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

Heba Sadoon Al-Mimar, Salih Muhammad Awadh
Department of Geology, College of Science, University of Baghdad, Baghdad, Iraq
Corresponding Author E-mail: salihauad2000@yahoo.com

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.

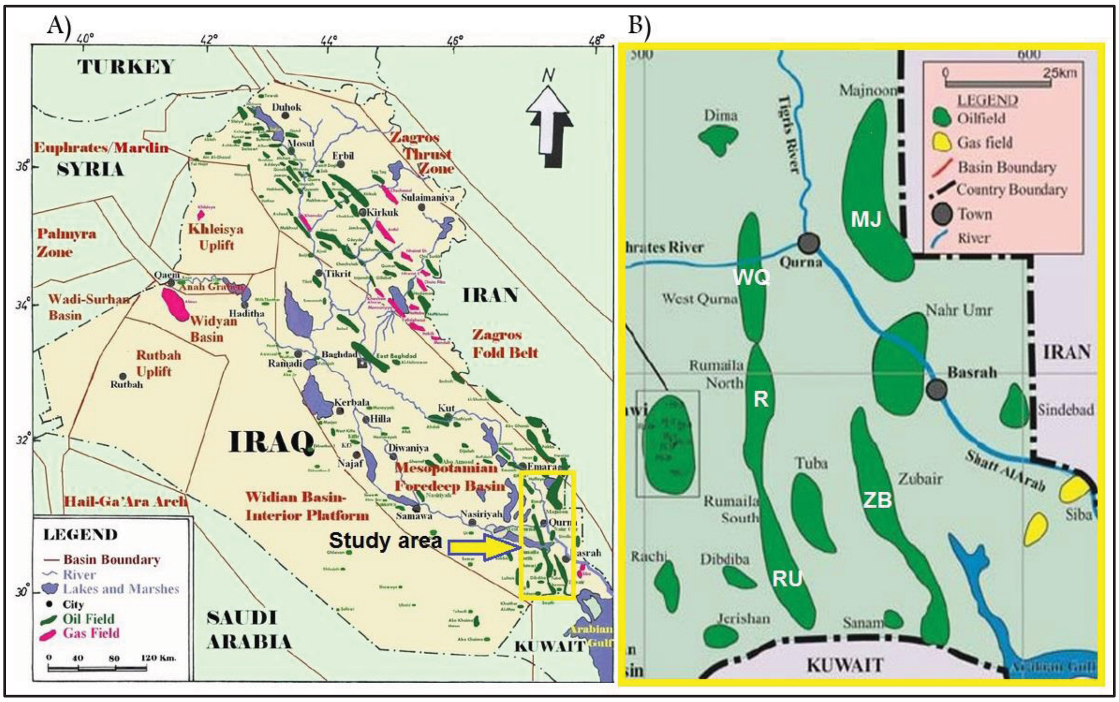

Fig. (1) Location map shows the oilfield studied [10].

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 epm in addition to pH and TDS [12] was expressed by the following equation:

$$TDS\ (gm/l)\ \frac{Anions\ epm\%\ \ in\ descending\ order}{Cations\ epm\%\ \ in\ descending\ order}\ pH$$

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

Scanning Electron Microsprobe (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 of 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 the 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^+	Ca^{2+}	Mg^{2+}	K^+	Cl-	SO_4^{2-}	HCO_3^-	TDS
			ppm							
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	2250	1800	145500	800	165	245000
	R-227	2258	80110	12076	2910	2810	155894	290	105	262541
	Min		77987	11200	2250	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	2100	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	2273	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	241500
	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	19400	2700	142	35000

*[14]

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 ($NaHCO_3$) may precipitates as a scale when there is an excess of Na and HCO_3 [17].

The average of HCO_3 ranges from 139 ppm in R to 335 ppm in MJ. The HCO_3 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.

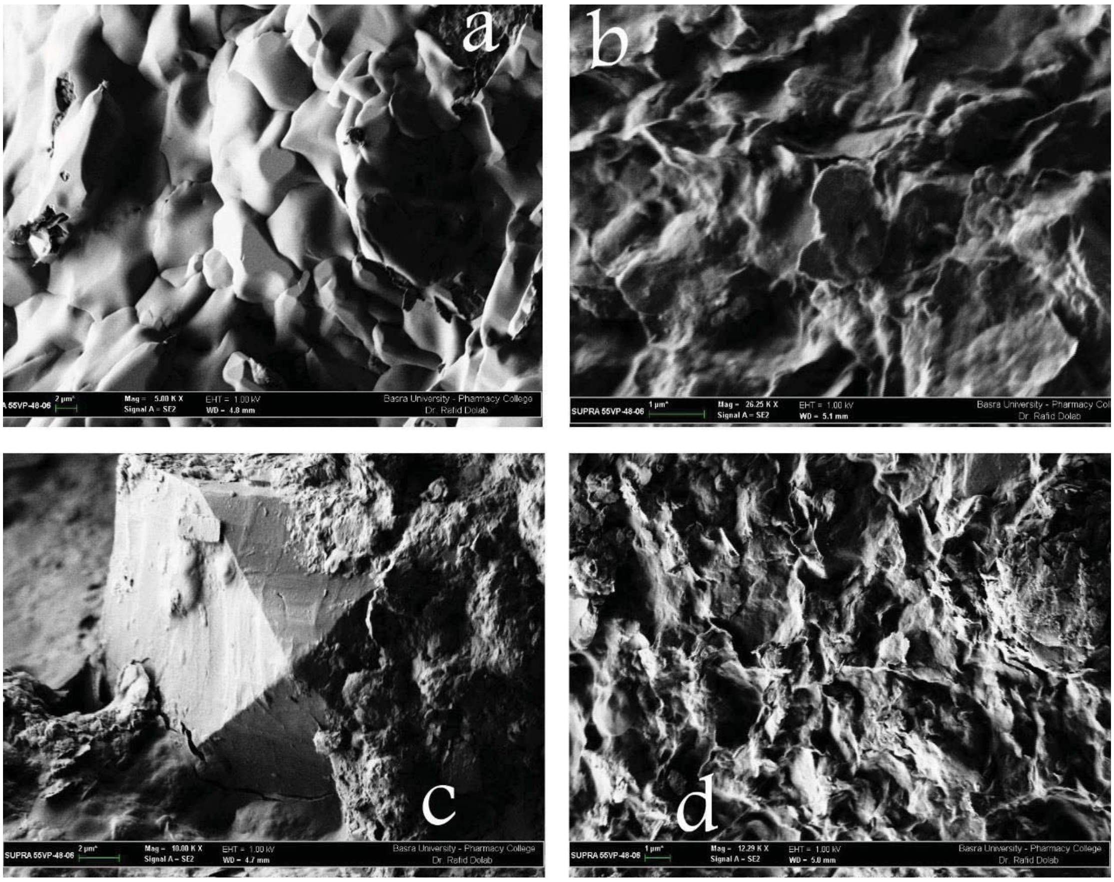

Fig. (2) Scanning electron microscope showing the mineralogy of the Mishrif reservoir, a) dissolved compact limestone formed from trigonal calcite; b) Montmorellonite; c) Authigenic quartz with chlorite; d) Smectite with chlorite.

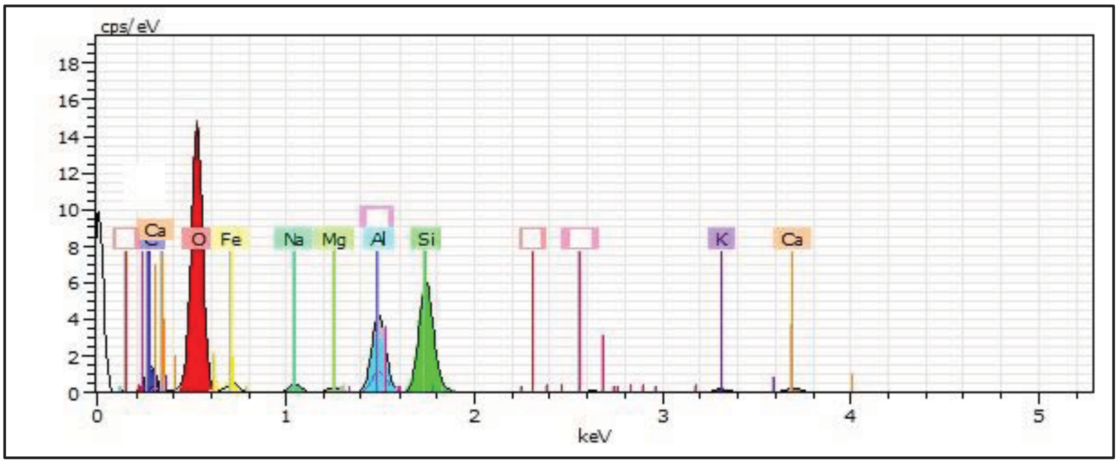

Fig. (3) Scanning electron microscope spectra showing kaolinite.

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.

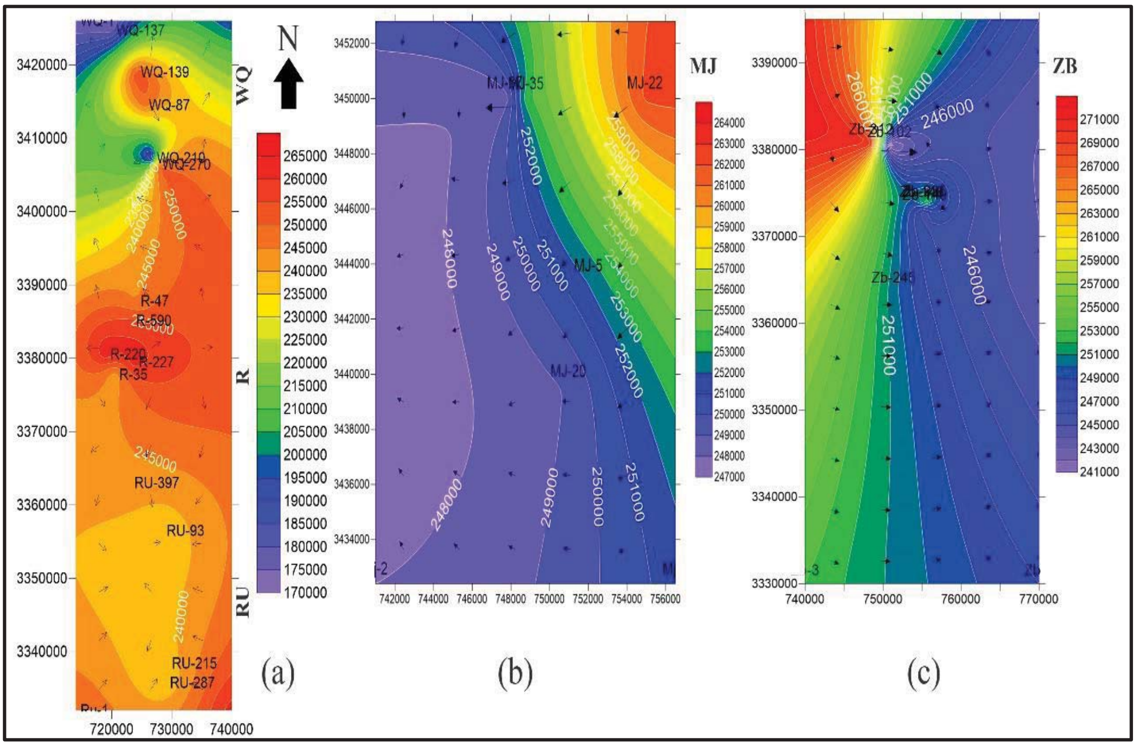

Fig. (4) Potential vector map of the West Qurna (WQ), Rumaila North (R), Rumaila South (RU), Majnoon (MJ) and Zubair (ZB) oil fields [9].

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 dames 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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