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Research Article

Statistical Analysis of Treated Flow-Back Water Measurements: An Industrial Insight for a Shale Reservoir

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Water production from unconventional reservoirs especially shale reservoirs has always been considered as the major challenges for petroleum industries that needs special requirements and facilities to treat the flow-back water and reinject to the reservoirs. The objective of this paper is to statistically measure the provided freshwater from treated water that is produced from reused water. The treated water is provided from different processes such as hydraulic fracturing, chemical enhanced oil recovery methods (such as polymer, surfactant, and foam flooding that are the main important techniques in recovery processes) from eight wells in Bangestan field in South of Iran. Moreover, photofenton-flotation separation methods are used in this field to treat the produced water from different processes. As a result, saving water percentage in the studied field for hydraulic fracturing processes is about 82% and therefore, the required fresh water is about 18%. Moreover, saving water percentage in the studied field for chemical recovery techniques is about 70% and therefore, the required fresh water is about 29%. The findings of this study can help for better understanding of the required fresh water for 1000 inhabitants can be saved through this system.

1. Introduction

During the operational performances of a hydrocarbon reservoir, flow-back water has contained different dissolved and hazardous materials such as solid droplets, toxic metals, and wide range of chemical materials that could be polluted the environment and might be hazardous for the working staffs on that area. Due to the application of crude oil in different industrial purposes such as petrochemical industries and drug production, it is beneficial to produce more oil volumes with the more efficient and economical features such as chemical enhanced oil recovery and hydraulic fracturing techniques. All of these techniques have required water for their performances, which should be recommended to reuse flow-back water instead of fresh water supply. Therefore, several treatment techniques such as biological, physical, and chemical methods have been utilized to treat the produced water accordingly. Supplementary information for different treatment techniques could be found in more detail in the following literatures.

Zhang et al. (2020) conducted an investigation on the fluid-rock interactions issue and how it has affected hydraulic fracturing performances. Their investigations were done for a shale reservoir in static and dynamic situation to provide a significant insight for petroleum industries. Scanning electron microscope device was administered to observe the total dissolved solids and the contents of each ions in the formation [1]. Bakken shale field is one of the important fields in USA that has been studied by different scientists and industries on how to manage the flow-back produced water and its treatment. According to the critical review of Conrad et al. (2020) about the efficient methods of treatment for produced water, they found that U-PW quantity and composition investigation would be of importance on the analysis of treated water. They have focused on several separation processes such as oxidation, floatation, and desalination techniques and their efficiency on the solids and chemical removals from flow-back water [2]. Suboyin et al. (2020) have investigated the different essential parameters

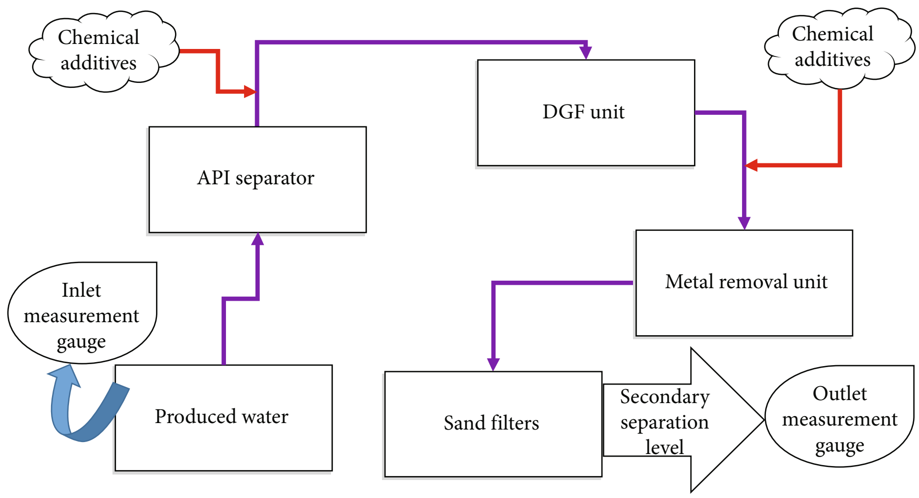

Figure 1: Separation process for water treatment process.

of fracturing fluid viscosity and fracture aperture on the volume of flow-back produced water in the surface. Thereby, it can be concluded that the profound impact of each parameter would be a useful criteria for the well development and fracturing designation performances [3].

The importance of water scarcity issue has challenged every society and industries. Regarding the necessity of producing crude oil for several industrial purposes, it is essential to have sufficient water supplies for different operational performances. Thereby, the main purpose of this comprehensive study is to observe the operational performances of Bangestan field and its separation unit (photofenton-floatation system). We set aside on the statistical measurement of flow-back treated water and how much water volume could be saved for each process in the studied field. To be more reliable on the obtained measurements, we repeated the measurements in five different stages and then provide an average value for them that can be used as future studies. In this regard, the photofenton-flotation separation technique as the method that we used in this study was explained. Then, the statistical method is described. Since then, the results of this study have been presented, and they were discussed with previous literature. Finally, the findings of this study were expressed in summary to have an overview and further improvements for petroleum industries.

2. Methodology

2.1. Photofenton-Flotation Separation Technique. Photofenton-flotation separation techniques are considered as the combination of hydrogen peroxide (usually with the ions of Fe^{2+} and Fe^{3+}) and UV radiation. These two processes can provide many hydroxyl radicals that help to enhance the organic pollutants degradation [4–6]. The separation process by this technique is schematically shown in Figure 1. As some chemical materials are really hazardous for environment, required environmental policy should be taken into consideration in the treatment processes.

2.2. Statistical Measurement. To measure the required fresh water and treated flow-back water, the following equation is used as a statistical method to accurately define the measurements. To be more validated, all the measurements were repeated five times, and the provided values in the results section were average values of five measurement stages.

Table 1: Treated flow-back water at different stages based on MM m^3 for one day in hydraulic fracturing techniques.

Well no.	Stage #1	Stage #2	Stage #3	Stage #4	Stage #5	Average value
Well-A	3.12	3.24	3.04	3.49	3.63	3.304
Well-B	3.89	4.17	4.11	3.94	4.35	4.092
Well-C	4.62	4.52	4.86	4.93	4.58	4.702
Well-D	2.78	3.16	2.89	3.06	3.3	3.038
Well-E	3.01	2.84	2.94	2.93	3.13	2.97
Well-F	3.43	3.56	3.24	3.37	3.32	3.384
Well-G	1.86	1.75	1.89	1.94	1.97	1.882
Well-H	2.14	2.35	2.28	2.23	2.08	2.216

$$V_T = [(V_2) - (V_1)]_n, \tag{1}$$

where n denotes each procedure such as hydraulic fracturing, chemical enhanced oil recovery techniques, and other well procedures, V_T is the total treated flow-back water in all stages, V_2 is the inlet flow-back water to the photofenton-flotation separation unit, and V_1 is the treated flow-back water at the outlet of the separation unit. All the measured volumes were in MM m^3. It is calculated for each well separately to determine how much water can be treated for each procedure. Total treated water is calculated with the following equation:

$$\text{Total treated flow} - \text{back water} = \sum_{m=1}^{5} (\text{Treated flow-back water})_n, \tag{2}$$

where m denotes the repeating stages for treatment processes. Before any measurements, inlet and outlet gauges were calibrated to provide proper calculations.

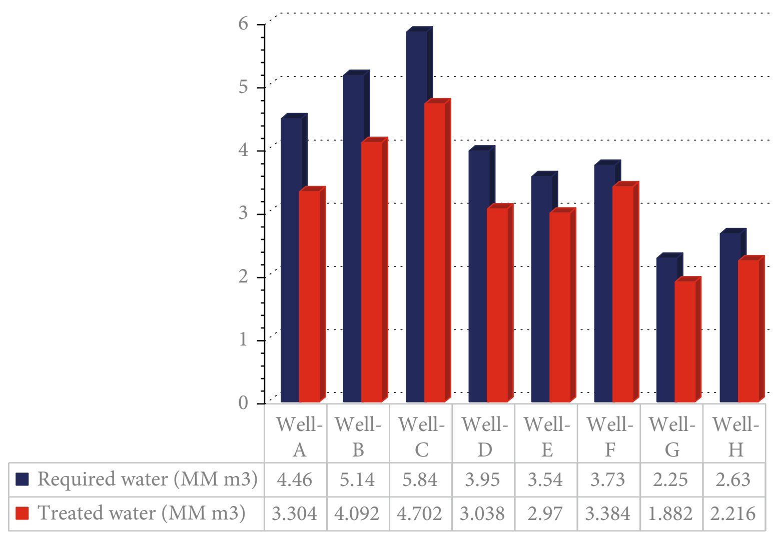

Figure 2: Comparison of treated flow-back water and fresh water in hydraulic fracturing.

Table 2: Annual and daily saving water in hydraulic fracturing processes.

Well no.	Daily saving water (MM m^3)	Annual saving water (MM m^3)	Saving water percentage (%)	Required fresh water (%)
Well-A	1.156	421.94	74.08	25.92
Well-B	1.048	382.52	79.61	20.39
Well-C	1.138	415.37	80.51	19.49
Well-D	0.912	332.88	76.91	23.09
Well-E	0.57	208.05	83.90	16.10
Well-F	0.346	126.29	90.72	9.28
Well-G	0.368	134.32	83.64	16.36
Well-H	0.414	151.11	84.26	15.74
Field	25.588	2172.48	81.71	18.29

Saving water percentage in the studied field for hydraulic fracturing processes is about 82% and therefore, the required fresh water is about 18%.

3. Results and Discussion

3.1. Measurement of Treated Water after Hydraulic Fracturing Processes. Hydraulic fracturing is one of the efficient techniques to improve oil recovery factor by creating new channels or expanding the existed pore throats. The fracturing fluid is water as the main fluid flow [7, 8]. According to experimental observation on the studied field, treated flow-back water was measured for each well separately in five stages. It is statistically depicted in Table 1. Average value is calculated as the following equations:

$$\text{Average value} = \sum_{k=1}^{5} \text{Stage}\#k, \tag{3}$$

where k denotes the number of stages.

Treated flow-back water and required fresh water are shown in Figure 2 to compare each well separately.

Table 3: Treated flow-back water at different stages based on MM m^3 for one day in chemical recovery techniques.

Well no.	Stage #1	Stage #2	Stage #3	Stage #4	Stage #5	Average value
Well-A	10.415	9.97	10.23	10.2	10.05	10.173
Well-B	9.54	9.62	9.68	9.47	9.44	9.55
Well-C	3.68	3.72	3.56	3.71	3.57	3.648
Well-D	9.13	9.24	9.08	9.32	9.2	9.194
Well-E	4.65	4.51	4.47	4.39	4.6	4.524

Saving water for the studied wells is calculated as the equation:

$$\text{Annual saving water} = \left(\frac{\text{Treated Water}}{\text{Required Water}} \times 100 \right) \times 365. \tag{4}$$

To calculate the saving water statistically in hydraulic fracturing processes, Table 2 can provide reliable information for petroleum industries to have a significant insights. Moreover, saving water percentage is calculated for each well statistically.

3.2. Measurement of Treated Water after Chemical Recovery Techniques. Chemical enhanced oil recovery techniques such as polymer injection, surfactant, and foam injection have required large volume of water to commence their injectivity patterns. Therefore, water supply for these processes would require fresh water or treated water as environmental policies that should be taken into consideration to have minimal effects on the environment. To be more validated, all the observations were done in five repeating stages, and then the average value is calculated. The results of this observation for chemical recovery techniques are shown in Table 3.

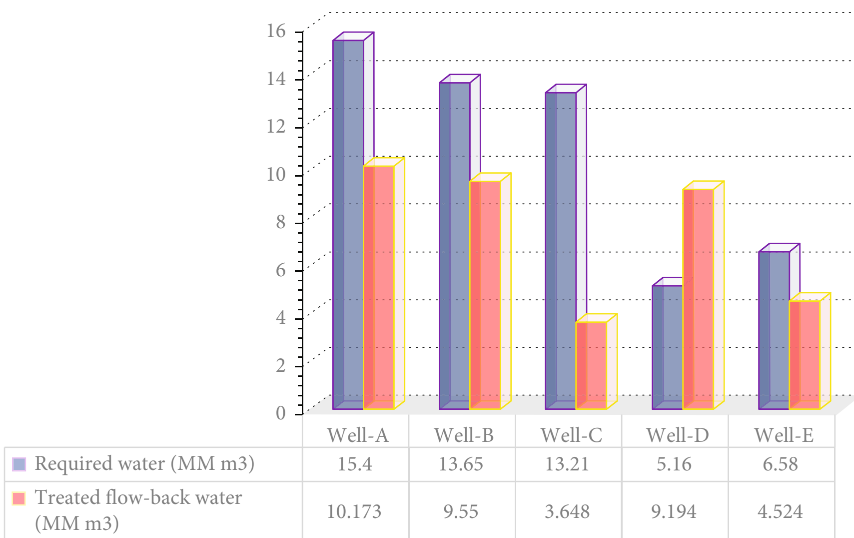

FIGURE 3: Comparison of treated flow-back water and fresh water in chemical recovery techniques.

TABLE 4: Annual and daily saving water in chemical recovery techniques.

Well no.	Daily saving water (MM m^3)	Annual saving water (MM m^3)	Saving water percentage (%)	Required fresh water (%)
Well-A	5.23	1907.86	66.06	33.94
Well-B	4.10	1496.50	69.96	30.04
Well-C	1.51	551.88	70.70	29.30
Well-D	4.02	1465.84	69.60	30.40
Well-E	2.06	750.44	68.75	31.25
Field	16.91	6172.52	69.01	30.99

Saving water percentage in the studied field for chemical recovery techniques is about 70% and therefore, the required fresh water is about 29% (see Figure 3 and Table 4).

TABLE 5: Daily and annual saving water for the studied field.

Utilized water/technique	Daily saving water (MM m^3)	Annual saving water (MM m^3)	Saving water percentage (%)	Required fresh water (%)
Hydraulic fracturing	16.91	6172.52	69.01	30.99
Chemical recovery techniques	25.588	2172.48	81.71	18.29
Well maintenance and drilling performances	5.89	2149.85	54.68	45.32
Total	48.38	10494.85	68.47	31.53

Therefore, the daily and annual saving water in the studied field is statistically explained in Tables 4 and 5. Total saving water volume for the studied field is 10495 MM m^3 that can provide the required fresh water for 1000 inhabitants.

4. Summary and Conclusions

Treatment separation would play a substantial role in well operational performances as it needs environmental policies to be considered for well designation and maintenance. Photofenton-flotation technique that is used in this field has provided efficient results as it can remove large volumes of chemical and toxic pollutants especially in hydraulic fracturing processes. To measure the treated flow-back water properly, two inlet and outlet measurement gauge valves were installed on the entrance and exit of the photofenton-flotation system. Then, the required and treated flow-back water is statistically calculated for each well in five repeating stages to be more sensible for the future well studies and management. Finally, average value of the five stages was calculated to analyze the obtained data and compare the efficiency of each process. The main findings of this study are as follows:

(i) Saving water percentage in the studied field for hydraulic fracturing processes is about 82% and therefore, the required fresh water is about 18%

(ii) Saving water percentage in the studied field for chemical recovery techniques is about 70% and therefore, the required fresh water is about 29%

(iii) Total saving water volume for the studied field is 10495 MM m^3 that can provide the required fresh water for 1000 inhabitants

Nomenclature

Fe: Ferrous ion
UV radiation: Ultraviolet radiation
n: Each procedure
V_T: Total treated flow-back water in all stages
V_2: Inlet flow-back water volume to the photofenton-flotation separation unit
V_1: Treated flow-back water volume at the outlet of the separation unit
MM m^3: Cubic meters $\times 10^{+6}$
m: The repeating stages for treatment processes
k: The number of stages.

Data Availability

All data, models, and code generated or used during the study appear in the submitted article.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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