water

MDPI

Article

Current Challenges and Advancements on the Management of Water Retreatment in Different Production Operations of Shale Reservoirs

Rahmad Syah [1], Alireza Heidary [2], Hossein Rajabi [2], Marischa Elveny [3,*], Ali Akbar Shayesteh [4,*], Dadan Ramdan [1] and Afshin Davarpanah [5]

[1] Data Science & Computational Intelligence Research Group, Universitas Medan Area, Medan 20223, Indonesia; rahmadsyah@staff.uma.ac.id (R.S.); dadan@uma.ac.id (D.R.)
[2] Department of Civil and Environmental Engineering, Shiraz University, Shiraz 71348-14336, Iran; Alireza.heidary66@gmail.com (A.H.); Rajabi.hossein1986@gmail.com (H.R.)
[3] Data Science & Computational Intelligence Research Group, Universitas Sumatera Utara, Medan 20155, Indonesia
[4] School of Environment, College of Engineering, University of Tehran, Tehran 14174, Iran
[5] Department of Petroleum Engineering, Science and Research Branch, Islamic Azad University, Tehran 1477893855, Iran; afshindpe@gmail.com
* Correspondence: marischaelveny@usu.ac.id (M.E.); Shayesteh.ali@ut.ac.ir (A.A.S.)

Citation: Syah, R.; Heidary, A.; Rajabi, H.; Elveny, M.; Shayesteh, A.A.; Ramdan, D.; Davarpanah, A. Current Challenges and Advancements on the Management of Water Retreatment in Different Production Operations of Shale Reservoirs. *Water* **2021**, *13*, 2131. https://doi.org/10.3390/w13152131

Academic Editor: Licínio M. Gando-Ferreira

Received: 23 April 2021
Accepted: 31 July 2021
Published: 2 August 2021

Abstract: Nowadays, water savings on industrial plants have become a significant concern for various plants and sections. It is vitally essential to propose applicable and efficient techniques to retreat produced water from onshore and offshore production units. This paper aimed to implement the PFF (Photo Fenton Flotation) method to optimize the water treatment procedure, as it is a two-stage separation technique. The measurements were recorded for the HF (hydraulic fracturing) and CEOR (chemically enhanced oil recovery) methods separately to compare the results appropriately. To assure the efficiency of this method, we first recorded the measurements for five sequential days. As a result, the total volume of 2372.5 MM m^3/year of water can be saved in the HF process during the PFF treatment procedure, and only 20% of this required fresh water should be provided from other resources. On the other hand, the total volume of 7482.5 MM m^3/year of water can be saved in CEOR processes during the PFF treatment procedure, and only 38% of this required fresh water should be provided from other resources. Therefore, the total water volume of 9855 MM m^3 can be saved each year, indicating the efficiency of this method in supplying and saving the water volume during the production operations from oilfield units.

Keywords: water treatment; CEOR; HF; PFF method; water saving

1. Introduction

Regarding the enormous demand of various industrial plants for water supplies and the dependency of human life on water, it is essential to be more conservative and careful about its consumption [1–5]. Moreover, it can cause droughts worldwide due to the lack of water supply to feed forests [6–10]. This is the main issue that researchers have tried to address in current decades, to increase the efficiency and accuracy of water treatment methods [11–13]. One of the most practical ways to reduce the water demand for industrial plants is to treat produced water to eliminate virtually the high water supply expenses from other resources [14–18]. For example, petroleum industries are one of the largest industrial plants worldwide that require water for their operations [19,20]. As the produced water contains hazardous materials and can pose significant environmental problems, it cannot be reused without retreatment [21–30]. Therefore, the use of treated water to continue the operations should be strictly promoted by the World Health Organization to [31–40]. These hazardous materials consisted of solid and heavy metals, chemical agents in produced water that might be highly toxic to the environment [41–51].

There are two main processes in petroleum industries that require large quantities of water to proceed with operations [51–55]. These procedures aim to increase the oil production to supply the necessary demand for industrial plants to crude oil [56–58]. Hydraulic fracturing is an essential process in petroleum industries that requires a large volume of water to create a fracturing fluid [59–63]. In this process, oil production has been increased by enlarging the previous and tight pores or creating new pore channels to simplify the oil mobilization through porous media [64–68]. As the fracturing fluid has been returned to the surface after the HF process, it should be treated in surface treatment facilities to remove solid and chemical particles in flow backwater. Therefore, an optimum and efficient method would be essential to provide the maximum water savings in the treatment performances [69–71]. These water savings can ensure the survival of several inhabitant and reduce the unnecessary expenses of freshwater supply. Another production operation that required water to continue its processes is CEOR, as water would be an essential part of preparing chemical agents such as polymers, foams, and surfactants [72–74]. The reason for this concerns the aqueous solution that needs to be provided for CEOR methods, as polymers and surfactants are in the form of powders [75–77]. Therefore, to control the processes in underground formations, it is crucial to use chemical agents as aqueous solutions [77]. Due to chemical agents' inflow backwater, which might be combined with reservoir chemical components, it is necessary to have adequate separation and treatment processes to remove most of these components [78]. This can help eliminate the hazardous impact of these materials when disposed of in the environment. The PFF method is considered the applicable method for onshore and offshore plants, as they treat water in two primary and secondary stages in different sections [79–84].

Coonrod et al. (2020) proposed an analytic review on the efficient and applicable treatment processes for Bakken shale oilfield to define the proper technique in water treatment performances among various separation and treatment techniques. They found that the U-PW method is the most applicable and efficient technique for water treatment in shale oilfields, rather than floatation, desalination, and oxidation methods [85]. Due to the lack of experimental and field application data for water treatment processes, especially in onshore plants, we aimed to implement the PFF method to optimize the water treatment procedure as a two-stage separation technique. The measurements were recorded for the HF and CEOR methods separately to compare the results appropriately. To assure the efficiency of this method, we first recorded the measurements for five sequential days.

2. Methods

One of the most efficient and applicable water treatment processes in onshore and offshore drilling operation plants is the PFF (Photo Fenton Flotation) method. In this method, ultraviolent hydrogen peroxide radiation was simultaneously implemented to treat the produced water from production wells. In this method, the degradation of organic pollutants was done by the generation of hydroxyl radicals during the processes, and it can help treat the water. Furthermore, the following steps were done sequentially to retreat the water during the production operations, and the facility services should be near the production wells to virtually eliminate the unnecessary expenses of water transfer (see Figure 1).

(1) Produced flow-back water from production wells was transferred to the system. Specific gauges measured the volume of produced water to measure the final stages of water retreatment accurately. The produced water was transferred to API (American Petroleum Institute) separators to separate solid phases, gas, water, and other simple components from produced water. This stage is called primary treatment.
(2) Then, the water separated at this stage reacted with chemical additives to adsorb small ions and settle them.

(3) Next, the treated water is moved to the dissolved gas floatation section, which can cause the elimination of the gas content by the floatation method in the system. Again, a chemical additive has been added to the system in this section to settle the ions.
(4) In this stage, the treated water moves toward the metal removal section consisting of several screen packs with various meshes.
(5) Then, it is transferred to the sand filtrations section to eliminate the micro- and nanoparticles in the water content. This section is known as the second separation section, and the treated water has been measured by sensitive gauges that can be used in the calculation of treated water.

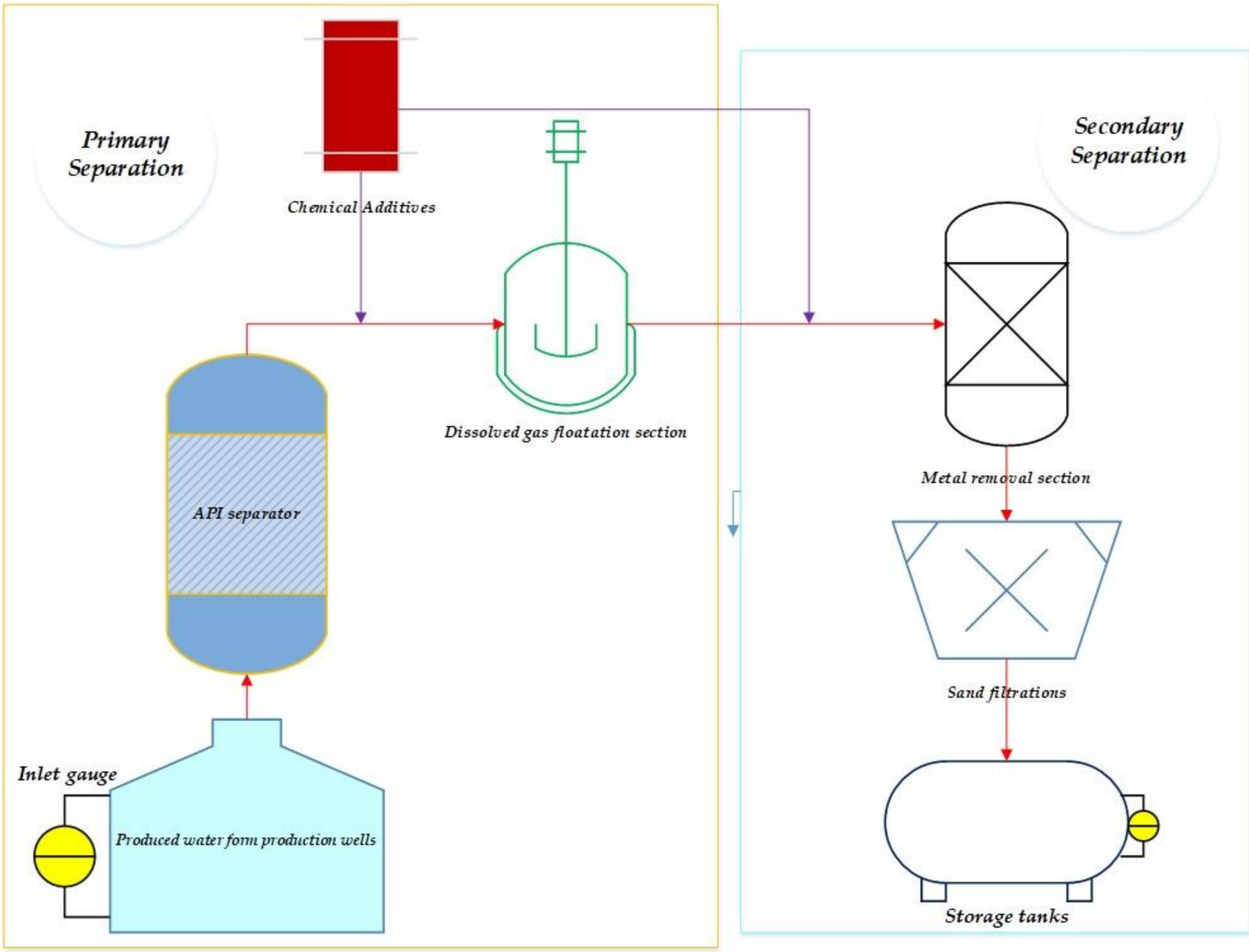

Figure 1. PFF method to retreat produced water.

In the PFF method, we used gauges at the inlet and outlet of the system to measure produced water. We repeated the measurements several times to check the accuracy of the implemented system. Therefore, the total volume of treated water is calculated as the following equation. It should be noted that produced water after each process is calculated separately to distinguish the efficiency and adequacy of the PFF treatment method.

Total treated water (MM m^3) = (Produced water before entering the primary separation) − (Produced water after the secondary separation) (1)

Finally, the total treated water is the summation of the treated water in each method to overview the total produced water and how much of this water volume can be saved to remove the required freshwater.

3. Results and Discussion

3.1. Water Treatment from HF Method

Regarding the water supply requirement for the commencement of the HF procedure, it is vitally essential to estimate the required water not to postpone the operations. Therefore, production engineers should adequately define the required water, as water is the central part of fracturing fluid. In this part, we have focused on the water retreatment after the HF procedure to estimate how much water volume can be saved and how much freshwater volume is required in the system. First, we divided the wells into oil and gas wells to be more distinguishable for each well. Then, as the treatment process may take a long time, we recorded our measurement for five sequential days by entering the specific produced water volume in the PFF system to check the system's accuracy. This is shown in more detail in Table A1, in the Appendix A. Next, the average volume after these five sequential daily measurements is calculated and statistically depicted in Table 1.

Table 1. A summary of water treatment savings for HF procedure.

Well no.	Avg. Pro. Water in PFF System (MM m^3/Day)	The Total Volume of Required Water (MM m^3/Day)	Saving Water (MM m^3/Day)	Saving Water (MM m^3/Year)	Saving Water (%)	Required Freshwater (%)
W_Oil#A	3.25	4.5	1.25	456.25	72	28
W_ Oil#B	4	5.25	1.25	456.25	76	24
W_ Oil#C	4.75	6	1.25	456.25	79	21
W_ Oil#D	3	4	1	365	75	25
W_ Oil#E	3	3.5	0.5	182.5	86	14
W_Gas#F	3.5	3.75	0.25	91.25	93	7
W_ Gas#G	2	2.5	0.5	182.5	80	20
W_ Gas#H	2.25	2.75	0.5	182.5	82	18
Total volume	25.75	32.25	6.5	2372.5	-	-
Average Percent	-	-	-	-	80	20

As shown in Table 1, in this field, the total volume of 2372.5 MM m^3 of water can be saved during the PFF treatment procedure, and only 20% of this required fresh water should be provided from other resources. It is indicated that this method is efficient in onshore and offshore plants.

3.2. Water Treatment from CEOR Methods

CEOR (Chemical enhanced oil recovery) methods are considered methods to improve the oil production from underground formations. In this part, we calculate the treated water for each well (see Table 2). As shown in Table 2, in this field, the total volume of 7482.5 MM m^3 of water can be saved during the PFF treatment procedure, and only 38% of this required fresh water should be provided from another resource. It is indicated that this method is efficient in onshore and offshore plants.

The summary of results was shown schematically in Figure 2. As shown in Figure 2, due to the large volume of chemical agents in CEOR methods mixed with formation chemical components, the value of saving water is lower than in the HF processes.

Table 2. A summary of water treatment savings for the CEOR procedure.

Well no.	Avg. Pro. Water in PFF System (MM m^3/Day)	The Total Volume of Required Water (MM m^3/Day)	Saving Water (MM m^3/Day)	Saving Water (MM m^3/Year)	Saving Water (%)	Required Freshwater (%)
W_Oil#A	10	15.5	5.5	2007.5	65	35
W_ Oil#B	10	13.75	3.75	1368.75	73	27
W_ Oil#C	5.25	13.25	8	2920	40	60
W_ Oil#D	3.75	5	1.25	456.25	75	25
W_ Oil#E	4.75	6.75	2	730	70	30
Total volume	33.75	54.25	20.5	7482.5	-	-
Average Percent	-	-	-	-	62	38

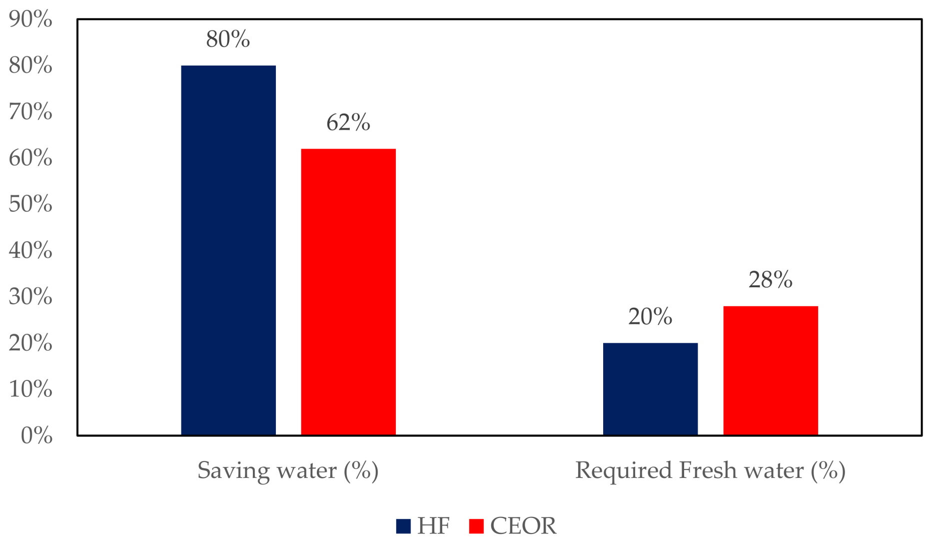

Figure 2. Summary of results.

4. Conclusions

The PFF (Photo Fenton Flotation) treatment method is considered efficient and applicable to improve water retreatment processes, as providing sustainable freshwater management is essential in onshore and offshore plants. To assure the efficiency of this method, we first recorded the measurements for five sequential days. As a result, the total volume of 2372.5 MM m^3 of water can be saved in the HF process during the PFF treatment procedure, and only 20% of this required fresh water should be provided from other resources. On the other hand, the total volume of 7482.5 MM m^3 of water can be saved in CEOR processes during the PFF treatment procedure, and only 38% of this required fresh water should be provided from other resources.

Author Contributions: Conceptualization, R.S. and D.R.; methodology, A.D.; software, H.R.; validation, A.H., A.A.S. and M.E.; formal analysis, A.A.S.; investigation, A.D.; resources, A.D.; data curation, H.R.; writing—original draft preparation, R.S.; writing—review and editing, A.D.; visualization, A.D.; supervision, A.D.; project administration, D.R.; funding acquisition, M.E. All authors have read and agreed to the published version of the manuscript."

Funding: There is no funding for this project.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: 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.

Appendix A

Table A1. Daily measurement of produced water in PFF system in HF process in MM m^3.

Well no.	Day #1	Day #2	Day #3	Day #4	Day #5
W_Oil#A	3.12	3.24	3.04	3.49	3.63
W_ Oil#B	3.89	4.17	4.11	3.94	4.35
W_ Oil#C	4.62	4.52	4.86	4.93	4.58
W_ Oil#D	2.78	3.16	2.89	3.06	3.3
W_ Oil#E	3.01	2.84	2.94	2.93	3.13
W_Gas#F	3.43	3.56	3.24	3.37	3.32
W_ Gas#G	1.86	1.75	1.89	1.94	1.97
W_ Gas#H	2.14	2.35	2.28	2.23	2.08

References

1. Al-Ghouti, M.A.; Al-Kaabi, M.A.; Ashfaq, M.Y.; Da'na, D.A. Produced water characteristics, treatment and reuse: A review. *J. Water Process. Eng.* **2019**. [CrossRef]
2. Corominas, L.; Foley, J.; Guest, J.S.; Hospido, A.; Larsen, H.F.; Morera, S.; Shaw, A. Life cycle assessment applied to wastewater treatment: State of the art. *Water Res.* **2013**. [CrossRef] [PubMed]
3. He, L.; Chen, Y.; Zhao, H.; Tian, P.; Xue, Y.; Chhen, L. Game-based analysis of energy-water nexus for identifying environmental impacts during Shale gas operations under stochastic input. *Sci. Total Environ.* **2018**. [CrossRef] [PubMed]
4. He, L.; Chen, Y.; Li, J. A three-level framework for balancing the tradeoffs among the energy, water, and air-emission implications within the life-cycle shale gas supply chains. *Resour. Conserv. Recycl.* **2018**. [CrossRef]
5. Cheng, X.; He, L.; Lu, H.; Chen, Y.; Ren, L. Optimal water resources management and system benefit for the Marcellus shale-gas reservoir in Pennsylvania and West Virginia. *J. Hydrol.* **2016**. [CrossRef]
6. Gitis, V.; Hankins, N. Water treatment chemicals: Trends and challenges. *J. Water Process Eng.* **2018**. [CrossRef]
7. Jiménez, S.; Micó, M.M.; Arnaldos, M.; Medina, F.; Contreras, S. State of the art of produced water treatment. *Chemosphere* **2018**. [CrossRef]
8. Chen, Y.; He, L.; Li, J.; Zhang, S. Multi-criteria design of shale-gas-water supply chains and production systems towards optimal life cycle economics and greenhouse gas emissions under uncertainty. *Comput. Chem. Eng.* **2018**. [CrossRef]
9. Chen, Y.; He, L.; Guan, Y.; Lu, H.; Li, J. Life cycle assessment of greenhouse gas emissions and water-energy optimization for shale gas supply chain planning based on multi-level approach: Case study in Barnett, Marcellus, Fayetteville, and Haynesville shales. *Energy Convers. Manag.* **2017**. [CrossRef]
10. Chen, Y.; Li, J.; Lu, H.; Yan, P. Coupling system dynamics analysis and risk aversion programming for optimizing the mixed noise-driven shale gas-water supply chains. *J. Clean. Prod.* **2021**. [CrossRef]
11. Sillanpää, M.; Shestakova, M. Electrochemical Water Treatment Methods. In *Fundamentals, Methods and Full Scale Applications*; Elsevier: Amsterdam, The Netherlands, 2017. [CrossRef]
12. Lu, H.; Tian, P.; He, L. Evaluating the global potential of aquifer thermal energy storage and determining the potential worldwide hotspots driven by socio-economic, geo-hydrologic and climatic conditions. *Renew. Sustain. Energy Rev.* **2019**. [CrossRef]
13. Zhang, K.; Wang, Q.; Chao, L.; Ye, J.; Li, Z.; Yu, Z.; Yang, T.; Ju, Q. Ground observation-based analysis of soil moisture spatiotemporal variability across a humid to semi-humid transitional zone in China. *J. Hydrol.* **2019**. [CrossRef]
14. El-Aziz, M.A.; Aly, A.M. MHD boundary layer flow of a power-law nanofluid containing gyrotactic microorganisms over an exponentially stretching surface. *Comput. Mater. Contin.* **2020**. [CrossRef]
15. Park, S.M.; Kim, Y.G. User profile system based on sentiment analysis for mobile edge computing. *Comput. Mater. Contin.* **2020**. [CrossRef]
16. Mualla, N.; Houssein, E.H.; Hassan, M.R. Dental age estimation based on X-ray images. *Comput. Mater. Contin.* **2020**. [CrossRef]
17. Elblr, A.; Llhan, H.O.; Aydin, N. The implementation of optimization methods for contrast enhancement. *Comput. Syst. Sci. Eng.* **2019**. [CrossRef]
18. Nejad, M.B.; Shiri, M.E. A new enhanced learning approach to automatic image classification based on salp swarm algorithm. *Comput. Syst. Sci. Eng.* **2019**, *34*, 91–100. [CrossRef]
19. Simos, T.E.; Tsitouras, C.; Kovalnogov, V.N.; Fedorov, R.V.; Generalov, D.A. Real-time estimation of R0 for COVID-19 spread. *Mathematics* **2021**, *9*, 664. [CrossRef]
20. Eyankware, M.O. Hydrogeochemical assessment of chemical composition of groundwater; A case study of the aptian-albian aquifer within sedimentary basin (Nigeria). *Water Conserv. Manag.* **2019**. [CrossRef]
21. Karami, B.; Janghorban, M.; Rabczuk, T. Forced vibration analysis of functionally graded anisotropic nanoplates resting on Winkler/Pasternak-foundation. *Comput. Mater. Contin.* **2020**. [CrossRef]

22. Wang, Y.; Subhan, F.; Shamshirband, S.; Asghar, M.Z.; Ullah, I.; Habib, A. Fuzzy-based sentiment analysis system for analyzing student feedback and satisfaction. *Comput. Mater. Contin.* **2020**. [CrossRef]
23. Oliva, A.F.; Perez, F.M.I.; Berna-Martinez, J.V.; Ortega, M.A. Non-deterministic outlier detection method based on the variable precision rough set model. *Comput. Syst. Sci. Eng.* **2019**. [CrossRef]
24. Kumar, C.R.; Jayanthi, V.E. A novel fuzzy rough sets theory based cf recommendation system. *Comput. Syst. Sci. Eng.* **2019**. [CrossRef]
25. Eyupoglu, C. A two-level morphological description of bashkir Turkish. *Comput. Syst. Sci Eng.* **2019**. [CrossRef]
26. Zhi, H.; Liu, S. A hybrid GABC-GA algorithm for mechanical design optimization problems. *Intell. Autom. Soft Comput.* **2019**. [CrossRef]
27. Hou, Y.; Zhu, W.; Wang, E. Hyperspectral mineral target detection based on density peak. *Intell. Autom. Soft Comput.* **2019**. [CrossRef]
28. Liu, H.; Liu, Q.; Sun, R. Deterministic vessel automatic collision avoidance strategy evaluation modeling. *Intell. Autom. Soft Comput.* **2019**. [CrossRef]
29. Gao, X.; Li, C.; Qiao, Y. Study on on-site monitoring of hydration heat of mass concrete for bridge slab based on measured data. *Intell. Autom. Soft Comput.* **2019**. [CrossRef]
30. Liu, Y.; Ding, J.; Cao, J.; Wang, Z.; Jiang, Z. Research on measuring method of crankshaft based on servo control mode. *Intell. Autom. Soft Comput.* **2019**. [CrossRef]
31. Davarpanah, A.; Mirshekari, B. Effect of formate fluids on the shale stabilization of shale layers. *Energy Rep.* **2019**. [CrossRef]
32. Davarpanah, A. The feasible visual laboratory investigation of formate fluids on the rheological properties of a shale formation. *Int. J. Environ. Sci. Technol.* **2019**. [CrossRef]
33. Davarpanah, A.; Razmjoo, A.; Mirshekari, B. An overview of management, recycling, and wasting disposal in the drilling operation of oil and gas wells in Iran. *Cogent Environ. Sci.* **2018**. [CrossRef]
34. Zarei, V.; Mirzaasadi, M.; Davarpanah, A.; Nasiri, A.; Valizadeh, M.; Hosseini, M.J.S. Environmental Method for Synthesizing Amorphous Silica Oxide Nanoparticles from a Natural Material. *Processes* **2021**, *9*, 334. [CrossRef]
35. Yang, H.; Wang, Z.; Song, K. A new hybrid grey wolf optimizer-feature weighted-multiple kernel-support vector regression technique to predict TBM performance. *Eng. Comput.* **2020**. [CrossRef]
36. Zhou, S.; Tan, B. Electrocardiogram soft computing using hybrid deep learning CNN-ELM. *Appl. Soft Comput.* **2020**, *86*, 105778. [CrossRef]
37. Long, M.; Chen, Y.; Peng, F. Simple and accurate analysis of BER performance for DCSK chaotic communication. *IEEE Commun. Lett.* **2011**, *15*, 1175–1177. [CrossRef]
38. Li, Z.; Cheng, R.; Chen, F.; Lin, X.; Yao, X.; Liang, B.; Hunag, C.; Sun, K.; Wang, A. Selective stress of antibiotics on microbial denitrification: Inhibitory effects, dynamics of microbial community structure and function. *J. Hazard. Mater.* **2021**, *405*, 124366. [CrossRef]
39. Quan, Q.; Gao, S.; Shang, Y.; Wang, B. Assessment of the sustainability of Gymnocypris eckloni habitat under river damming in the source region of the Yellow River. *Sci. Total Environ.* **2021**, *778*, 146312. [CrossRef]
40. Yang, Y.; Tao, L.; Yang, H.; Iglauer, S.; Wang, X.; Askari, R.; Yao, J.; Zhang, K.; Zhang, L.; Sun, H. Stress Sensitivity of Fractured and Vuggy Carbonate: An X-Ray Computed Tomography Analysis. *JGR Solid Earth* **2020**, *125*, e2019JB018759. [CrossRef]
41. Xu, J.; Li, Y.; Ren, C.; Wang, S.; Vanapalli, S.K.; Chen, G. Influence of freeze-thaw cycles on microstructure and hydraulic conductivity of saline intact loess. *Cold Reg. Sci. Technol.* **2021**, *181*, 103183. [CrossRef]
42. Liu, M.; Xue, Z.; Zhang, H.; Li, Y. Dual-channel membrane capacitive deionization based on asymmetric ion adsorption for continuous water desalination. *Electrochem. Commun.* **2021**, *125*, 106974. [CrossRef]
43. Sun, M.; Hou, B.; Wang, S.; Zhao, Q.; Zhang, L.; Song, L.; Zhang, H. Effects of NaClO shock on MBR performance under continuous operating conditions. *Environmental Sci. Water Res. Technol.* **2021**, *7*, 344–396. [CrossRef]
44. Zhang, K.; Chao, L.; Wang, Q.; Huang, Y.; Liu, R.; Hong, Y.; Tu, Y.; Qu, W.; Ye, J. Using multi-satellite microwave remote sensing observations for retrieval of daily surface soil moisture across China. *Water Sci. Eng.* **2019**, *12*, 85–97. [CrossRef]
45. Han, X.; Wei, Z.; Zhang, B.; Li, Y.; Du, T.; Chen, H. Crop evapotranspiration prediction by considering dynamic change of crop coefficient and the precipitation effect in back-propagation neural network model. *J. Hydrol.* **2021**, *596*, 126104. [CrossRef]
46. Nabavi, M.; Nazarpour, V.; Alibak, A.H.; Bagherzadeh, A.; Alizadeh, S.M. Smart tracking of the influence of alumina nanoparticles on the thermal coefficient of nanosuspensions: Application of LS-SVM methodology. *Appl. Nanosci.* **2021**, *11*, 2113–2138. [CrossRef]
47. Bahramian, F.; Akbari, A.; Nabavi, M.; Esfandi, S.; Naeiji, E.; Issakhov, A. Design and tri-objective optimization of an energy plant integrated with near-zero energy building including energy storage: An application of dynamic simulation. *Sustain. Energy Technol. Assess.* **2021**, *47*, 101419.
48. Cao, Y.; Doustgani, A.; Salehi, A.; Nemati, M.; Ghasemi, A.; Koohshekan, O. The economic evaluation of establishing a plant for producing biodiesel from edible oil wastes in oil-rich countries: Case study Iran. *Energy* **2020**, *213*, 118760. [CrossRef]
49. Karim, S.H.T.; Tofiq, T.A.; Shariati, M.; Rad, H.N.; Ghasemi, A. 4E analyses and multi-objective optimization of a solar-based combined cooling, heating, and power system for residential applications. *Energy Rep.* **2021**, *7*, 1780–1797. [CrossRef]
50. Ghasemi, A.; Moghaddam, M. Thermodynamic and Environmental Comparative Investigation and Optimization of Landfill vs. Incineration for Municipal Solid Waste: A Case Study in Varamin, Iran. *J. Therm. Eng.* **2020**, *6*, 226–246. [CrossRef]

51. Ghasemi, A.; Shayesteh, A.A.; Doustgani, A.; Pazoki, M. Thermodynamic assessment and optimization of a novel trigeneration energy system based on solar energy and MSW gasification using energy and exergy concept. *J. Therm. Eng.* **2021**, *7*, 349–366.
52. Davarpanah, A.; Mirshekari, B.; Jafari Behbahani, T.; Hemmati, M. Integrated production logging tools approach for convenient experimental individual layer permeability measurements in a multi-layered fractured reservoir. *J. Pet. Explor. Prod. Technol.* **2018**. [CrossRef]
53. Davarpanah, A. Feasible analysis of reusing flowback produced water in the operational performances of oil reservoirs. *Environ. Sci. Pollut. Res.* **2018**. [CrossRef]
54. Yang, Y.; Yao, J.; Wang, C.; Gao, Y.; Zhang, Q.; An, S.; Song, W. New pore space characterization method of shale matrix formation by considering organic and inorganic pores. *J. Nat. Gas. Sci. Eng.* **2015**. [CrossRef]
55. Liu, B.; Yang, H.; Karekal, S. Effect of Water Content on Argillization of Mudstone During the Tunnelling process. *Rock Mech. Rock Eng.* **2020**. [CrossRef]
56. Davarpanah, A.; Mirshekari, B. Experimental Investigation and Mathematical Modeling of Gas Diffusivity by Carbon Dioxide and Methane Kinetic Adsorption. *Ind. Eng. Chem. Res.* **2019**. [CrossRef]
57. Hu, X.; Xie, J.; Cai, W.; Wang, R.; Davarpanah, A. Thermodynamic effects of cycling carbon dioxide injectivity in shale reservoirs. *J. Pet. Sci. Eng.* **2020**. [CrossRef]
58. Lei, Z.; Hao, S.; Yang, J.; Dan, X. Study on solid waste pyrolysis coke catalyst for catalytic cracking of coal tar. *Int. J. Hydrogen Energy* **2020**. [CrossRef]
59. Davarpanah, A.; Shirmohammadi, R.; Mirshekari, B.; Aslani, A. Analysis of hydraulic fracturing techniques: Hybrid fuzzy approaches. *Arab. J. Geosci.* **2019**. [CrossRef]
60. Davarpanah, A.; Mirshekari, B. Mathematical modeling of injectivity damage with oil droplets in the waste produced water re-injection of the linear flow. *Eur. Phys. J. Plus* **2019**. [CrossRef]
61. Sun, S.; Zhou, M.; Lu, W.; Davarpanah, A. Application of symmetry law in numerical modeling of hydraulic fracturing by finite element method. *Symmetry* **2020**, *12*, 1122. [CrossRef]
62. Yang, H.Q.; Xing, S.G.; Wang, Q.; Li, Z. Model test on the entrainment phenomenon and energy conversion mechanism of flow-like landslides. *Eng. Geol.* **2018**. [CrossRef]
63. Zhu, M.; Yu, L.; Zhang, X.; Davarpanah, A. Application of Implicit Pressure-Explicit Saturation Method to Predict Filtrated Mud Saturation Impact on the Hydrocarbon Reservoirs Formation Damage. *Mathematics* **2020**, *8*, 1057. [CrossRef]
64. Zhang, K.; Zhang, J.; Ma, X.; Yao, C.; Zhang, L.; Yang, Y.; Wang, J.; Yao, J.; Zhao, H. History Matching of Naturally Fractured Reservoirs Using a Deep Sparse Autoencoder. *SPE J.* **2021**. [CrossRef]
65. Yang, Y.; Li, Y.; Yao, J.; Iglauer, S.; Luquot, L.; Zhang, K.; Sun, H.; Zhang, L.; Song, W.; Wang, Z. Dynamic Pore-Scale Dissolution by CO_2-Saturated Brine in Carbonates: Impact of Homogeneous Versus Fractured Versus Vuggy Pore Structure. *Water Resour. Res.* **2020**. [CrossRef]
66. Yang, H.Q.; Zeng, Y.Y.; Lan, Y.F.; Zhou, X.P. Analysis of the excavation damaged zone around a tunnel accounting for geostress and unloading. *Int. J. Rock Mech. Min. Sci.* **2014**. [CrossRef]
67. Zhang, K.; Jia, C.; Song, Y.; Jiang, S.; Jiang, Z.; Wen, M.; Huang, Y.; Liu, X.; Jiang, T.; Peng, J.; et al. Analysis of Lower Cambrian shale gas composition, source and accumulation pattern in different tectonic backgrounds: A case study of Weiyuan Block in the Upper Yangtze region and Xiuwu Basin in the Lower Yangtze region. *Fuel* **2020**. [CrossRef]
68. Li, Y.; Jia, D.; Rui, Z.; Peng, J.; Fu, C.; Zhang, J. Evaluation method of rock brittleness based on statistical constitutive relations for rock damage. *J. Pet. Sci Eng.* **2017**. [CrossRef]
69. Yang, H.Q.; Li, Z.; Jie, T.Q.; Zhang, Z.Q. Effects of joints on the cutting behavior of disc cutter running on the jointed rock mass. *Tunn. Undergr. Sp. Technol.* **2018**. [CrossRef]
70. Davarpanah, A. A feasible visual investigation for associative foam >\ polymer injectivity performances in the oil recovery enhancement. *Eur. Polym. J.* **2018**. [CrossRef]
71. Davarpanah, A. Parametric study of polymer-nanoparticles-assisted injectivity performance for axisymmetric two-phase flow in EOR processes. *Nanomaterials* **2020**, *10*, 1818. [CrossRef] [PubMed]
72. Hu, Y.; Zhao, Z.; Dong, H.; Mikhailova, M.V.; Davarpanah, A. Hybrid application of nanoparticles and polymer in enhanced oil recovery processes. *Polymers* **2021**, *13*, 1414. [CrossRef] [PubMed]
73. Davarpanah, A.; Mirshekari, B. Numerical simulation and laboratory evaluation of alkali–surfactant–polymer and foam flooding. *Int. J. Environ. Sci. Technol.* **2019**. [CrossRef]
74. Pan, F.; Zhang, Z.; Zhang, X.; Davarpanah, A. Impact of anionic and cationic surfactants interfacial tension on the oil recovery enhancement. *Powder Technol.* **2020**, *373*, 93–98. [CrossRef]
75. Simos, T.E.; Tsitouras, C. 6th Order Runge-Kutta Pairs for Scalar Autonomous IVP. *Appl. Comput. Math.* **2020**, *19*, 412–421.
76. Nejad, R.M.; Berto, F.; Wheatley, G.; Tohidi, M.; Ma, W. On fatigue life prediction of Al-alloy 2024 plates in riveted joints. In *Structures*; Elsevier: Amsterdam, The Netherlands, 2021; Volume 33, pp. 1715–1720. [CrossRef]
77. Davarpanah, A.; Shirmohammadi, R.; Mirshekari, B. Experimental evaluation of polymer-enhanced foam transportation on the foam stabilization in the porous media. *Int. J. Environ. Sci. Technol.* **2019**. [CrossRef]
78. Davarpanah, A.; Mirshekari, B. A mathematical model to evaluate the polymer flooding performances. *Energy Rep.* **2019**. [CrossRef]

79. Ahmad, N.A.; Goh, P.S.; Yogarathinam, L.T.; Zulhairun, A.K.; Ismail, A.F. Current advances in membrane technologies for produced water desalination. *Desalination* **2020**. [CrossRef]
80. Al-Maamari, R.S.; Sueyoshi, M.; Tasaki, M.; Okamura, K.; Al-Lawati, Y.; Nabulsi, R.; Al-Battashi, M. Flotation, filtration, and adsorption pilot trials for oilfield produced water treatment. In Proceedings of the Abu Dhabi International Petroleum Conference and Exhibition Conference 2012, Abu Dhabi, United Arab Emirates, 11–14 November 2012. [CrossRef]
81. Bhojwani, S.; Topolski, K.; Mukherjee, R.; Sengupta, D.; El-Halwagi, M.M. Technology review and data analysis for cost assessment of water treatment systems. *Sci. Total Environ.* **2019**. [CrossRef]
82. Cai, H.; Shen, C.; Ren, M.; Cao, F. Loop flotation for oil-containing water treatment. *Huagong Xuebao/CIESC J.* **2015**. [CrossRef]
83. Chang, H.; Liu, B.; Wang, H.; Zhang, S.Y.; Chen, S.; Tiraferri, A.; Tang, Y.Q. Evaluating the performance of gravity-driven membrane filtration as desalination pretreatment of shale gas flowback and produced water. *J. Memb. Sci.* **2019**. [CrossRef]
84. da Silva, S.S.; Chiavone-Filho, O.; de Barros Neto, E.L.; Foletto, E.L. Oil removal from produced water by conjugation of flotation and photo-Fenton processes. *J. Environ. Manag.* **2015**. [CrossRef] [PubMed]
85. Coonrod, C.L.; Ben Yin, Y.; Hanna, T.; Atkinson, A.J.; Alvarez, P.J.J.; Tekavec, T.N.; Reynolds, M.A.; Wong, M.S. Fit-for-purpose treatment goals for produced waters in shale oil and gas fields. *Water Res.* **2020**. [CrossRef]