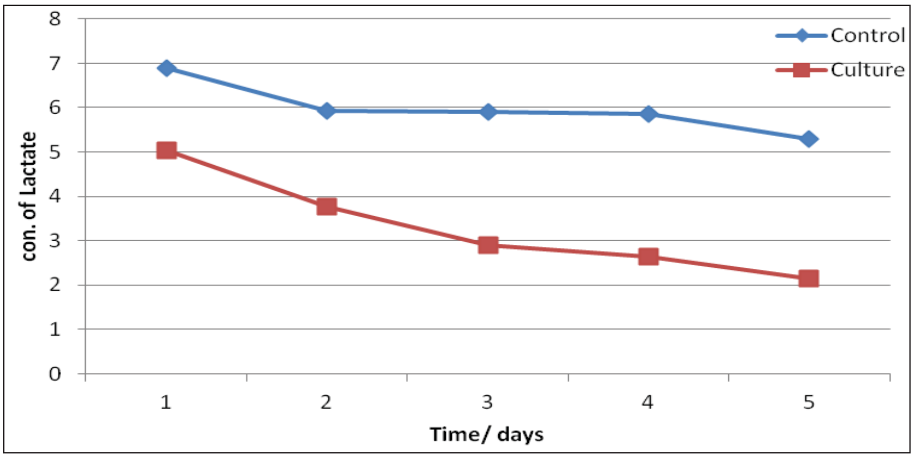


Fig. (1) Utilization of lactate in SRB culture [8].

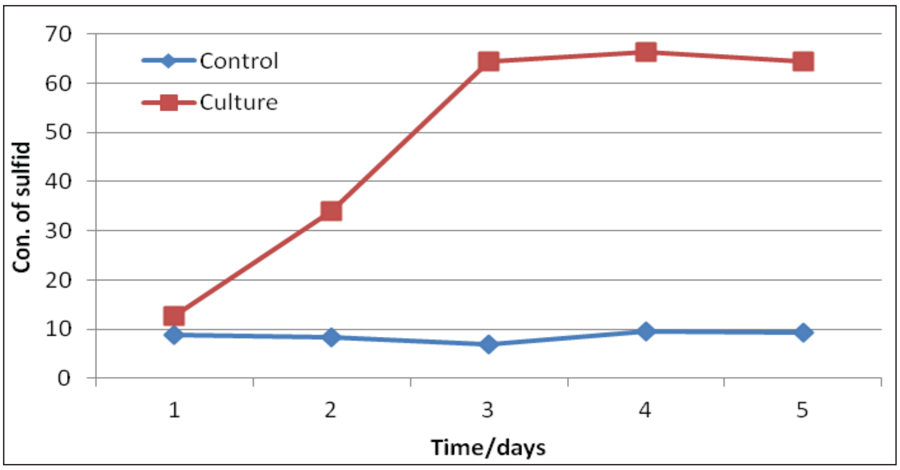


Fig. (2) Production of H2S in SRB culture [8].

It is beyond the scope of the above work to measure the relevant parameters of reservoir souring modeling in order to design prediction models of biogenic reservoir souring due to water injection [8].

Designing a reservoir model comprises several steps enables to get a closer perception of the reservoir and the fluid movement within the present conditions under the surface of the earth. These steps are include inserting a reservoir and its fluid data, deal with these data properly to obtain the results, export as tables, data and graphs are easy to understand.

## Full Reservoir Model Characterization

The two-dimensional Specialized Reservoir Numerical Simulator; Reveal Reservoir Simulation Software was utilized to design a model for the reservoir characteristics and performance predictions for the Mauddud formation in the Ahdeb oilfield.

### Grid Construction

The grid geometry defines a Cartesian grid system for Mauddud reservoirs which represented by two dimension grids system of 15 grid elements along the x-axis and 15 grids along the y-coordinate.

The dimension along x-axis (15*2000) ft, along y-axis (15*667) ft, so the size of this field was 30000 * 10005 ft covers the reservoirs and the aquifer.

### Fluid Physical Properties

The Mauddud reservoir crude is heavy oil with a stock tank gravity of 22.5 API and an initial GOR of 112.88 $M^3/M^3$. The bubble point pressure was 3157.58 psi and original formation pressure was 4100 psi at a reference depth of 3070 m.

### Rock Compressibility

The rock compressibility of Mauddud formation was $5\times10^{-5}$ 1/psi at the reference pressure of 4100 psi.

### Water-Oil Relative Permeability Curves

The relative permeability for the fluid of Ahdeb oilfield/ Mauddud formation was obtained from core analysis. Figure (3) showed the water oil relative permeability in Mauddud.

After make averaging to these curves, the outcomes of water oil relative permeability data entered in the program were present in Figure (4).

### Water Chemistry Properties

The souring parameters of the field were taken from the results of the research under publishing [8] which includes:

- **Temperature dependence**

  Minimum and maximum temperature at which the SRB may grow was 38 – 88 °C.
- **Concentration dependence**

  A maximum concentration of SRB was 2000 ppm.
- **Growth and respiration dependence**

  The amount of $H_2S$ generated for carbon source used during metabolism was 2.4 and the amount of $H_2S$ generated for carbon source used during growth was 25.5.

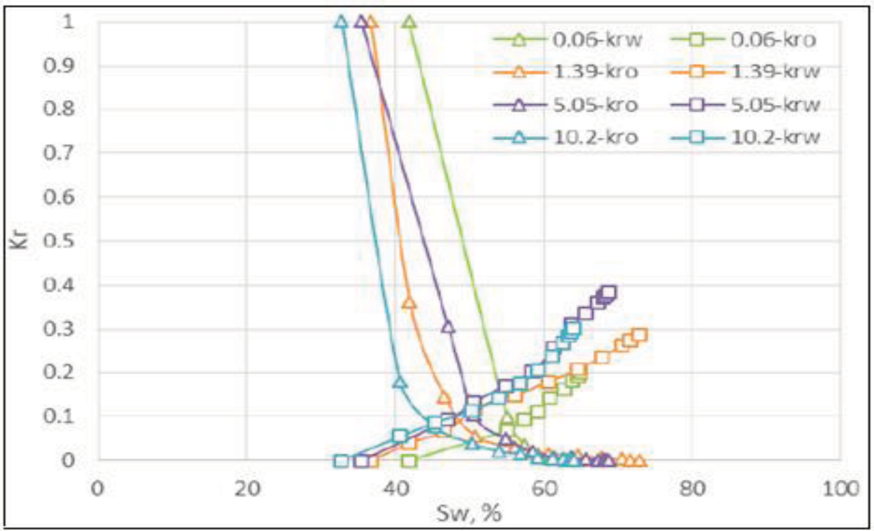


**Fig. (3) Water oil relative permeability in Mauddud formation [14].**

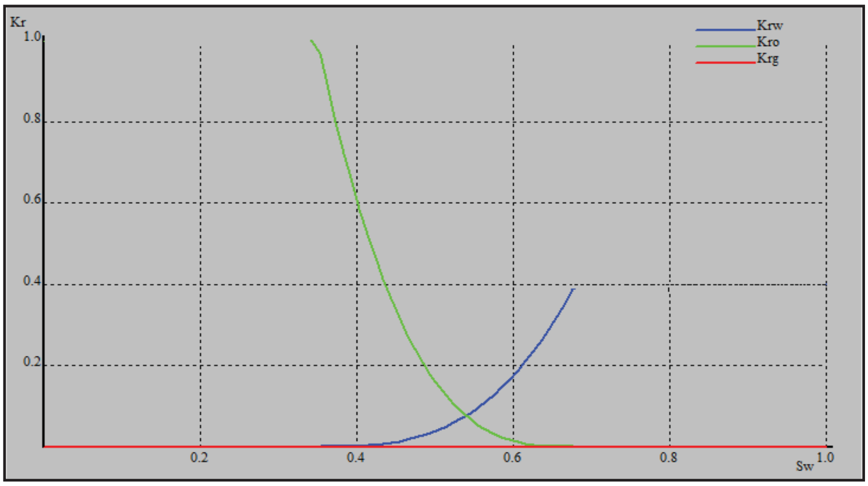


**Fig. (4) Oil/water relative permeability curves for Mauddud formation after averaging.**

## Wells Positions:

Quarter of five spot model was built which consists of two pairs of well production and injection to the Ahdeb oilfield / Mauddud formation. Defined wells position by a completion table containing the I, J coordinates of the completed blocks. The location of producer well was 567200 m long × 3590600 m width and the injection well location was 568800 m long × 3589200 m width .The range between production and injection well was 7874 ft. The depth of the production well was 3091m and to the injection well was 3148m. The type of completion was tubing to the production and injection well and in the production well there was Submersible pumps. The locations of the producer and injector wells for the Mauddud formation in Ahdeb oilfield in the model are present in Figure (5).

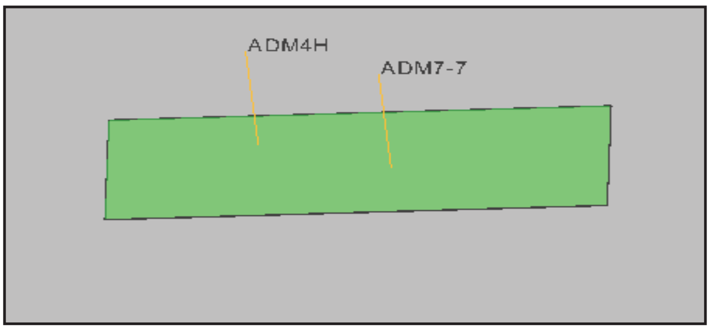


**Fig. (5) The locations of the producer and injector wells for Mauddud formation in Ahdeb oilfield.**

## Component Initialization:

The concentrations of component get from the physical and chemical analysis of produced water of Ahdeb oilfield which taken from the results of the research under publishing [8]. The result of physical and chemical analysis for water was present in Table (2).

**Table (2) Physical and chemical characteristics of the produced and injection water samples of Ahdeb oil field [8].**

| Sample | Temp. °C | PH | Salinity (ds.m-1) | Ca | Mg | Cl | $So_4$ |
|---|---|---|---|---|---|---|---|
| | | | | ppm | | | |
| Produced water | 42 | 6.4 | 170.2 | 829303 | 2331 | 80849.7 | 624.6 |
| Injection water | 38 | 6.8 | 170.9 | 8877.5 | 2503 | 100224.3 | 669.9 |

## Production and Injection Schedule:

In 2016 the well ADM4H started production from Mauddud formation in the Ahdeb oilfield and the production rate was range from 1300 to 600 STB/day. The well was closed for some months in various years of production because of lowering the pressure. In 2017 ADM7-7 was added to injection to the reservoir and the rate of injection was 683 STB/day. The injection continued from this well till now.

## The Simulation Results:

The oil produced and the pressure of production well was shown in Figure (6) which present the matching with the field data that show the oil rate was 1300 STB/day for the first months and begin decreased gradually after six months of produced in the same time that the pressure decreased where the static pressure was 3370 psi due to the continues production from the well and the quantity of the water injection was little to maintained on the pressure and sweep the crude oil toward the production wells.

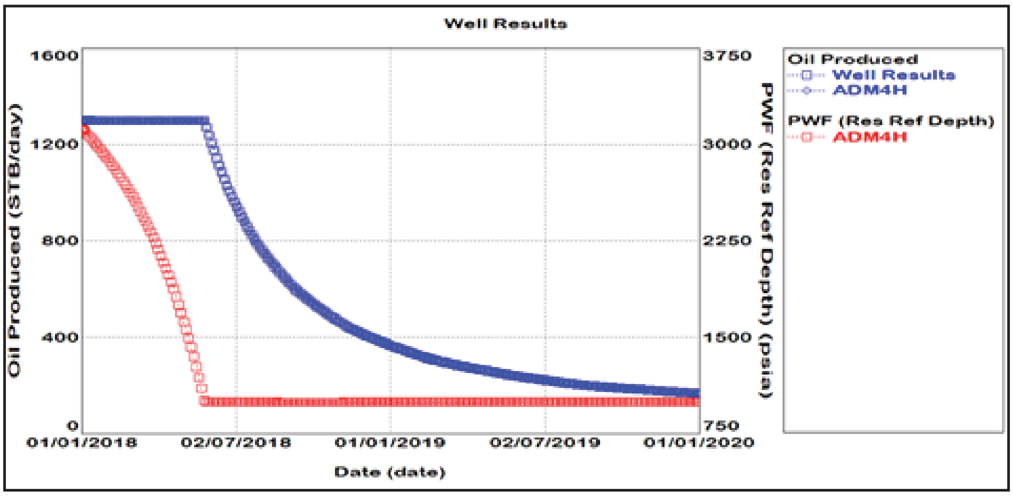


**Fig. (6) Oil produced rate (STB/day) and the Reservoir pressure (Psia) for the field.**

Figure (7) was shown the water cut for the well was range 5-60% in the time period of the actual production of the field but it began to increase to reach to 80% at the prediction period due to increasing in the water produced in this field and also showed the rate of injection water for the well ADM7-7 was 683 STB/day and it is a constant value as present.

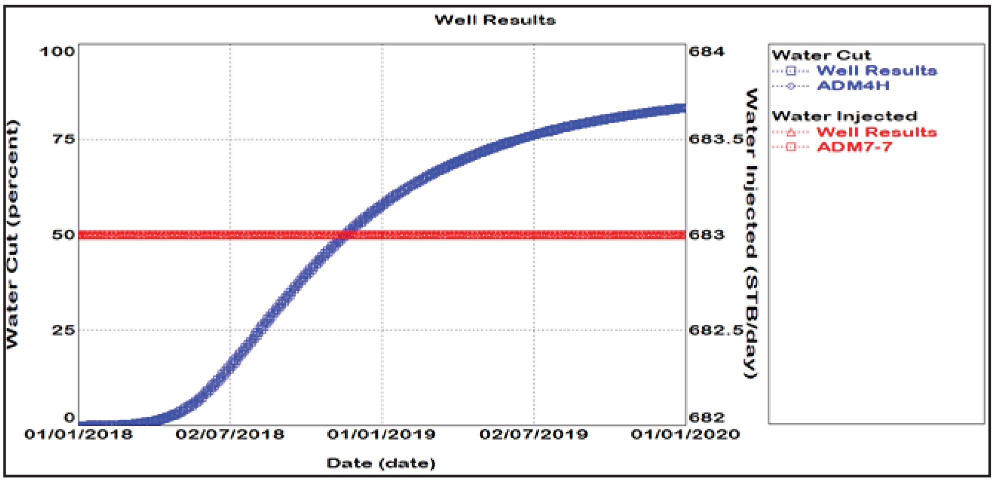


**Fig. (7) The water cut for the field (percent) and water injection rate for the field (STB/day).**

Figure (8) show that the mass-produced rate of sulfate is decreased while the mass produced rate of sulfide is increased due to the fact that the SRB reduced sulfate to sulfide, these bacteria became active when sulfate and the organic compounds are available to do their metabolic and grow, and this mechanism caused the microbial reservoir souring [15].

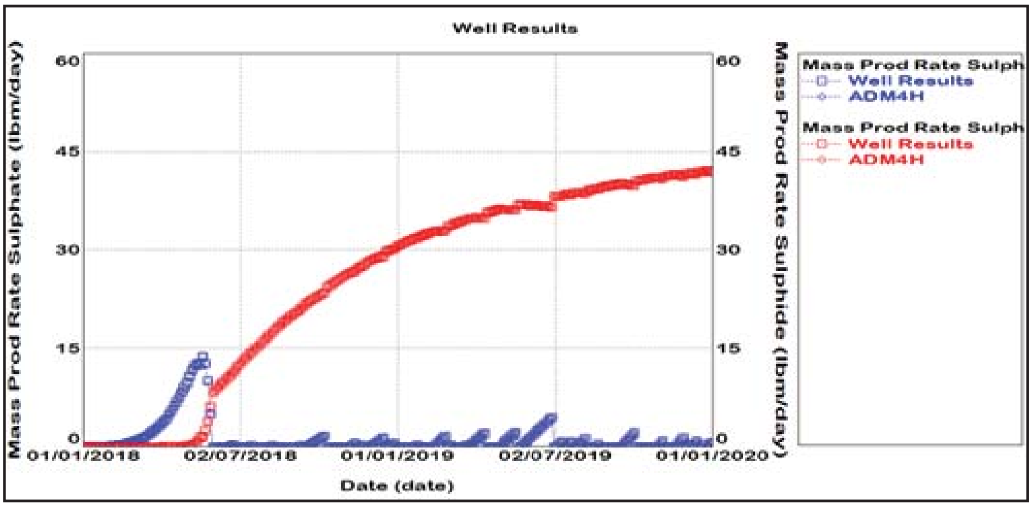


**Fig. (8) Mass produced rate of Sulfate and Sulfide (Ibm/day).**

The result of prediction of $H_2S$ in the production well is given in Figure (9) which shows that maximum concentration of the observed $H_2S$ in the ADM4H well was 2.9 Ibm/day which occurs after around 180 days because of the shortest distance between injector and producer but after that the curve is decreased gradually due to the effect of adsorption, dispersion and $H_2S$ transport [1, 16].

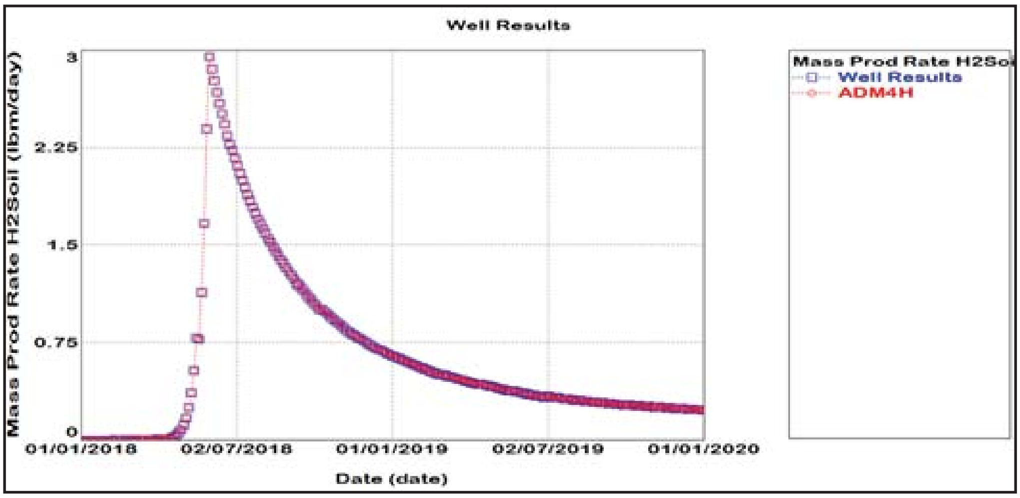


**Fig. (9) The prediction of $H_2S$ in the produced well (Ibm/day).**

The initial conditions of the reservoir is show in the Figure (10 and 11) which was the reservoir temperature about 192 °F and the SRB concentration 0 ppm and when the ADM7-7 well began injected water the temperature become lowered around the injector after around 129 days to reach about 186 °F as shown in Figure (12) which is suitable for SRB growth, Figure (13), because these bacteria are able to grow at high temperatures which excess of 80 °C like the *thermophiles* and *hyperthermophiles* species [17].

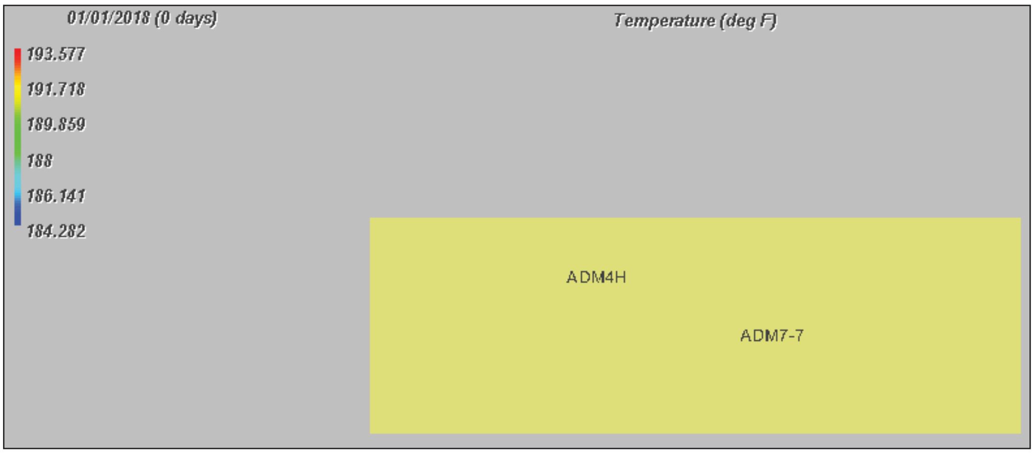


**Fig. (10) The temperature of the reservoir at first (°F).**

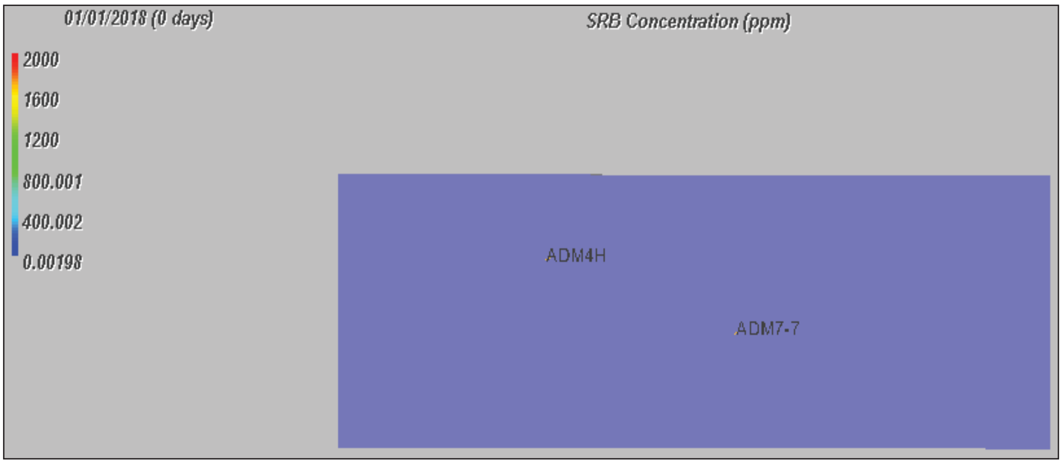


**Fig. (11) The SRB concentration of the reservoir at first (ppm).**

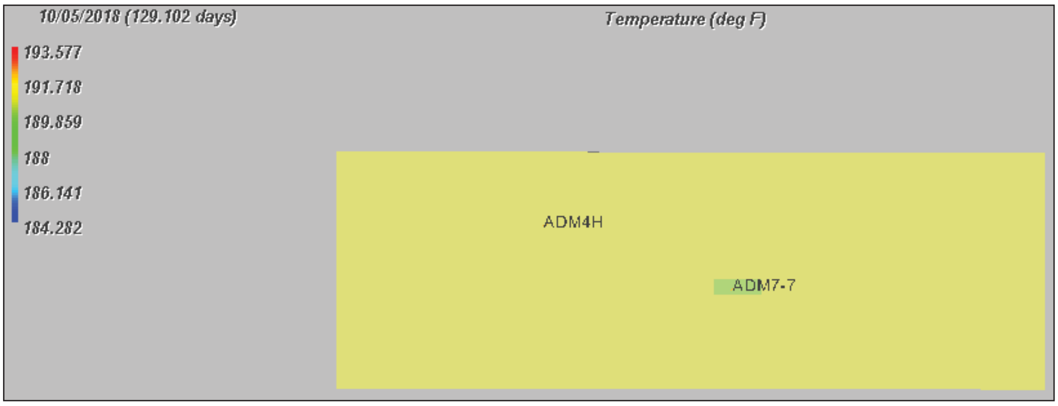


Fig. (12) The Temperature of the reservoir after 129 days of water injection (°F).

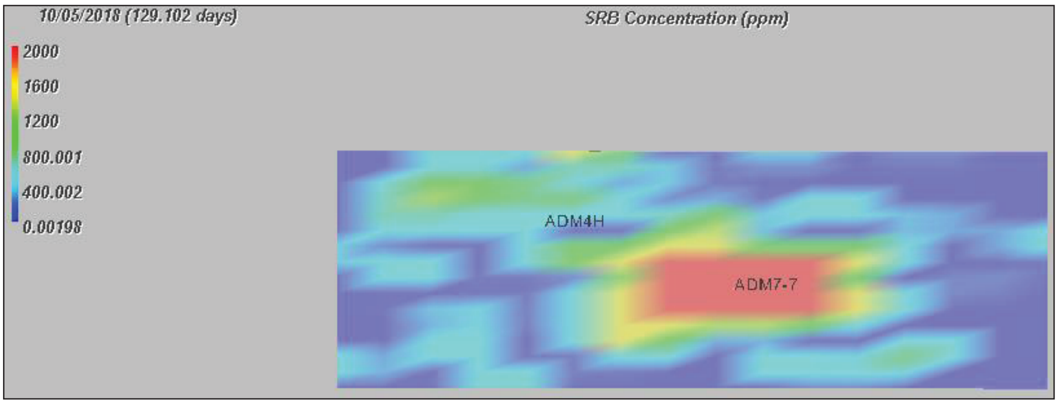


Fig. (13) The SRB distribution in the reservoir after 129 days of water injection (ppm).

Also Figure (14) show the $H_2S$ concentration was increasing in the same area that the SRB increased while the sulfate concentration decreased, Figure (15), because of the fact that the SRB are obligate anaerobic bacteria that gain their energy from reducing of sulfate to sulfide, as well as SRB need a balanced nutrition to do their metabolic and grow [18, 19]. From this can found a direct relation between the SRB concentration and $H_2S$ concentration [20].

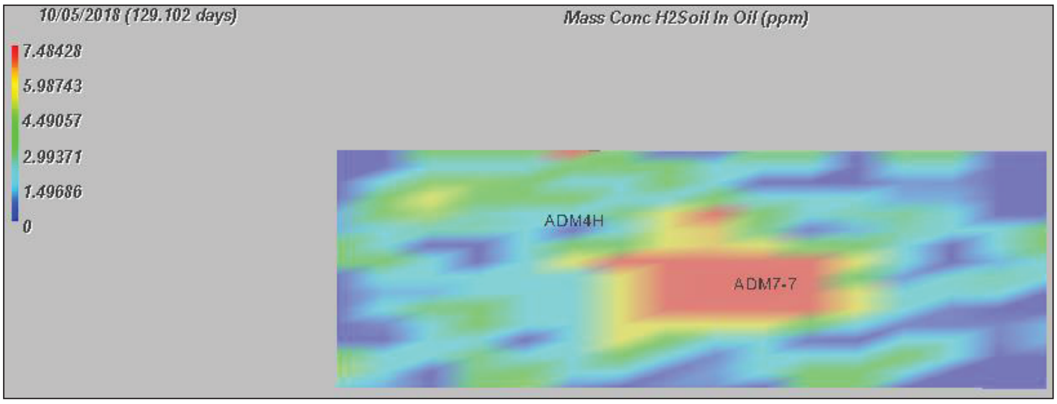


**Fig. (14) Mass concentration of $H_2S$ in oil after 129 days of water injection (ppm).**

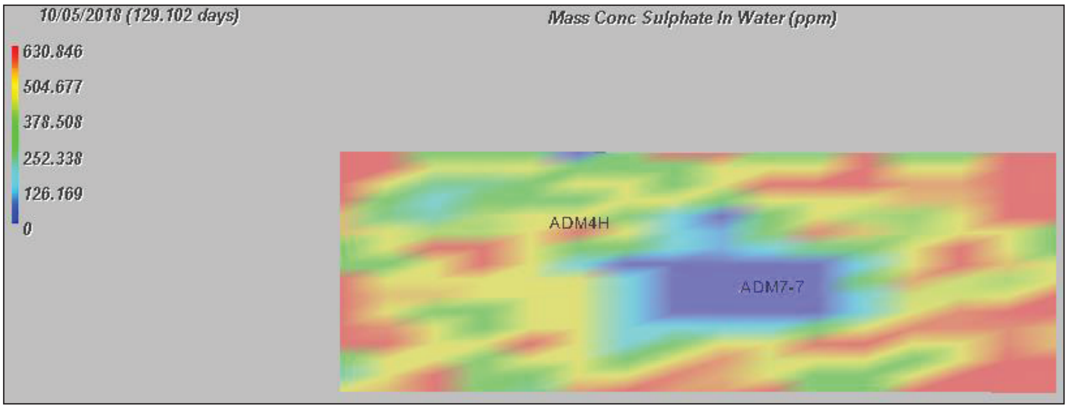


**Fig. (15) Mass concentration of sulfate in water after 129 days of water injection (ppm).**

## Conclusion:

1. The maximum concentration of the hydrogen sulfide ($H_2S$) in the produced well was 2.9 Ibm/day which occurs after around 180 days.
2. The SRB concentration is increasing in areas where the sulfate is in high concentration.
3. A direct relationship was noted between the SRB concentration and the $H_2S$ concentration.

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