Physiochemical Characteristics of Produced Water in Oilfields and Its Environmental Impacts

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***Abstract*: Produced water is referred as the largest volume source of waste stream product generated through oil and gas exploration and production. These waters are generated as a result of crude oil and natural gas production, including both onshore and offshore sources. Produced water comes from formation water that naturally trapped under the hydrocarbon layer in oil and gas reservoirs. The traditional method to dispose of produced water involves deep well injection, but this option is becoming more challenging due to high operational cost, limited disposal capacity, and more stringent regulations. Great quantities of produced water (formation water, brine) are associated with the production of oil and gas in oilfields. Therefore, evaluation of produced water characteristics is very important and essential for both environmental and reservoir management. This study has evaluated the physical/chemical properties of formation water in Sarir oilfield, Libya. The study carried out on the quantities of produced water of five gathering centers and the water produced through 2018 and 2019 years, as well as washing water. The evaluation included the analysis of physical/chemical such as pH, specific gravity, salinity, Total Dissolved Solids (TDS), cations and anions constituents. These parameters show a wide variation in the investigated water. The characterizing parameters such as formation volume factor of formation water (B_w), density (ρ), isothermal compressibility coefficient (C_w), coefficient of viscosity (μ_w) and water resistivity (R_w) have been estimated, as well as Stiff diagrams plotting. They show a variable result in the studied waters, and similarity with Stiff diagrams behaviour. The salinity of produced water in year 2018 is less than that of 2019.**

***Index Terms*: Oil and gas fields, produced water, characterizing parameters, salinity, cations, anions, concentration.**

I. INTRODUCTION

With the increasing demand for oil and its derivatives, the increasing production of oily water and its treatment has been a challenge due to the complexity and amount of waste generated, because this undesirable effluent requires treatment before its final disposal in order to meet the legal requirements for disposal in the environment or technical requirements for injection into oil wells. In the oil and gas industry, produced water is considered as one of the single and largest most important waste streams, and as it is a residue of complex chemical composition, which contains relatively higher concentration of hydrocarbons, heavy metals and other pollutants, it can't be simply discarded into the environment, but must be treated appropriately [14]. Due to the increase in industrial activities, the generation of produced water has increased all over the world and its treatment for reuse is now important from environmental perspective [3].

Oil reserves in Libya are the largest in Africa and among the ten largest globally with 46.4 billion barrels (7.38×10^9 m^3) as of 2010. Libya is a major oil producer in Africa with an oil production reaching 1.2 million barrels/day. The increased oil production will certainly result in more produced water that requires handling and treatment. The Sarir oil and gas field is situated at southeastern portion of the Sirt Basin, north central Libya. Sarir field which is part of a three-field complex is 56 km long and 40 km wide covering approximately 378 km². The District lies from 28.22° North latitudes and 19.13° East longitudes. Sarir is operated by the Arabian Gulf Oil Company, a subsidiary of the state-owned National Oil Corporation. This study has evaluated the physical/chemical properties of formation water in Sarir oilfield, Libya.

Characteristics of produced water differ from well to well and the determination of the produced water characteristics is required. Produced water is separated from the oil and gas and either re-injected into the reservoir or discharged to the environment. Produced water is a very complex mixture and contains different compounds that can have negative impact on the environment and economical problems associated with oil and gas production [6]. Produced water represents the largest waste stream generated during oil and gas production. When petroleum hydrocarbons are extracted, formation water is brought up to the surface contributing to produce water [1].

Produced water often is generated during the production of oil and gas from onshore and offshore wells [12]. However, water produced during oil and gas extraction operations may be called formation water, oilfield water or brine, and constitutes the industry's most important waste stream on the basis of volume [1]. Formation water is seawater or fresh water that has been trapped for millions of years with oil and natural gas in a geologic reservoir consisting of a porous sedimentary rock formation between layers of impermeable rock within the earth's crust [12].

Today, nearly 115 billion barrels per year (bbl/y) of water are produced worldwide as a by-product of oil and gas [13, 19]. In average, for every barrel of oil, three barrels of water are produced from oil wells. As the well ages, this ratio dramatically increases, sometimes rising as high as 50 barrels of water per barrel of oil produced [10].

The water varies greatly in quality and quantity and in some cases the water can be a useful by-product or even a salable commodity. Produced water is most often considered a waste, but the industry is beginning to consider this material as a potential profit stream. Whether waste or commodity, produced water has management costs that need to be kept in-line with each specific production project and region or it could adversely affect the life of the well, thereby leaving substantial recoverable reserves in the ground. Produced water handling practices must also be environmentally protective or the operator could face regulatory action. Produced water handling methodology depends on the composition of produced water, location, quantity and the availability of resources [8, 5].

II. CHARACTERISTICS OF PRODUCED WATER

The physical and chemical properties of produced water vary widely depending on geographic location of the field, the geologic age, depth, and geochemistry of the hydrocarbon bearing formation, in addition to the geological formation with which the produced water has been in contact for thousands of years[6], and the type of hydrocarbon product (e.g. heavy oil, medium oil, light oil, lean gas, rich gas, …) [11] being produced, as well as the chemical composition of the oil and gas phases in the reservoir[6] type (e.g. oil, gas or coal) [11], and production chemicals added to the production.

Produced waters discharged from gas/condensate platforms are about 10 times more toxic than the produced waters discharged from oil wells, but, the volumes from gas production are much lower; hence the total impact may be less [6]. Table 1 represents the summary of typical oil field PW characteristics.

Produced water is a complex mixture of dissolved and particulate organic and inorganic chemicals compounds (mostly salts, minerals and oils) is a major wastewater stream generated during oil and gas production processes [12]. Due to increase oil and gas exploration and production, especially from unconventional resources like shale oil and gas reservoirs, the volume of this effluent production is increasing around the world and its discarding to the environment is one of the global concerns [11].

Moreover, the Produced water characteristics and volume of Produced water varies throughout the lifetime of the proposed reservoir, in which, the water production is very small as the production starts from the reservoir and it increases as the reservoir gets older [11]. Because no two produced waters are alike, region specific studies are needed to address the environmental risks from its discharge [12].

Table 1: Characteristics of typical oil field PW [1, 11]

Parameter	Unit	Value
Density	kg/m^3	1014-1140
Surface	dynes/cm	43-78
TOC	mg/l	0-1500
COD	mg/l	1220
TSS	mg/l	1.2-1000
pH	-	4.3-10
Total oil	mg/l	2-565
Volatile (BTX)	mg/l	0.39-35
Chloride	mg/l	80-200000
Bicarbonate	mg/l	77-3990
Sulphate	mg/l	2-1650
Sulphide	mg/l	10
Total polar compounds	mg/l	9.7-600
Higher acids	mg/l	1-63
Phenols	mg/l	0.009-23

III. COMPOSITION OF PRODUCED WATER

The composition of water produced is subject to change between wells and within the same field. It depends on water, and whether it comes from crude oil or natural gas, while the water produced is generally deoxygenated. It contains organic and inorganic stuffs that chiefly contain oleic acid salts and hydrocarbons that know how to contribute toward environmental toxicity after disposal [4]. For instance, the concentrations of TDS in elevated mineral satisfied components range from 500-600 and above to over 100,000 mg / L for natural gas on behalf of coal litter, and the oil may also be naturally dispersed in water [9].

The oil content can be expressed as:

1- Dissolved oils (aromatics containing BTEX and PAHs, and acids containing fatty acids, naphthenic acids and phenols).

2- Oil dispersed (aromatic materials containing mainly polycyclic aromatic hydrocarbons and acids containing fatty and aliphatic acids). However, in both onshore and offshore operations, the focus is on the components of oil and lubricants in the producing waters, and for land operations, there are concerns about salinity (expressed, salinity, conductivity or TDS) as a major component, inorganic and organic compounds or chemical additives used for the etching of naturally accumulating radioactive materials (NORM) [18].

IV. PRODUCED WATER MANAGEMENT

Produced water can be disposed using discharge, injection, removal to an offsite disposal facility, and evaporation. These management options are described along with numerous technologies currently used by the international oil and gas industry for treating produced water [17]. An example of key parameters of produced water is listed below in Table 2.

Produced water management and disposal challenges are growing, along with the increased production of oil and gas wells. It is estimated that for every 1 barrel of oil produced there is 8 to 10 barrels of produced water recovered. To decrease costs associated with produced water management, water reuse and recycle technologies are implemented.

Table 2: Key parameters of importance in produced water treatments [1]

Parameter	Natural Gas Produced Water	Oilfield Produced Water
Oil/grease (ppm)	40	560
pH	4.4-7.0	4.3-10
TSS (ppm)	5500	1000
TDS (ppm)	360,000	6554
TOC (ppm)	67-38,000	1500
COD (ppm)	120,000	1220
Density (kg/m^3)	1020	1140
Arsenic (ppm)	0.005-151	0.005-0.3
Lead (ppm)	0.2-10.2	0.008-8.8
Chromium (ppm)	0.03	0.02-1.1
Mercury (ppm)	--	0.001-0.002
Oil droplet size (μw)	2 to 30	

Produced water is considered as a waste stream in oil and gas production processes and its management which is usually done to decrease its environmental pollution issues, is very expensive. For the Produced water management, three major successive manners can be considered which could respectively be summarized as minimizing the production of produced water, reusing or recycling the produced water and if none of them could be applied, discarding of Produced water must be considered. Produced water treatment process, which is used before recycling or discarding the PW, is very important to decrease the harmfulness of the PW and valuable products would be achieved through it [17].
Produced water management is a very expensive process, which needs to be kept in-line with each specific production plan and this way; it can play an important role in determining the economic recovery of the reservoir which may lead to leaving a substantial amount of recoverable hydrocarbons in the reservoir [17]. In the following, some of the options for managing the produced water in petroleum industry have been summarized [8, 13, 17].

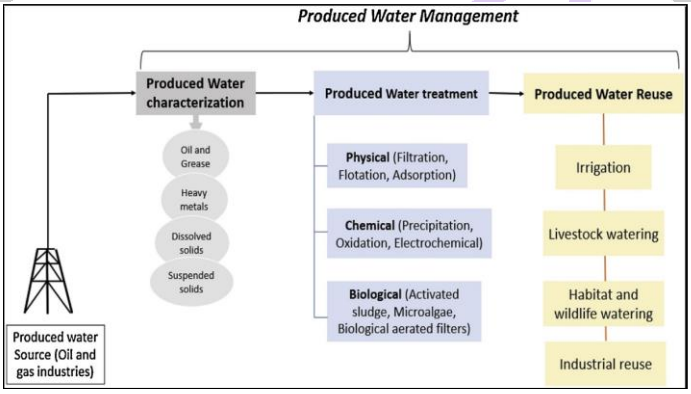

Fig. 1: Produced water management [3]

V. COMPOSITION OF OILFIELD WATER

All formation waters contain dissolved solids, primarily sodium chloride. The water sometimes is called brine or salt water. Generally, oilfield waters contain much higher concentrations of solids than seawater does. Formation waters have been reported with total solid concentrations ranging from as little as 200 ppm to saturation, which is approximately 300,000 ppm. Seawater contains about 35,000 ppm total solids. The dissolved cations commonly found in oilfield waters are Na^+ Ca^{++}, and Mg^{++} occasionally K^+, Ba^{++}, Li^+, Fe^{++}, and Sr^{++} are present. The most common anions are Cl^-, SO_4^- and HCO_3. Also CO_3, NO_3, Br, I, Bo3, and S are often present [5, 7].

VI. OBJECTIVES OF STUDY

1. Describe the characteristics of produced water: constituent, concentration and volumes produced.
2. Identify constituents in produced water that exceed water quality requirements of beneficial uses and constituents that will be problematic for treatment of produced water.
3. Determination the characterization engineering parameters e. g. density, viscosity, compressibility and formation volume factor.

VII. LOCATION OF STUDY

The selection of site was made after consideration of the location of major volumes of produced water discharges and the potentially most sensitive environments. This study has been conducted on the oilfield water that associated oil and gas production in Sarir oil field. The field is located in the southeastern portion of the Sirt Basin, in Libya.

VIII. MATERIALS AND METHODS

The physiochemical properties of produced water were determined through the data of tests and chemical analysis that have been carried out on the brine of Sarir field samples.

The samples will be collected periodically and chemically analyzed in field labs through the period of study. The concentrations of different constituents were determined by using different analytical techniques.

The physical and chemical parameters of the disposal water are estimated. The physical parameters include: pH, specific gravity, turbidity, viscosity and conductivity. While the chemical parameters represented by total hardness, total dissolved solids (TDS), calcium, magnesium, sodium, potassium, ammonia and sulphate .etc.

On the other hand, the characterizing parameters such as formation volume factor of formation water (B_w), density (ρ), coefficient of isothermal compressibility (C_w), coefficient of viscosity (μ_w), and (R_w) have been estimated, as well as Stiff diagrams.

IX. RESULTS AND DISCUSSION

Physiochemical Characterization of Formation Water

The physiochemical characterization parameters of formation water (brine) in Sarir oil field that determined included five gathering centers are GC1, GC2, GC3, GC4 and GC5 as reported in Table 3.

Table 3: Physiochemical properties of produced water [2]

Well No. / Parameters	Unit	GC1	GC2	GC3	GC4	GC5
Physical properties						
pH @ 25℃	--	6.07	6.7	5.6	5.15	8.10
Specific gravity @ 60°F	g/cm^3	1.1125	1.484	1.113	1.1260	1.103
Turbidity	FAU	298	300	185	320	190
Conductivity	μmhos/cm	114400	21000	75600	26530	23900
Viscosity	cst	0.75	0.80	0.55	0.66	0.62
Chemical properties						
Total dissolved solids, TDS	ppm	68200	11800	220718	163545	24600
Total hardness	ppm	38540	3200	45000	42806	8000
Calcium	ppm	27000	1813	15170	34458	43003
Magnesium	ppm	11540	1387	29830	8348	10600
Alkalinity, HCO_3	ppm	140	268.4	73.688	90	150
Salinity, NaCl	ppm	205000	26325	207090	184750	17000
Chloride, Cl^-	ppm	172000	15953	125493	112113	10300
Permanent hardness	ppm	38440	3040	44940	42714	20544
Temporary hardness	ppm	100	160	60	92	120
Total iron	ppm	87	14.4	69.75	195	75.5
Sulphate	ppm	290	120	365	533	263
Phosphate	ppm	1.55	0.4	3.9	2.3	1.4
Nitrate, (NO_3-N)	ppm	1.5	2.0	1.3	1.5	1.02
Nitrogen ammonia (NH_3-N)	ppm	115.0	13.4	110	114	78
Nitrite (NO_2-N)	ppm	0.44	0.20	0.75	0.90	0.88
NO_3	ppm	13.8	10.0	6.0	9.5	8.16
NH_4	ppm	20.3	17.2	8.0	12.0	15.2
NH_3	ppm	9.8	4.0	10.2	16.4	7.9
Oil in water	ppm	44.9	38	50.2	40.5	28.9

These parameters include the physical properties e.g. specific gravity, turbidity, pH, conductivity and viscosity, while the chemical properties represented by different parameters e.g. total dissolved solids (TDS), total hardness, salinity, chloride, calcium, magnesium, phosphate, nitrate, nitrogen compounds etc. In addition to the produced water through years of 2018 / 2019 as shown in (Tables 4 and 5).

Figures 2 and 3 illustrated the total quantity produced water in oilfield through 2018 and 2019 years represented by disposal water, washing water and produced water. It seems that the amount of disposal water in 2018 is greater than that of 2019, as well as the produced water is excessed than that produced in 2019.

Table 4: Produced water data through 2018 [2]

Months	Produced water, bbls	Washing water, bbls	Total of water, bbls	Disposal water, bbls	Salinity, ppm	Oil content, ppm	TDS ppm
January	2268587	144187	2412774	2412774	184266	76	103
February	1380475	93449	1473924	1473924	136000	76	103
Mars	3864313	277685	4141998	4141998	134500	65	814
April	3361315	217638	3578953	3578953	184275	65	79
May	3512769	270416	3783185	3783185	141700	53	87
June	4303004	255150	4558154	4558154	184290	76	103
July	2867076	215450	2902526	2902526	137300	33	79.5
August	2929042	226154	3155195	3155195	204555	5	106
September	2915423	279911	3195333	3195333	184275	76	103
October	2921366	308848	3230214	3230214	181545	46	77.3
November	3566887	273917	3840804	3840804	184275	76	103
December	3829459	316777	4146236	4146236	184470	24	83.6

Table 5: Produced water data through 2019 [2]

Months	Produced water, bbls	Washing water, bbls	Total of water, bbls	Disposal water, bbls	Salinity, ppm	Oil content, ppm	TDS ppm
January	3549949	243452	3793401	3793401	184275	70	76.4
February	3859960	242354	3689506	3488502	190255	76	103
Mars	3340438	249164	3589602	3589602	109800	55	654
April	6200479	331390	6531869	6531869	179400	16	85.3
May	2053096	132742	2185838	2185838	196365	6	64.7
June	3600152	150025	3750177	3750177	149955	55	654
July	2079038	108522	2187560	2187560	109800	55	654
August	1706753	90646	1797398	1797398	109800	55	654
September	3317723	168199	3485922	3485922	109800	77	28.4
October	4746371	297973	5044344	5044344	181115	77	28.4
November	6012350	338326	6350676	6350676	171115	95	89.7
December	4242783	267968	4510751	4510751	178425	78	68

Fig. 2: Total quantity of produced water in oilfield through 2018

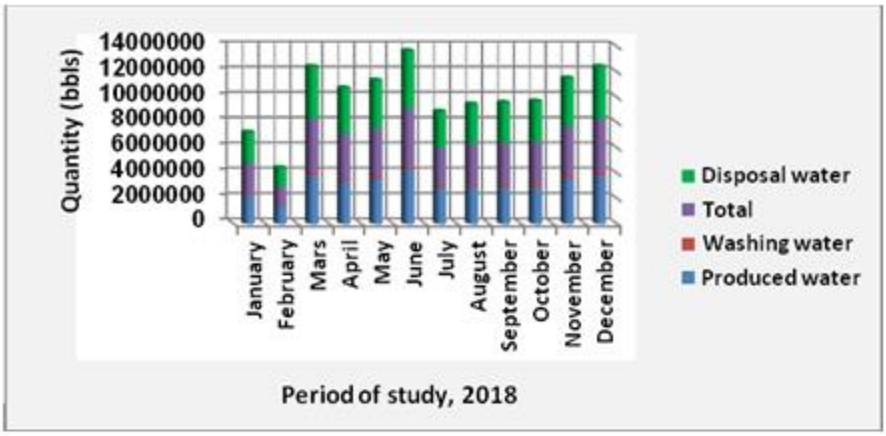

Fig. 3: Total quantity of produced water in oilfield through 2019

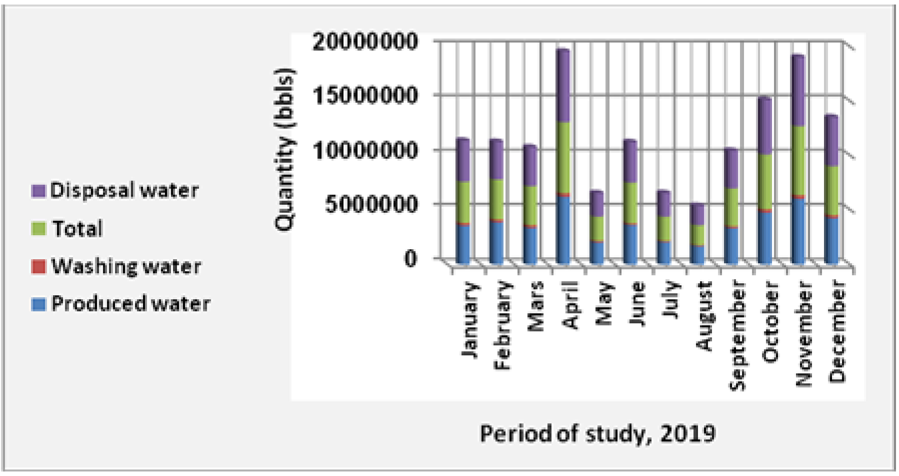

Fig. 4 shows salinity concentration in produced water through the two years 2018 & 2019. The figure reveals that salinity concentration in year 2019 is greater than the concentration in 2018.

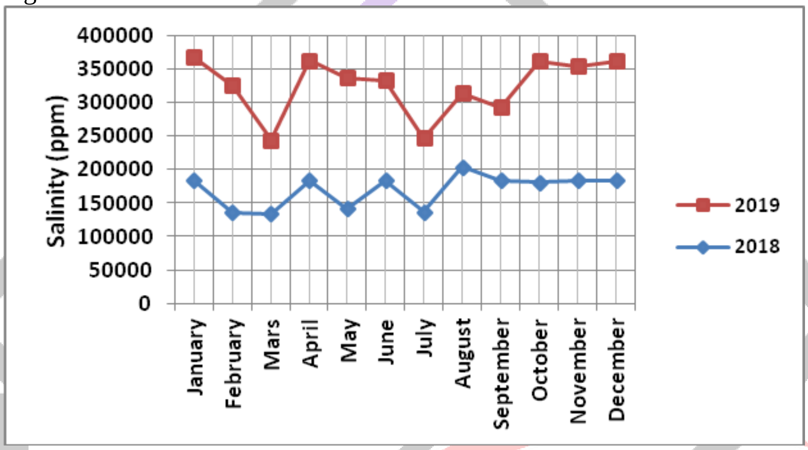

Fig. 4: Salinity concentrations in produced water in 2018 & 2019 years

Figure 5 depicts the concentration of TDS and oil content in produced water through 2018 and 2019 years. The TDS show very wide range in their concentration through 2018 and 2019 particularly in Mars, June, July and August months. On the other hand, oil content exhibits more or less similar behavior of variation through the two years.

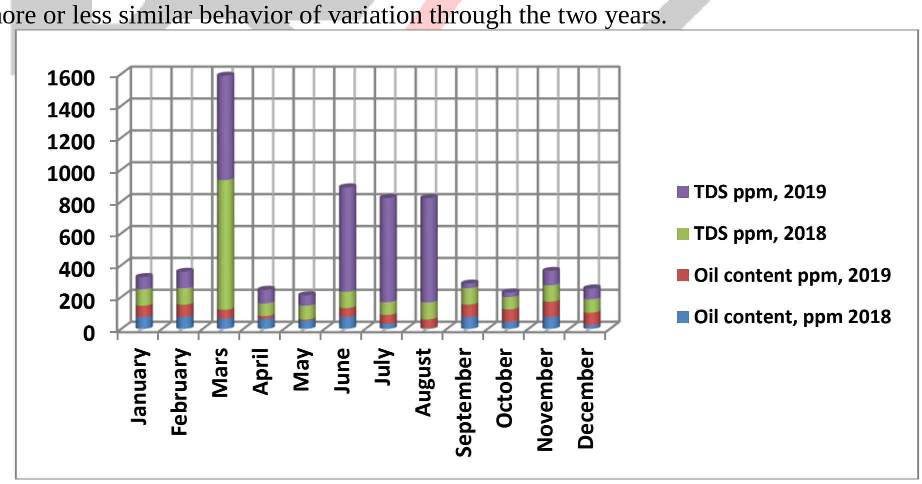

Fig. 5: Contents of TDS and oil in produced water in 2018 & 2019

Determination the characteristics properties using correlations

1- Water Formation Volume Factor (B_w)

The formation volume factor (B_w) of oilfield water can be determined by knowing temperature and pressure and by using the standard correlation. The calculations of formation volume factor are listed in Table 6, at the reservoir pressure (psia) and temperature (°F).

Table 6: Water formation volume factor

Well No. / Parameter	Unit	GC1	GC2	GC3	GC4	GC5
Pressure	Psia	2500	2940	3005	2010	2200
Temperature	°F	160	185	192	150	155
ΔV_{wT}	--	0.024	0.035	0.038	0.021	0.022
ΔV_{wP}	--	-0.003	-0.0045	-0.0042	-0.0021	-0.0021
Water formation volume factor (B_w)	bbl/stb	1.021	1.030	1.034	1.019	1.020

2- Density of oilfield water

The density of formation water can be estimated by using published charts after the conversion the total dissolved solids from ppm into percent as following in Table 7.

Table 7: Determination of brine density

Gathering center / Parameter	Unit	GC1	GC2	GC3	GC4	GC5
Total dissolved solids, TDS	ppm	68200	11800	220718	163545	24600
Total dissolved solids, TDS	%	6.82	1.18	22.07	16.4	2.5
Brine density	lb/cu ft	65.20	62.50	72.40	69.70	63.30

From the data obtained that represented in Table 7 the highest density of brine water produced from GC3 (72.80 lb/ft^3) and the lowest value in GC2 (62.50 lb/ ft^3).

3- Coefficient of isothermal compressibility of water

The coefficient of isothermal compressibility of brine water can be estimated by knowing the temperature and pressure from the correlation as in Table 8.

Table 8: Brine compressibility factor (C_w)

Gathering center / Parameter	Unit	GC1	GC2	GC3	GC4	GC5
Pressure	psia	2500	2940	3005	2010	2200
Temperature	°F	160	185	192	150	155
Compressibility factor (C_w)	$psi^{-1} \times 10^6$	2.95	3.09	3.16	3.01	2.99

4- The Coefficient of Viscosity of oilfield Water (μ_w)

The viscosity coefficient of brine can be determine by knowing the temperature and the salinity (NaCl) after conversion from ppm into percent (%) and use the correlation in as in Table 9.

Table 9: Viscosity coefficient of brine

Gathering center / Parameter	Unit	GC1	GC2	GC3	GC4	GC5
Salinity, NaCl	ppm	205000	26325	207090	184750	17000
Salinity, NaCl	%	20.5	2.6	20.7	18.5	1.7
Temperature	°F	160	185	192	150	155
Viscosity coefficient	μ_w	0.62	0.32	0.52	0.63	0.42

The obtained data shows that the highest viscosity brine in GC4 and the lowest value is recorded in GC2 (Table 9).

5- Resistivity of Oilfield Water

If the concentration of dissolved solids is known, the resistivity of the water at any temperature can be determined. If the resistivity of brine at surface temperature is measured, it can be converted to reservoir temperature. Finally, if the resistivity is measured, the brine concentration can be estimated.

The resistivity of brine can be determined by knowing the temperature and the salinity (NaCl) in ppm units or after conversion from ppm into grain at 75°F and use the correlation as in Table 10.

X. STIFF DIAGRAMS

The chemical analysis of produced water involved a range from 6 to 10 of numbers that representing the different composition of ions. So, the best way to represent the data was developed in patterns, these patterns called Stiff diagrams (Figure 6). From these patterns we can distinguish easy the difference between brines.

Table 10: Resistivity of brine

Gathering center / Parameter	Unit	GC1	GC2	GC3	GC4	GC5
Salinity, NaCl	ppm	205000	26325	207090	184750	17000
Temperature	°F	160	185	192	150	155
Resistivity	R	0.029	0.022	0.025	0.034	0.18

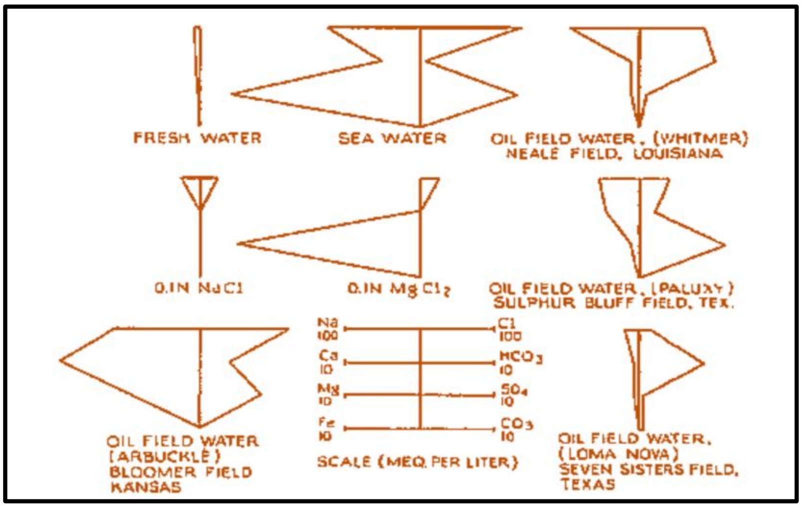

Fig. 6: Stiff patterns of formation water [15]

To construct Stiff diagrams we must be applied the following procedure:

Conversion the Concentrations from ppm to mg/l

1. Conversion the total dissolved solids, TDS from ppm into percentage (%) by dividing to 10^6.
2. Brine density (lb/ft^3) can be determined from the chart of density using the obtained TDS in percentage (%).
3. Conversion the brine density (lb/ft^3) into g/cc.
4. Multiply the concentrations of cations and anions of brine in ppm by brine density to obtain the concentrations in mg/l.
5. The results obtained are presented in Tables 11 and 12.

Table 11: Determination of brine density

Well No. / Parameter	Unit	GC1	GC2	GC3	GC4	GC5
Total dissolved solids, TDS	Ppm	68200	11800	220718	163545	24600
Total dissolved solids, TDS	%	6.82	1.18	22.07	16.4	2.5
Brine density	lb/cu ft	65.20	62.50	72.40	69.70	63.30
ρ_w	g/cc	1.044	1.001	1.159	1.116	1.014

Table 12: Conversion the concentrations to mg/l

Chemical properties	*Concentration (mg/l)*				
	GC1	GC2	GC3	GC4	GC5
Calcium	28188	1892	17582	38455	43605
Magnesium	12047	1448	34572.9	932	10748
Salinity, NaCl	214020	27483	240017	206181	17238
Chloride, Cl^-	179568	16655	145446	125118	10444
Total iron, Fe	91	15.0	80.8	217.6	76.6
Sulphate, SO_4	302	125	423	595.0	266.7
Alkalinity, HCO_3	146.2	268.7	85.5	100.4	152

Conversion the Concentrations from mg/l into meq/l

To convert from mg/l to meq/l for cations and anions follow the following steps:

The atomic weight of Ca is 40.08 g/g mole, valence is 2 eq wt/g mole, then the equivalent weight is:

For Ca, $\frac{40.08\,\frac{g}{g\,mole}}{2\,\frac{eq\,wt}{g\,mole}}$ = 20.04 g/eq wt = 20.04 mg/meq.

and the milliequivalent is: $\frac{28188\,\frac{mg}{l}}{20.04\,\frac{mg}{meq}}$ = 1406.6 meq/l

Similarly the conversion performed for Na, Mg, Cl^-, Fe, SO_4 and HCO_3. The results are presented in Table 13.

Table 13: Conversion from mg/l to meq/l for cations and anions

Chemical properties (Cations and anions)	Ion concentration (meq/l)				
	GC1	GC2	GC3	GC4	GC5
Calcium, Ca^{++}	1406.6	94.41	877.4	1918.9	2175.9
Magnesium, Mg^{++}	1003.9	120.7	2896.1	77.7	895.7
Sodium, Na^{+}	9309.3	1200.1	10481.1	9003.5	752.8
Chloride, Cl^{-}	5058.3	469.2	4097.1	3524.5	294.2
Total iron, Fe	4.87	0.80	4.3	11.6	4.10
Sulphate, SO_4	6.29	2.60	8.81	12.40	556
Alkalinity, HCO_3	47.9	8.8	2.8	3.29	4.98
Carbonate, CO_3	0.0	0.0	0.0	0.0	0.0

The Stiff diagrams of the studied formation water were constructed for the different gathering centers as shown in Figure 7 through Figure 11 and compared with different patterns of Stiff diagrams. Most of the studied water exhibits a similarity of these patterns, but some of them show slightly deviation, this may be attributed to the type of formation and the source of brine.

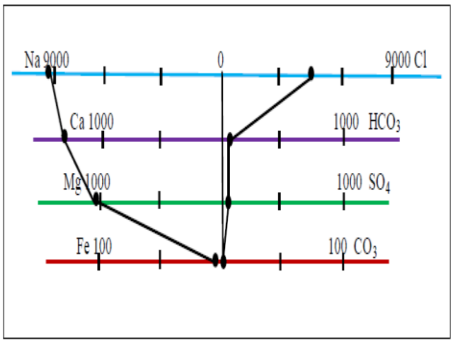

Fig. 7: Stiff diagram for GC1

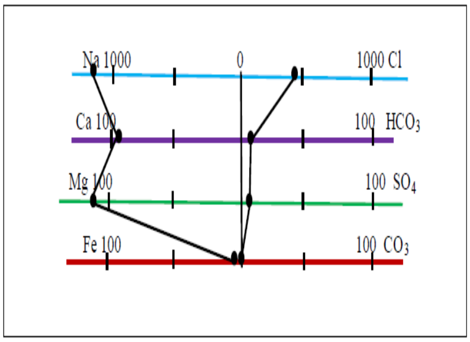

Fig. 8: Stiff diagram for GC2

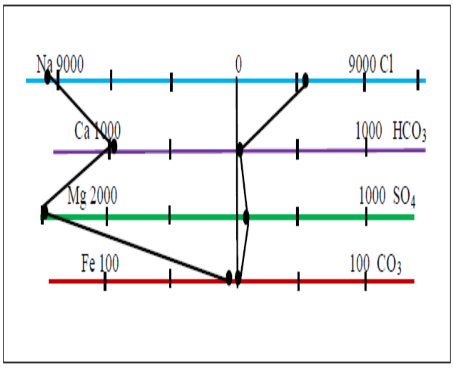

Fig. 9: Stiff diagram for GC3

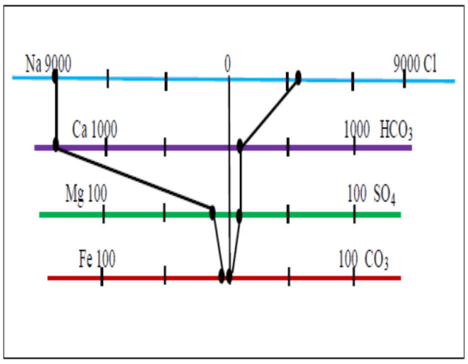

Fig. 10: Stiff diagram for GC4

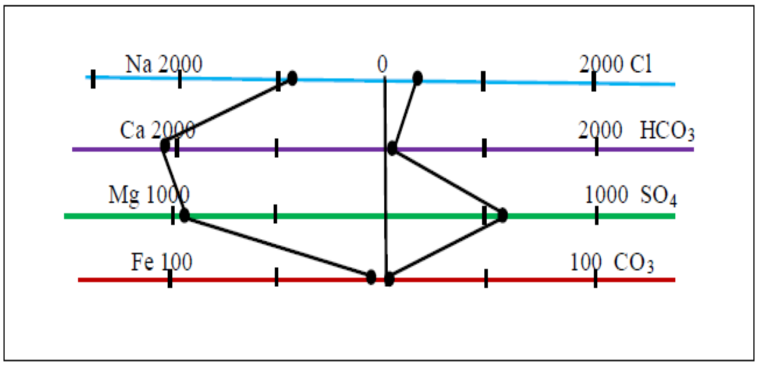

Fig. 11: Stiff diagram for GC5

XI. ASSESSMENT OF GROUND WATER QUALITY

To make sure the groundwater quality, some samples were collected from the ground water wells in oilfield; these wells are well-537, well-542, well-538 and well-543 as depicted in Figure 12, which illustrated sketch of the distribution of fresh water wells and disposal wells as well as the two disposal pits. These wells with different distances from the disposal area of produced water. Table 12 illustrates the analysis of groundwater.

The data obtained from the chemical analyses of ground water reveals that the ground water has been affected by the disposal of produced water through surface pits and ponds. The pollution of groundwater demonstrated that the wells close to the pollution source that represented by well-542 and well-537 are high concentration of Cl, TDS and conductivity than the other wells that far away from this source (Figure 13).

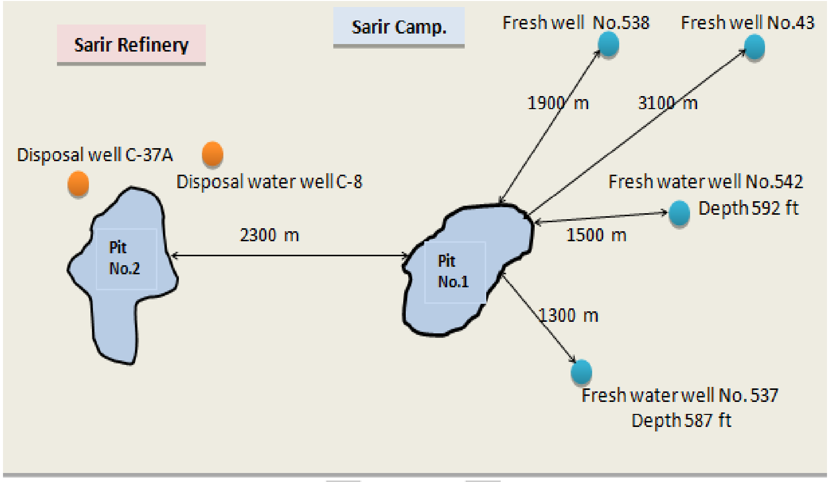

Fig. 12: Sketch shows the distribution of fresh and disposal wells and the pits of disposal water

However, these values compared with standard values of Libyan drink water, where the exceed the permissible limits of drink water (Table 14).

Also, from Figure 13 it is obviously that the water of the two wells 542 and 537 contains high concentrations of different salts comparing with the other ones.

Table 14: Groundwater analyses data

No.	Well No.	Well-537	Well-542	Well-538	Well-543	Libyan Stand. Values*
	Parameter	Result	Result	Result	Result	
1	Colour (C. U.)	Colourless	Colourless	Colourless	Colourless	-
2	Turbidity (NTU)	Clear	Clear	Clear	Clear	-
3	Taste	Acceptable	Acceptable	Acceptable	Acceptable	-
4	Odour	Acceptable	Acceptable	Acceptable	Acceptable	-
5	pH	7.6	7.5	7.86	7.8	6.5-8.5
6	Conductivity (μs)	1147	2120	959	925	-
7	TDS (mg/l)	688	1269	566	555	500-1000
8	Cl^- (mg/l)	421	1230	290	273	200-250
9	SO_4^{-2} (mg/l)	70	74	78	66	200-400
10	Ca^{++} (mg/l)	52	180	36	50	-
11	T. H. as $CaCO_3$ (mg/l)	298	850	263	205	200-500
12	Total Fe (mg/l)	0.17	1.57	0.15	0.12	
13	H. CO_3 (mg/l)	217	220	228	224	75-200
14	T. alk. as $CaCO_3$ (mg/l)	178	180	187	184	-
15	NO_3^- (mg/l)	2.10	2.6	2.10	1.9	45
16	NO_2^- (mg/l)	0.10	0.008	0.003	0.009	-

* Source: Libyan standard values for drink water [16]

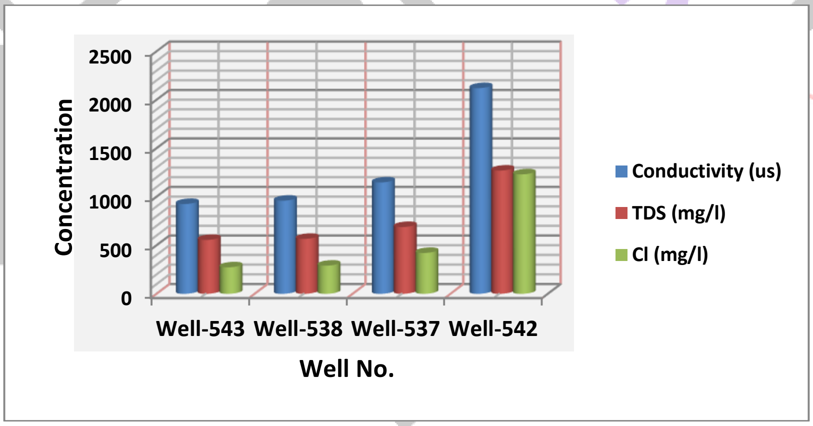

Fig. 13: Conductivity, TDS and Cl distribution in groundwater

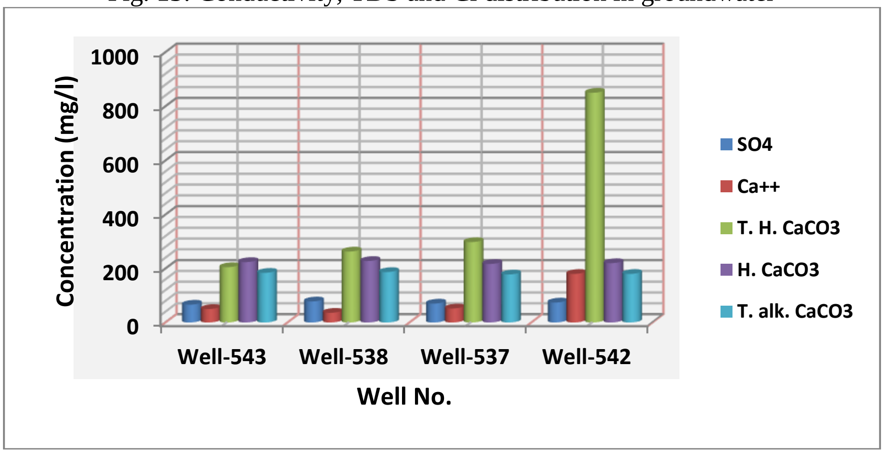

Fig. 14: Salts concentrations in groundwater

Both NO_2 and NO_3 tend to increase toward the source of pollution vice versa with the total Iron which gives the higher content in well-543 (Figure 15).

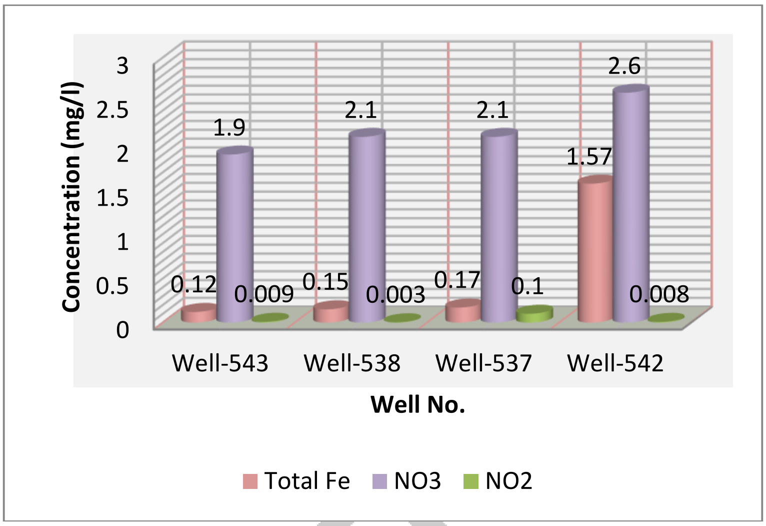

Fig. 15: Total Fe, NO_2 and NO_3 concentration in groundwater

XII. CONCLUSION

Produced water may be treated using different methods of operation. The criteria used to compare the technologies are in general, robustness, reliability, mobility, flexibility, modularity, cost, chemical and energy demand, and brine or residual disposal requirements. Many process and water quality specific factors should be taken into account when selecting a produced water treatment process. Water analysis is very important for petroleum engineering industry from both upstream and downstream activities. Produced water represents the largest waste stream associated with oil and gas production in the studied oilfield. The results of the evaluation of characterization properties of Sarir oilfield produced water as following:

- Most produced water a characteristic varies from well to another and independent of the production year of the oilfield.
- Many characteristics of the produced water such as specific gravity, salinity, TDS, Na and Cl exhibit variable values, this may due to nature of reservoir formations.
- Generally, oilfield produced waters contain elevated levels of specific gravity, salinity, TDS, cations and anions more than the standards characteristics of seawater.
- The salinity concentration in year 2019 is less than the concentration in 2018.
- The characterizing parameters such as formation volume factor of formation water (B_w), density (ρ), coefficient of isothermal compressibility (C_w), coefficient of viscosity (μ_w), and (R_w) show variable results in the studied waters.
- The Stiff diagrams of the studied formation water were constructed for the different gathering centers and compared with different patterns of Stiff diagrams. Most of the studied water exhibits a similarity of these patterns, but some of them show slightly deviation, this may be attributed to the type of formation and the source of brine.
- The physiochemical properties of the disposal water can be affected harmful on the environmental medium specially the soil and ground water.
- The groundwater analyses revealed that the disposal of produced water at surface affected harmfully on the groundwater quality.

XIII. RECOMMENDATIONS

1. The associated water can be treated and reused for different processes e.g. reinjection to maintain reservoir pressure.
2. The water also can be used for enhanced oil recovery operation.
3. Associated water can be used in the oil field after treatment as alternative for fresh water.
4. The produced water can be stored in closed reservoirs instead of disposal in open pits.
5. Environmental studies should be carried out to determine environmental impacts assessment and the effect of ground water by surface disposal.
6. We recommended also by applying Membrane Biological Reverse (MBR) treatment technique because more effective.

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