Chemical and biological compatibility of different injection waters with Zubair Formation Water of Upper Sand Member in Zubair Oil Field, South of Iraq

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Abstract. Water injection by water flooding was used to enhance and increase oil production in Zubair oil field, southern Iraq. Physical-chemical and biological analysis of five water samples from different sources were collected to evaluate its compatibility with formation water using biological experiments and chemical compatibility simulation. The results show that injection water is classified weakly acidic-weakly alkaline and saline water, whereas surface water samples are considered weakly acid- weakly alkaline. The total dissolved solids results show brackish types accept for Formation water which classified weakly acid and Brine water. All the studied water samples contain bacteria colonies of Escherichia coli and Coliform expect for one sample, while Sulfate Reducing Bacteria was founded in all studied samples. Mathematical model of chemical compatibility between studied water samples and Zubair Formation water of the scale prediction model show that there are no needs for any inhibition treatments of all scales except for Geothite and Dolomite that should be treated before water injection. The biological compatibility experiments results show Formation damage about (61%) and (69%) in the studied core samples, while Bacteria in water injection caused formation damage about (20%) and (51%).

Keywords: Zubair Formation, water flooding, hydrogeochemical modeling, biological compatibility, Iraq.

1. Introduction
Water flooding considered as a secondary production approach that help in push the hydrocarbons towards the produced wells [1] to increase the oil production. Injection surface water or sea water with low salinity or ions were used in order to change the water viscosity to become higher than oil viscosity and increase the productivity of oil [2]. Basrah Oil Company used water flooding approach in Zubair Formation after water treatment. The Company used the water of Nahran Ummar aquifer to injection purposes since 2011 in order to improving oil production in the Mishrif and Zubair Formations in Zubair Oil Field [3]. The aims of the present study is to evaluate the physical, chemical and biological properties of the injection waters (Shatt Al-Arab River water and two injection station waters: Qarmat Ali river station and Nahran Ummar aquifer) that used in the Zubair Formation and assess them compatibility with water reservoir using chemical compatibility simulation, in addition to determine the effects of water injection on the reservoir properties and Formation damage by chemical and biological compatibility with Zubair Formation water.
2. Geological and stratigraphic setting
Lower Cretaceous depositional cycle in Iraq consist from many Formations, Zubair Formation is one of them [4]. Its thickness about 389.33m according to its section in Zubair area well Zu-24 [5]. Figure (1) shows the five members of Zubair Formation where [6]. The petrophysical properties of the upper sand member in Zubair Formation was evaluated by [7] [8], where the results reveal improved in its properties in the northern parts of Zubair oil field, additionally, the best units as good reservoir units were AB, DJ, and LN in Zubair Formation.

3. The general description of the study area
Zubair oil field is located about twenty kilometers far from Basra city between (47° 32’ – 47° 45’) Latitude and (30° 05’ – 30° 42’) Longitude Figure (1). The Field has extends over an area of 1170 Km2 [7]. The upper sand member considered as the 3rd pay reservoir which consisting of complex sand and shale where 55meter of its thickness containing oil.

![location and Structural maps of upper sandstone member](image)

Figure 1. location and Structural maps of upper sandstone member[8].

4. Methodology
In order to achieve the aims of the present study, three surface water samples (S1, S2, and S3) and two injection water samples (I1 and I2 ) that described in table (1), were collected to analyzed the physical-chemical and biological properties according to the routine approaches in the Central Laboratories of Basrah Oil Company (Figure 2). Four core samples (plugs) (three inch height to one and half inch diameter) were taken from two well core samples that stored in Basrah Oil Company. The permeability in addition to the chemical and biological laboratory compatibilities were tested in the Basrah Oil Company.

![image](image)

Table 1. The core and water samples used in the present study.

| Formation  | Core well Samples | Shatt Al Arab water samples | Injection water samples |
|------------|------------------|----------------------------|-------------------------|
|            |                  |                            |                         |
Chemical compatibility simulation was done according to the calculation of the mineral saturation indices (SI) using Pitzer equations that represent the activity in high saline water [9]. The hydrogeochemical PHREEQC Version 3 computer program according to the equation below:

\[
(\text{SI}) = \frac{\text{IAP}}{K_{sp}}
\]  

Where SI = saturation index of minerals
IAP = ion activity product
Ksp = solubility product.
The calculation of (SI) could confirms the dissolution or precepitation processes resulting from mixing between surface testing injection waters and Zubair Formation water by assess the minerals scales that dissolved or precipitate [10].

The compatibility between water injection and reservoir rocks were done, firstly by testing the effect of suspended material in water injection on the permeability, and the second experiment evaluate the effect of Bactria in water injection and clay move ment on the permeability in the reservoir rocks when saturated with water injection, thes two experimnants were done in Basrah Oil Company laboratories. After calculating the porosity and air permeability of the samples (plugs), the experiments were done for two samples of well (ZB-40) at depth (2361.14), and (3334.63) using the processor injection water only, with many stages, in addition to the particle size of suspended materials is measurd in the injection water before and after pumping. Permeability of liquid calculated accordance to Darcy Law as followed:

\[
KL = \frac{245V\mu L}{A\Delta P T}
\]

Where:
KL = permeability of the liquid (Milli Darcy)
\(\mu\) = the viscosity of the liquid (cp).
V = Sample size (ML)
L = Sample length (cm).
A = Sample section space (cm²).
\(\Delta P\) = Pressure on the sample (PSI).
T = Fluid flow time (Min).

Graphic forms are drawn to explain the change in relative permeability (Krw) with the amount of injected water

\[
K_{rw} = \frac{K_{f}}{K_{wi}} \%
\]

The following equation is used for computing the Formation damage (Dr\%)

\[
Dr = 100 - \frac{K_{f}}{K_{wi}} \times 100
\]

Klf: finaly permeability, Kwi = Initial water permeability.
5. Results and Discussion

5.1 Physical properties of Water

The descriptive statistics of physical water samples are shown in (Table 2). PH results show weakly acidic – weakly alkaline according to [11]. Total dissolved solids TDS results show brackish water type according to [12] and [13] for surface water, while the I1 and I2 water samples considered as saline and brine water types.

Total Suspending Salts TSS may found in petroleum a associated waters as organic and inorganic matter [14]. Its range between (11-24mg/l), (53-104mg/l), and (153mg/l) in surface, injection and formation waters respectively. EC(μs/cm) results show the same like TDS. The values of specific gravity were ranged between (1.0202-1.0205), (1.13-1.14), and (1.176) in surface, injection, and formation waters respectively. Turbidity ranged between (3-18.7NTU), (31.9-268 NTU), and (153 NTU) in the same water samples order.

| Type water         | Sample no. | pH    | TDS(mg/l) | TSS(mg/l) | EC(μs/cm) | SP. Gravity (15°C) | Turbidity NTU |
|--------------------|------------|-------|-----------|-----------|------------|---------------------|---------------|
| surface            | S1         | 6.4   | 12590     | 11        | 18.87      | 1.0205              | 4             |
|                    | S2         | 7.2   | 8450      | 7         | 13.44      | 1.0202              | 3             |
|                    | S3         | 7.2   | 6420      | 24        | 10         | 1.0203              | 18.7          |
|                    | MAX.       | 7.2   | 12590     | 24        | 18.87      | 1.0205              | 18.7          |
|                    | MIN.       | 6.4   | 6420      | 7         | 10         | 1.0202              | 3             |
|                    | AVR.       | 6.9   | 9153      | 14        | 14.1       | 1.0201              | 8.56          |
| Injection Water    | I1         | 7.4   | 15690     | 53        | 23.9       | 1.1351              | 31.9          |
|                    | I2         | 6.2   | 234460    | 104       | 207        | 1.141               | 268           |
|                    | AVR.       | 6.8   | 125075    | 78.5      | 115.45     | 1.138               | 149.95        |
| Formation Water    | FW         | 6.3   | 120120    | 85        | 109        | 1.1764              | 153           |
5.2 Chemical composition of water samples
The Calcium concentration is considered good indicators of erosion of pyroxene; amphibole and feldspar minerals [15]. Calcium Concentration in the Zubair oilfield is the highest between the cations concentrations ranged between 13600-15900 mg/l (Table 3). These high values confirm dissolving of carbonate in upper sandstone member.

Mg$^{2+}$ concentrations results show ranged between (317-477.1 mg/l), (623.4-1805 mg/l), and (458 mg/l) in surface, injection and formation waters, respectively. The value of the Na$^+$ concentration a varied between (1760-4578 mg/L) in the surface water, and in I1, I2 are varied (172.2-1717.5 mg/l) and (665 mg/l) in surface, injection and formation waters, respectively. The low solubility of minerals that contain Kfeldspar is the main reason for lowering potassium concentration in groundwater [16]. Chloride concentration in the present water samples is more than the other cations due to its easer of solubility in the water [17]. Sulfates in oil reservoirs have important relationship with Strontium and Barite in oil reservoir that make negative effects on reservoir at it will plogs the pores and reduce the fluid permeability through the reservoir rocks (Al- Atabi, 2009). The SO$_4^{2-}$ concentrations were ranged between (947-1508 mg/l), (323-1669) and (616 mg/l) in surface, injection and formation waters, respectively. The bicarbonate concentration in the present water samples are varied between (232-238 mg/l), (222-232 mg/l), and (227 mg/l) in the same samples order (Table 3).

| Type of water | Sample no. | Ca$^{2+}$ (mg/l) | Mg$^{2+}$ (mg/l) | Na$^+$ (mg/l) | K$^+$ (mg/l) | Cl- (mg/l) | HCO$_3^-$ (mg/l) | CO$_3^{2-}$ (mg/l) | SO$_4^{2-}$ (mg/l) |
|--------------|------------|------------------|-----------------|-------------|-------------|------------|----------------|----------------|---------------|
| Surface Water | S1         | 275.4            | 477.1           | 4578        | 121.2       | 6262       | 238            | Nil            | 1508          |
|              | S2         | 213.9            | 317             | 2394        | 87.8        | 4088       | 238            | Nil            | 1012          |
|              | S3         | 200              | 246.55          | 1760        | 54.75       | 2957       | 232            | Nil            | 947           |
|              | MAX.       | 275.4            | 477.1           | 1760        | 121.2       | 6262       | 238            | Nil            | 1502          |
|              | MIN.       | 200              | 246.55          | 2394        | 54.75       | 2957       | 232            | Nil            | 947           |
|              | AVR.       | 229.76           | 346.88          | 2910.66     | 87.916      | 4435.6     | 236            | Nil            | 1155.6        |
| Injection Water | I1        | 327              | 623.4           | 4400        | 172.2       | 8002       | 222            | Nil            | 1669          |
|              | I2         | 13450            | 1805            | 71250       | 1717.5      | 139160     | 232            | Nil            | 323           |
|              | AVR.       | 6888.5           | 1214.2          | 37825       | 944.85      | 73581      | 22             | Nil            | 996           |
| Formation water | F         | 6750             | 458             | 38000       | 665         | 72853      | 227            | Nil            | 616           |

5.3 Chemical Compatibility simulation

Chemical compatibility simulation is important in oil production as good technique to understand the suitability of two water types mixed and evaluate the types of mineral scales that results from mixing process. When testing the compatibility of these water samples with formation water sample, it will considered as compatible if they mixed without precipitation, whereas they considered incompatible waters if precipitate minerals [18]. Before starting the injection operation it is important to know the suitability of water that used in injection purposes with Formation water [19]. The scales known in the oil reservoirs like calcium carbonate, Calcium sulfates, Gypsum, Anhydrite, Hemihydrate, Barium and Strontium sulfates are the main scales[20].

6. The model of chemical compatibility results
6.1 Chemical compatibility results of water samples
Figures (3, 4, 5, 6 and 7) show the results of simulation mixing ratios between Formation water and present water samples S1, S2, S3, I1, and I2. The chemical compatibility simulation model of Zubair Formation water with Shat AL-Arab and injection water samples that results show Anhydrite, Gypsum, Siderite, Strontianite, and Witherite scales in all mixing ratio were under saturation due to low saturation index and indication no need for them inhibition treatments. Geothite scale was needed permanent inhibition because of high saturation index and precipitation will be possible. All the scales results show no need for treatments due to low saturation index accept for dolomite which needs periodic inhibition [10].
Figure 6. Mineral Scales results from mixing in (I1).

Figure 7. Mineral Scales results from mixing in (I2).

7. Compatibility between water injection and reservoir rock
It will be able from these experiments results to obtain the size of the suspended material of the injection water that allowed which have no effect on water flow rate or cause any Formation damage. In addition, we will be able to assess the permeability due to the effect of clay minerals swelling and movement with the increasing the saturation rates by increasing the injection water rates with time of testing sample.

7.1 Experiments the effect of suspended material in water injection on permeability
Table (4), Figures (8) and (9) show the results of the experiment and the graphic forms of permeability of the air (Ka) after and before water injection. The suspended material in the injection water has a great impact on reducing the flow of water in the rocks by reducing the permeability. The percentage of reducing is depending on the shape, size and amount of the suspended material [21]. Figures (8) and (9) show the results of the suspended materials effect experiment on reservoir permeability, where firstly through pumping injection water of two samples without a filter, the relative permeability will reduced from (0.92) to (0.18) and from (0.88) to (0.20) in the first and second samples respectively. Through the second stage of the experiment when pumping with filtered injection water in the opposite direction. The relative permeability result became 0.66 and 0.63 in the first and second sample respectively because this enabled the samples to remove the suspended materials that could not influence inside it because of its large diameters [22]. The relative permeability of water would be
decreased when pumping the filtered injection water in the normal direction where it became 0.35 in the first sample and 0.27 in the second sample. Figure (10) and (11) shows the results of the diameter of the suspended material in the treated water injection before and after injection in the sample (ZB - 40) (S1) respectively, where the primary diameter was (3.3-16.7 µm), after pumping the diameter became (2.3µm) indicates that the suspended material larger than the (2.3µm) remained in the pores of reservoir rock reducing the permeability. At well sample (ZB-40) (S2) the diameter of the suspended material in the treated water injection was (2.3-5.2 µm). After injection, the diameter was (2.3 µm) due to remained the suspended particles larger than (2.3 µm) to remain in the pores of the rock reservoir causing reducing in permeability as shown in the (Figures 12 and 13).

| Well No. | Samples No. | ZB-40 | ZB-40 |
|----------|-------------|-------|-------|
| Depth (m) | 1           | 3261.14 | 3334.63 |
| K-air before injection (md) | 2 | 452.7 | 366.9 |
| K-air after injection and drying (md) | 3 | 426.3 | 348.6 |
| Q-befor injection % | 4 | 21.2 | 21.7 |
| Q-after injection % | 5 | 21.2 | 21.9 |
| V-p before injection (cc) | 6 | 12.42 | 12.3 |
| V-p after injection (cc) | 7 | 12.46 | 12.36 |
| Kw origin with filter (md) | 8 | 356.94 | 298.35 |
| KL(with out filter) in first hundred | 9 | (328.26) | (261.16) |
| KL(with out filter) in last hundred | 10 | (64.28) | (59.67) |
| Kw(with out filter) in first hundred | 11 | 0.92 | 0.88 |
| Kw(with out filter) in last hundred | 12 | 0.18 | 0.20 |
| KL(with filter inverse the sample) (md) | 13 | 240.30 in 400cc | 162.42 in 400cc |
| | 14 | 326.65 in 500 cc | 189.34 in 500cc |
| Krw(with filter inverse the sample) | 15 | 0.67 in 400cc | 0.54 in 400cc |
| | 16 | 0.66 in 500 cc | 0.63 in 500 cc |
| KL(with filter in normal direction) | 17 | 132.83 in 400cc | 84.72 in 44cc |
| | 18 | 125.99 in 500 cc | 82.01 in 500 cc |
| Krw(with filter in normal direction) | 19 | 0.37 in 400cc | 0.28 in 400cc |
| | 20 | 0.35 in 500 cc | 0.27 in 500 cc |
| Dr% | 21 | 61 | 69 |
| Partial diameter -before injection (µm) | 22 | 3.3-16.7 | 2.3-12.9 |
| Partial diameter -after injection (µm) | 23 | 2.3 | 2.3 |
Figure 8. The change in relative permeability ($K_{rw}$) with the amount of injected water (ZB-40,S1) depth (3261.14m).

Figure 9. The change in relative permeability ($K_{rw}$) with the amount of injected water (ZB-40,S2) depth(3334.63m).
Figure 10. Particle of suspended material of water injected before injected it in (ZB-40, S-1) depth (3261.14m).

Figure 11. Particle of suspended material of water injected after injected it in(ZB-40, S-1) depth (3261.14m).

Figure 12. Particle of suspended material of water injected before injected it in(ZB-40, S2) depth (3334.63m).
The air permeability of the two samples were damaged and did not return to the original value prior to injection, whereas the porosity remained without any affected. The above results revealed reducing in permeability and an increase in the Formation damage, where the damage results was (61%) and (69%) in the first and second sample respectively Table (4).

7.2 The effect of Bactria on rock reservoir Experiment
After determining the air permeability and porosity of the samples (plugs) two Experiments were done for two samples of well (233) in Zubair oil Formation (ZB-233) at depth (3323.45) and (3361.29) using the brine water and processor injection water with the many stages. The result effect of Bactria in water injection on the permeability after the injection of water in those rocks shows in table (5). Draw the results to explain the change in relative permeability (Krw) with time during the amounts of injected water.

\[ Krw = \frac{K_1}{K_{wo}} \times 100 \quad (4-6) \]

Take samples of injected water and examine it a biologically to determine the growth of bacteria inside the rocks. Depending on the results shown in table (5), we found that the permeability have been reduced with continuing pumping water treatment from (453.57 md) to (332 md) and from (99.06 md) to (67.01 md) for the first and second samples respectively. Whereas in pumping brine water the permeability was decreased from (392.15 md) to (356.17 md) and from (62.92 md) to (47.61 md) for the first and second samples respectively. The relative permeability in pumping water treatment with filter was reduced from (0.72) to (0.53) in the first sample and from (2.20-1.49) in the second sample (Figure 14 and 15).

Table 5. The result effect of Bactria in water injection on the permeability after the injection of water in those rocks.

| Well No. | ZB-233 | ZB-233 |
|----------|--------|--------|
| Samples No. | 1      | 2      |
| Depth(m)  | 3323.45| 3361.29|
| K<sub>air</sub> before saturation (md) | 680.1  | 155.9  |
| K<sub>air</sub> after injection and drying (md) | 477.1  | 52.0   |
| Φ before injection% | 20.9   | 16.3   |
Figure 14. The change in relative permeability (Krw) with time during the amounts of injected water (ZB-233,S1) depth(3323.45m).

Figure 15. The change in relative permeability (Krw) with time during the amounts of injected water (ZB-233,S2) depth(3361.29m).
The results of porosity and air permeability of both samples reveal a decrease in its value without returning to their original value before injection due to the movement of clay minerals within the samples and growth in Bacteria [23]. The growth Bacteria is shown in the tables 6 and 7. The results show that there are damage in water relative permeability about 20 % and 51 % in the first and second tested samples respectively.

Table 6. Growth of Bacteria in injection water samples before and after injection it in reservoir rock (ZB-233,S1) depth (3323.45).

| Type of Bacteria(col/ml) | Treated water Before injection | Treated water After injection Day -1 | Treated water After injection Day -2 | Treated water After injection Day -3 |
|-------------------------|--------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| General aerobic Bacteria | 2135                           | 2500                                | 2315                                | 1600                                |
| An aerobic Bacteria     | 1915                           | Uncountable(very high)              | 1095                                | Uncountable(very high)              |
| Sulfate Reducing Bacteria | 460                           | 336                                | 280                                 | Uncountable(very high)              |

Table 7. Growth of Bacteria in injection water samples before and after injection it in reservoir rock (ZB-233). depth (3361.29)m.

| Type of Bacteria(col/ml) | Treated water Before injection | Treated water After injection Day -1 | Treated water After injection Day -2 | Treated water After injection Day -3 |
|-------------------------|--------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| General aerobic Bacteria | 2135                           | 1305                                | 1000                                | 1020                                |
| An aerobic Bacteria     | 1915                           | Uncountable(very high)              | Uncountable(very high)              | Uncountable(very high)              |
| Sulfate Reducing Bacteria | 350                           | Uncountable(very high)              | Uncountable(very high)              | Uncountable(very high)              |

8 Conclusions
1- Water flooding by water injection was used for enhancement and increasing oil production in Zubair oil field.
2- According to pH values the reservoir Formation indicating weakly acid that have a positive effect on reservoir petro-physical characteristics (porosity and permeability), while the pH values of all surface and injection water samples reveal weakly acid - weakly alkaline.
3- The surface and injection water samples were considered as brackish and saline water type respectively according to TDS. Sodium and Chlorite are the predominant ions in all water samples. The hydrochemical formula show the cations in order: Na⁺ > Mg²⁺ > Ca²⁺ > K⁺ and of anions in order Cl⁻ > SO₄²⁻ > HCO₃⁻.
4- Chemical compatibility simulation model of Zubair Formation water with Shat AL-Arab and injection water samples results show no need for scales inhibition treatments except for Geothite scale which needed permanent inhibition because of high saturation index and precipitation will be possible. In addition to periodic treatment for Dolomite scale.
5- 61% and 69% Formation damage in the first and second core samples respectively were found through the experiment of affected of suspended material in water injection on permeability that reduced even with using filter during the experiment.
6- During the experiment of the effect of Bacteria in water injection and the effect of the clay mineral of core samples on Formation permeability, the results show that permeability will reduce from (453.57 md) to (332 md) in the first sample and (99.06 md) to (67.01 md) in the second sample. During pumping brine water the permeability did not increase because of movement of clay minerals and growth of Bacteria. Finally the Formation damage was approximately 20% and 51% at the first and second core samples respectively.
9. References

[1] Jreou G N 2012 Increasing of oil field productivity by implementation of re-entry horizontal injection well, case study *Iraqi J. Chem. Pet. Eng.* **13** 17–34
[2] Morrow N and Buckley J 2011 Improved oil recovery by low-salinity waterflooding *J. Pet. Technol.* **63** 106–12
[3] ZFOD, Zubair Field Operating Division 2017 Annual Report of Zubair Formation. (internal Report unpublished).
[4] Al-Sayyab A 1989 Geology of petroleum 472
[5] Owen R M S and Nasr S N 1958 Stratigraphy of the Kuwait-Basra Area: Middle East
[6] Al-Naqib K M 1967 Geology of the Arabian peninsula USGS Prof. Pap. No
[7] Zainab M H A L, Almallah I A and Al-Najm F M 2019 Petrophysical properties evaluation using well logging of the upper sand member of Zubair Formation in Zubair oil Field, Southern Iraq. *Basrah J. Sci.* **37** 457–480
[8] Al-Ameri T K and Batten D J 1997 Palynomorph and palynofacies indications of age, depositional environments and source potential for hydrocarbons: Lower Cretaceous Zubair Formation, southern Iraq *Cretac. Res.* **18** 789–797.
[9] Pabalan R T and Pitzer K S 1991 Mineral solubilities in electrolyte solutions *Act. Coefficients Electrolyte Solut.* **2**.
[10] Ghalib H B and Almallah I A R 2017 Scaling simulation resulting from mixing predicted model between Mishrif formation water and different waters injection in Basrah oil field, southern Iraq *Model. Earth Syst. Environ.* **3** 1557–1569
[11] Komatina M 2004 *Medical geology: effects of geological environments on human health* (Elsevier).
[12] Freeze RA, Cherry JA 1982 *Groundwater*. Prentice-Hall, Englewood Cliffs.
[13] Todd D K and Mays L W 2004 *Groundwater hydrology* (John Wiley & Sons)
[14] Rainwater F H and Thatcher L L 1960 *Methods for collection and analysis of water samples* (US Government Printing Office)
[15] Pradhan B and Pirasteh S 2011 Hydro-chemical analysis of the ground water of the basaltic catchments: upper Bhatsai region, Mahararashtra *Open Hydrol. J.* **5** 51-57.
[16] Al-Yasiri A A 2000 A Study of geochemistry and hydrogeochemistry of the Upper Sandstone Member–Zubair Formation in South Rumaila Field/Sothern Iraq *Unpubl. Thesis, MS* ((In Arab. Coll. Sci. Univ. Basra, p. 77)
[17] Mason, B. and Moore, C.B., 1982:Principle of Geochemistry, 4th ed., John Wiely and Sons. INC. New York. 344p.
[18] Henkel H O 1953 Surface and underground disposal of chemical wastes at Victoria, Texas *Sewage Ind. Waste.* **1044–1049**.
[19] Collins, A.G., and Bryant, R.S., 1985: Potential MEOR environmental hazard. Unpublished Report. NIPER-25. 13p.
[20] Moghadasi J, Jamialahmadi M, Müller-Steinhagen H, Sharif A, Ghalambor A, Izadpanah M R and Motaie E 2003 Scale formation in Iranian oil reservoir and production equipment during water injection *International Symposium on Oilfield Scale* (Society of Petroleum Engineers)
[21] SOC, (South Oil Company ), -Basra-1980: central laboratory department, Compatibility the injection water of Qarmat –Ali with the reservoir water ,and reservoir rock at Zubair oil field,( internal Report unpublished).
[22] SOC, (South Oil Company),-Basra-1983: central laboratory department, decrees the permeability during injection water ,causes and treatment . (internal Report unpublished).
[23] SOC, (South Oil Company),-Basra -2012: An updated study of reservoir water analysis. Internal report. Baghdad. Iraq (Unpublished)