The Role of Chemistry of the Oil-Field Water in the Distribution of Reservoir Pressures: A Case Study of Mishrif Reservoir in the Southern Oil-Fields, Iraq

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Abstract:

Mishrif Formation is the main reservoir in oil-fields (North Rumaila, South Rumaila, Majnoon, Zubair and West Qurna) which located at Basrah southern Iraq. The Inductively coupled plasma-Mass spectrometer (ICP-MS) was used for the water chemistry analysis and Scanning Electron Microprobe (SEM) for the purpose of mineralogy diagnosis. A weak acidic water of salinity six-time greater than seawater plays a role in generating the formation pressure and controlling the fluid flow. The potentiometric subsurface maps were modeled and the direction of super-pressure sites that are of a great importance in the oil exploration were marked to pay attention during future drilling.

Key words: Potentiometric map; Salinity; Mishrif Formation; Oil-field water.

1. Introduction:

The Mishrif Formation in southern Iraq (North Rumaila oil-field (R), South Rumaila oil-field (RU), West Qurna oil-field (WQ), Zubair oil-field (ZB) and Majnoon oil-field (MJ)) was studied Figure (1). The Mishrif Formation, Cenomanian - Early Turonian in age is a regional shallow water limestone succession that shoals upward, due to progradation, from basinal deposits [1]. It overlies oligosteginal carbonates of the Rumaila Formation near the Iraq-Iran borders and Basra area in SE Iraq [2, 3, 4, &5]. The Mishrif carbonate facies is recognized by four facies: restricted shelf, rudist build-up, open shelf and sub basinal. Mishrif facies merge into each other and boundaries are not sharp or distinct [6]. Rule of the hydrochemical indices is used in prospecting hydrocarbons based on the hydrochemical data of the Mishrif oil-field waters [7]. Chloride and sodium are predominant ions in the
Mishrif reservoir [8&9]. Fluid movement often is studied based on the values of reservoir pressure by taking readings and ignoring the study of solution salinity. The hydrochemical studies seem to be few or not available in the Mishrif reservoir, particularly, those dealing with fluid-rock interactions. The dissolution and precipitation are the main chemical processes that determine the amount of salinity which is an effective factor in determining the flow path in the reservoir [9]. The aims of the present study are to define the type of the oil-field water, model the flow direction of the fluid in the reservoir using vector potentiometric maps and then pinpoint the high-pressure sites in the reservoir which serve drilling and prospecting processes.

Fig. (1) Location map shows the oilfield studied [10].

2. Location and structure of the study area:
The studied oil-fields are located in Basrah, southern Iraq Figure (1). The dimensions (length and width) of these oil-fields are: West Qurna (35, 8km), Majnoon (48, 11 km), Zubair has three domes; Shuaiba (34, 17 km), Rafidiya (11, 8 km), and Safwan (4, 6 km) [10]. The West Qurna, North Rumaila and South Rumaila are considered as one structure according to the seismic data collected from the Oil South Company in 1987. The study
area is relatively flat terrain with a gradient of less than 10 cm/km. It is a part of the Stable Shelf within Zubair subzone of the Mesopotamian zone. The fold structures of the study area mainly have trend NW-SE in the eastern part and N-S in the southern part. It has a uniform structural style controlled by the underlying basement. Structures of the Mesopotamian zone usually have positive residual gravity anomaly except for the structures of Zubair, Rumaila is associated with the negative residual gravity anomaly. The negative gravity anomalies within the structures are underlain by infra-Cambrian salt. The Sanam salt plug is a result of the action the salt dome in the southern part of the Zubair subzone [11].

3. Materials and Methods:

The chemical composition and physical parameters of oil-field waters in the Mishrif Formation are studied in twenty-five oil wells; five water samples from each of the Rumaila North (R), West Qurna (WQ) and Majnoon (MJ), four samples from the Rumaila South (RU), and six samples from Zubair (ZB). The analysis was conducted by inductively coupled plasma- mass spectrometry (ICP-MS) technique in the laboratories of ALS, Spain. The salinity potential maps were drawn using the surfer software to clarify the fluid path flow. The hydrochemical formula depends on cations and anions in em in addition to pH and TDS [12] was expressed by the following equation:

\[
TDS \ (gm/l) = \sum \text{Anions em\% in descending order} \times pH
\]

Equation calculated the concentrations more than 15%, and concentrations less than 15% were ignored.

Scanning Electron Microscope (SEM) was conducted to identify the mineralogy of the reservoir.
4. Results and discussion:

4.1 Reservoir hydrochemistry

The detailed chemistry results of the studied reservoir are presented in Table (1). The Na$^+$, Ca$^{2+}$, Cl$^-$ and SO$_4^{2-}$ ions compose of more than 90% of the total TDS; where ions descended as Na$^+$ > Ca$^{2+}$ > Mg$^{2+}$ > K$^+$ and Cl$^-$ > SO$_4^{2-}$ > HCO$_3^-$, so the oil-field waters are dominated by Na and Cl. The Na content is seven times more than seawater and ranges from 68779 ppm in WQ to 81895 ppm in MJ. The Na availability in the oil-fields is attributed to the long-term water trapping period and sodium solubility, where [13] pointed out that the high sodium content in the brines related to its high mobility in the hydrosphere. Salt domes are well known in the study area and may contribute to add Na and Cl to the brines.

The Ca content shows twenty-eight times in comparison to seawater, ranging from 9837 ppm in MJ to 12196 ppm in the WQ. The availability of Ca is a function of reservoir dissolution and calcium carbonate scale may be formed when is being oversaturated, where it is a most common scale found in plugged oil-field reservoirs [14].

The lack of Mg in brine is linked directly to dolomitization [15], a twice as much as seawater was recorded varying from 2031 ppm in MJ to 3091 ppm in WQ. The high Mg content indicates a low rate of dolomitization and dissolving of Mg-bearing minerals. Potassium content increases in aqueous solutions under high temperature until the sylvite precipitates [16]. Potassium is found as five times as much in seawater, where the lowest content (897 ppm) in the ZB, and the higher (2366 ppm) in the RU. Shale is a responsible agent of K, particularly where containing illite. Chloride is a predominant ion in all oil-fields, the lower average (131751 ppm) is in WQ, whilst the higher (153934 ppm) in MJ.
Table (1) Brine chemistry in the Mishrif Formation.

| Field       | Well | Depth (m) | Na⁺ | Ca²⁺ | Mg²⁺ | K⁺ | Cl⁻ | SO₄²⁻ | HCO₃⁻ | TDS |
|-------------|------|-----------|-----|------|------|----|-----|-------|-------|-----|
| **Rumaila North (R)** |      |           |     |      |      |    |     |       |       |     |
| R-220       | 2210 | 83890     | 12120 | 2713 | 2782 | 157898 | 342 | 137 | 264000 |
| R-590       | 2233 | 77987     | 11980 | 2895 | 2740 | 155341 | 360 | 120 | 255997 |
| R-35        | 2235 | 81000     | 11800 | 2300 | 1700 | 143800 | 850 | 170 | 242000 |
| R-47        | 2277 | 79000     | 11200 | 250  | 1800 | 145500 | 800 | 165 | 245000 |
| R-227       | 2258 | 80110     | 12076 | 2910 | 2810 | 155894 | 290 | 105 | 262541 |
| Min         |      | 77987     | 11200 | 250  | 1700 | 143800 | 290 | 105 | 220000 |
| Max         |      | 83890     | 12120 | 2910 | 2810 | 157898 | 850 | 170 | 264000 |
| Av.         |      | 80397     | 11835 | 2614 | 2366 | 151687 | 528 | 139 | 248256 |
| **Rumaila South (RU)** |      |           |     |      |      |    |     |       |       |     |
| RU-397      | 2262 | 82650     | 12365 | 1890 | 900  | 142356 | 328 | 123 | 243562 |
| RU-287      | 2700 | 83500     | 10300 | 2000 | 1750 | 143000 | 1000 | 200 | 235500 |
| RU-93       | 2685 | 79250     | 11250 | 210  | 1920 | 135000 | 1100 | 187 | 231700 |
| RU-215      | 2660 | 78750     | 12245 | 2630 | 2632 | 140500 | 332 | 110 | 238000 |
| Min         |      | 78750     | 10300 | 1890 | 900  | 135000 | 328 | 110 | 120000 |
| Max         |      | 83500     | 12365 | 2630 | 2632 | 143000 | 1100 | 200 | 250000 |
| Av.         |      | 81038     | 11540 | 2155 | 1801 | 140214 | 690 | 155 | 222680 |
| **Majnoon (MJ)** |     |           |     |      |      |    |     |       |       |     |
| MJ-20       | 2402 | 80945     | 10105 | 2445 | 2290 | 152410 | 213 | 416 | 249123 |
| MJ-37       | 2480 | 80032     | 9880  | 2365 | 2500 | 152360 | 187 | 407 | 248387 |
| MJ-5        | 2452 | 81100     | 10000 | 2424 | 2374 | 151400 | 188 | 360 | 252100 |
| MJ-35       | 2475 | 83200     | 9500  | 1400 | 2000 | 152000 | 1300 | 260 | 253500 |
| MJ-22       | 2493 | 84200     | 9700  | 1520 | 2200 | 161500 | 1350 | 230 | 262150 |
| Min         |      | 80032     | 9500  | 1400 | 2200 | 151400 | 187 | 230 | 248387 |
| Max         |      | 84200     | 10105 | 2445 | 2500 | 161500 | 1350 | 416 | 262150 |
| Av.         |      | 81895     | 9837  | 2031 | 1801 | 153934 | 648 | 335 | 253052 |
| **Zubair (ZB)** |     |           |     |      |      |    |     |       |       |     |
| Zb-140      | 2245 | 77994     | 11356 | 1880 | 480  | 154260 | 385 | 196 | 246798 |
| Zb-245      | 2258 | 81345     | 12465 | 2200 | 485  | 152457 | 255 | 135 | 250345 |
| Zb-235      | 2260 | 79854     | 11345 | 2130 | 540  | 154683 | 390 | 210 | 253678 |
| Zb-148      | 2195 | 84000     | 11800 | 2000 | 1600 | 142543 | 700 | 180 | 249412 |
| Zb-102      | 2230 | 82000     | 11600 | 2400 | 1550 | 140500 | 750 | 170 | 241500 |
| Zb-312      | 2259 | 77994     | 11356 | 1880 | 480  | 154260 | 385 | 196 | 270000 |
| Min         |      | 77994     | 11345 | 1880 | 480  | 140500 | 236 | 100 | 245000 |
| Max         |      | 84256     | 13254 | 2974 | 1600 | 165890 | 750 | 210 | 270000 |
| Av.         |      | 81575     | 11970 | 2264 | 879  | 151722 | 453 | 165 | 251956 |
| **West Qurna (WQ)** |      |           |     |      |      |    |     |       |       |     |
| WQ-87       | 2295 | 82413     | 9870  | 2587 | 1800 | 148900 | 550 | 162 | 248000 |
| WQ-270      | 2555 | 79341     | 10250 | 3187 | 1240 | 147324 | 549 | 364 | 250987 |
| WQ-210      | 2554 | 51100     | 14400 | 2700 | 1800 | 102100 | 900 | 180 | 178000 |
| WQ-137      | 2545 | 50500     | 15000 | 3200 | 1750 | 105000 | 870 | 187 | 177000 |
| WQ-139      | 2530 | 80543     | 11460 | 3780 | 600  | 155432 | 498 | 220 | 254317 |
| Min         |      | 50500     | 9870  | 2587 | 600  | 102100 | 498 | 162 | 177000 |
| Max         |      | 82413     | 15000 | 3780 | 1800 | 155432 | 900 | 364 | 254317 |
| Av.         |      | 68779     | 12196 | 3091 | 1438 | 131751 | 673 | 223 | 221660 |
| *Sea water  |      |           |     |      |      |    |     |       |       |     |
|             |      | 11000     | 400  | 1300 | 350  | 194000 | 2700 | 142 | 35000  |
The high chloride content is attributed to the evaporation and difficulties to absorb by clay or other mineral surfaces. The presence of sulfate in brines is linked with reducing bacterial biogenic processes and availability of some cations such as Ca, Ba and Sr. The sulfate content will be very low due to the linkage with these cations forming different insoluble compounds that cause plug in the pore network and damage the petroleum reservoirs. The average sulfate ranges from 453 ppm in the ZB to 690 ppm in R. Sodium bicarbonate (NaHCO₃) may precipitates as a scale when there is an excess of Na and HCO₃ [17].

The average of HCO₃ ranges from 139 ppm in R to 335 ppm in MJ. The HCO₃ content clarifies the carbonate dissolution response in the Mishrif reservoir. The Na-chloride type is characterized the Mishrif reservoir in all oil-fields except WQ which defined by the facies of Na-Ca-chloride type as presented by the hydrochemical formula shown in Table (2).

**Table (2) Water type based on the hydrochemical formula of the Mishrif reservoir in the studied oilfields.**

| Oilfield | Hydrochemical formula | Water type |
|---------|-----------------------|------------|
| R       | $TDS_{(250)} g/l \frac{Cl_{(99.7)}}{Na_{(80.1)}} pH_{(6)}$ | Na-chloride |
| RU      | $TDS_{(238)} g/l \frac{Cl_{(99.6)}}{Na_{(81.4)}} pH_{(6.4)}$ | Na-chloride |
| MJ      | $TDS_{(251)} g/l \frac{Cl_{(99.6)}}{Na_{(83.2)}} pH_{(5.9)}$ | Na-chloride |
| ZB      | $TDS_{(249)} g/l \frac{Cl_{(99.7)}}{Na_{(81.4)}} pH_{(5.9)}$ | Na-chloride |
| WQ      | $TDS_{(218)} g/l \frac{Cl_{(99.5)}}{Na_{(76.8)} Ca_{(15.7)}} pH_{(5.8)}$ | Na-Ca-chloride |
4.2 Reservoir mineralogy

Reservoir heterogeneities are known to exist in the Mishrif Formation, which result in significant laterally and vertically variations in reservoir properties including permeability and porosity as well [18]. This non-uniformity may be a reflection of the depositional environment and sedimentary facies. The petrophysical properties of the R, QW and MJ oilfields are improved towards north indicated by the changing in facies from river mouth bar at south coral reef at north. Argillaceous mudstones facies are marked by irregular thin, clay-rich laminations containing detrital quartz, and calcite cement in documenting the early lithification of the mudstone at the water-sediment interface in the Mishrif Formation [18]. The apparent increase in calcite content in the Mishrif Formation is marked an unconformity separates them from the overlain Khasib Formation. Mineralogy has been studied using SEM and presented in Figure (2 a-d). The top of Mishrif is composed of compact limestones as shown in Figure (2a). The carbonate of the Mishrif Formation belongs to different environments indicated by the calcite abundance (90% av. with shale 10%) with a varying amount of montmorillonite Figure (2b), autogenic quartz Figure (2c), smectite, chlorite in Figure (2d) and kaolinite Figure (3). Carbonate ramp buildup of rudist shoal and lagoonal complex is suggested to be a depositional model. To the west and south direction over Rumaila Formation, the shallow facies was developed [19]. After initial flooding of the platform, mixed shallow-water and planktonic facies developed on top of the platform [18]. The north part of the oil-field was developed with a shallow-water platform, followed by a coral-rudist build-up dominated platform. The south part of the oil field is characterized by the domination of mid-outer ramp restricted facies [19]. The changing in facies resulted in changes in permeability. The permeability and salinity of oil-field water in addition to the compaction are the main factors have played an important role in formation pressure distribution.
Fig. (2) Scanning electron microscope showing the mineralogy of the Mishrif reservoir, a) dissolved compact limestone formed from trigonal calcite; b) Montmorellonite; c) Authigenic quartz with chlorite; d) Smectite with chlorite.

Fig. (3) Scanning electron microscope spectra showing kaolinite.
4.3 Potentiometric mapping model

A considerable variation in TDS (221660 WQ- 253052 MJ ppm) has been recorded in the oil-field studied. The high salinity was due to a later diagenetic processes, where it increases at sites containing mudstone. The montmorillonite in the early diagenetic stage is one of the most important reasons for salinity increasing. Sodium and K are easy to be replaced by those higher ones such as Ca and Mg to form more stable montmorillonite compounds [20].

The Mishrif Formation consists of (top to base) a fine-grained limestone followed by dense fractured or stylolite turn into detrital porous partly very shelly to foraminiferal limestone with banks of rudist grades downwards into marly limestones [2]. The presence of marl and shale beds within the reservoir is one reason for the super salinity. Other reasons for salinity are salt domes nearby the shoreline.

The salt plug of the Jabal Sanam located 45 km southwest Basrah [21] may be considered as a potential source of salinity. Movement of the fluids in the subsurface environment depends on different variables, commonly density of the fluids, salinity, temperature and pressure [22].

The subsurface formation pressure produced by a variety of different mechanism may be physical, chemical or combination of both. The chemical factors which increase the pressure include the variety in the water density distribution owing to the salinity and temperature. The fluid path flow is from concentrated to less concentrated sites. The interstitial water must carry additional loads of ions to generate suitable subsurface pressure to move the fluids.

Increasing of the temperature in the reservoir will increase the pressure and contribute to the fluid movement [23]. The salinity dataset Table (1) were used to estimate the general paths and mapping the fluid flow patterns in subsurface environment. The fluid path flow inside the entrapments was constructed based on the potentiometric maps.

The three oil-fields (WQ, RU and R) were constructed as a one folded structure Figure (4) based on seismic data collected from South Oil Company. The MJ and ZB oil-fields are also constructed by salinity model maps shown in Figure (4). The potentiometric maps show that the fluid moves from R (anticline center) towards the north and south (plunges)
in the sense towards RU and WQ Figure (4a), and westward to the western limb in MJ Figure (4b) but eastward (eastern limb) in the ZB Figure (4c). The direction of fluid movement has pointed out the low pressure positions in the oil-fields.

![Potential vector map of the West Qurna (WQ), Rumaila North (R), Rumaila South (RU), Majnoon (MJ) and Zubair (ZB) oil fields [9].](image)

**5. Conclusions**

Through the studying of oil-filed water chemistry in five giant oil-fields in southern Iraq and its influence on the pressure distribution inside oil reservoir, the findings can be drawn as follows:

1. Sodium and chloride are the predominant ions in the all oil-fields, so the water type is Na-chloride, except for the WQ oil-field which characterized by an increase in the calcium content in addition to sodium and chloride, so it has Na-Ca-Chloride type.
2. The oil-field waters are characterized by high salinity, six times greater than seawater with relative variation; where the highest salinity was recorded in the MJ field and lowest salinity was recorded in WQ field.

3. The origin of high salinity is due to connate marine water and diagenesis processes and it is believed that salt domes contributed to increased salinity as there is evidence on the salt domes including Jabal Snam in Basrah (southern Iraq) which is an extension of the series salt domes of Hormuz Formation in southern Iran, the northern part of the Arabian Gulf.

4. The flow path of fluids into the Mishrif Formation was determined within five Iraqi giant oil-fields, depending on salinity distribution, and was modeled via a constructing vector potentiometric map for each oil-field. The direction of fluid flow follows the salinity. Based on the potentiometric subsurface maps, the pressure values in the Mishrif reservoir in RU, R and WQ oil fields increase towards the anticline plunges, whereas to the western limb and eastern limb in the ZB and MJ respectively.
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