Journal of Applied Research in Water and Wastewater

E-ISSN: 2476-6283

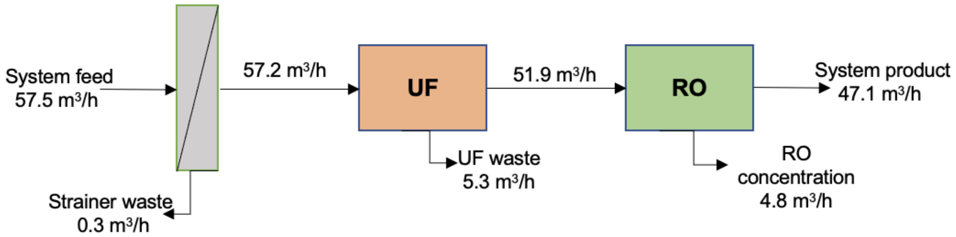
Journal homepage: https://arww.razi.ac.ir

Kermanshah's oil refinery water and wastewater management: providing a sustainably potential platform for water consumption minimization through wastewater reclamation

Safoora Nazari[1], Ali Akbar Zinatizadeh[1, 2,*], Parviz Mohammadi[3], Sirus Zinadini[1]

[1]Environment Research Center (ERC), Department of Applied Chemistry, Faculty of Chemistry, Razi University, Kermanshah, Iran.
[2]Department of Environmental Sciences, University of South Africa, Pretoria, South Africa.
[3]Department of Environmental Health Engineering, School of Public Health, Kermanshah University of Medical Sciences, Kermanshah, Iran.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 12 January 2021
Reviewed 25 March 2021
Received in revised form 14 May 2021
Accepted 16 May 2021
Available online 18 May 2021

Keywords:
Kermanshah's oil refinery
Wastewater reclamation
Sustainability
Minimization
Water management

Article type: Research Article

ABSTRACT

In recent years, water scarcity has posed significant challenges to oil refineries. The escalating water demands of developing oil refineries in pace with the progressively stringent environmental, economic, and technical regulatory and suitability constraints necessitate seeking sustainable water and wastewater management strategies that encourage minimizing fresh water consumption through treated wastewater reuse. Thus, the main scope of the present study is to investigate a general procedure using innovative post treatment technologies in order to attain an almost zero discharge water management in real life - Kermanshah's oil refinery case study. The results obtained are proofs enough that the selected post treatment scenario can effectively minimize the overall fresh water demand.

1. Introduction

Given its utmost global importance in our daily lives, recreation and industrial activities, water has become scarce in many parts of the world. In most process industries, water plays a major role in operations with various purposes (e.g. product formulation, high-purity water makeup systems, cooling, waste conveyance, general plant service water, sanitary service, and fire protection) (Rosain. 1993; Northey et al. 2019). However, due to being subjected to the economic and increasingly stringent environmental restrictions of handling the wastewater and the growing demand for fresh water, these processes and systems using water are now facing a powerful driving force to seek sustainable solutions in rationalizing the water use and improving its management (Diepolder. 1992; Goldblatt et al. 1993; Alves et al. 2006). The basic concept of the main strategies leading to the sustainable water and wastewater management revolves around water consumption minimization through maximizing water reuse and identifying wastewater reclamation opportunities for recycling and reusing purposes (Wang and Smith. 1994; Bagajewicz. 2000; Mohsen and Jaber. 2003). Therefore, recycle and reuse of treated wastewater has become a sustainably international practice containing a large variety of applications such as industrial (Nair. 1990; Ciardelli et al. 2001; Baskaran et al. 2003; Mohsen and Jaber. 2003; Feng and Chu. 2004; Rajkumar et al. 2010; Karimi Pashaki et al. 2017), irrigation (Vazquez-Montiel et al. 1996; Lazarova and Bahri. 2004), aquaculture (Alderson et al., 2015; Chatla et al., 2020), urban/recreational uses (Meneses et al. 2010; Owusu-Boateng and Adjei. 2014), and groundwater recharge (Kanarek and Michail.1996; Asano and Cotruvo. 2004). However, in order to comply with the sustainable development indicators mainly involving social, environmental, economic, and technological criteria, prioritizing the most promising post treatment technologies as well as the treated wastewater reuse application

*Corresponding author Email: zinatizadeh@gmail.com

How to cite: S. Nazari, A.A. Zinatizadeh, P. Mohammadi, S. Zinadini, Kermanshah's oil refinery water and wastewater management: providing a sustainably potential platform for water consumption minimization through wastewater reclamation, *Journal of Applied Research in Water and Wastewater*, 8 (1), 2021, 28-35.

alternatives, is a must-make multi-criteria decision (Mujeriego and Asano. 1999; Metcalf et al. 2007; Jimenez and Asano. 2008; Akhoundi and Nazif. 2018).

As one of those complex process industries consuming significantly large quantities of water based on their size and process configuration for multiple operations (65-90 gallons of water per each barrel of crude oil) (Alva-Argáez et al. 2007), oil refineries consequently produce large volumes of wastewater of diverse nature (0.4-1.6 times the amount of the processed crude oil) (Speight, 2014). As aforementioned, recycling and reusing this significant amount of wastewater for various purposes such as meeting the water requirements of cooling systems, process units, irrigation, and fire protection succeeding the post treatment implementation (based on quality standards) in oil refineries, is a remarkably sustainable option that so far has drawn researchers' attention to itself. Numerous post treatment approaches depending upon the nature, type and size of process units in oil refineries have evolved throughout the recent decades ultimately aiming at improving the water and wastewater management (Pombo et al. 2011). These approaches include investigation and implementation of traditional techniques such as distillation, evaporation, activated carbon filtration, sand filtration, chemical oxidation (Bush. 1976; Meidl. 1997; Goldblatt et al. 2006; IPIECA. 2010; Jafarinejad and Jiang. 2019) and advanced ones such as pressure driven membrane separations, electrodialysis, ion exchange, and advanced oxidation processes (Bonnelye et al. 2004; Into et al. 2004; Nikazar and Jamshidi. 2008; Yan et al. 2010; Salahi et al. 2011; Barthe et al.2015; Jafarinejad. 2016; Aghababaei. 2017) Amongst these diverse technologies, membrane separation is a strong candidate providing a potential platform to reuse wastewater.

While being the fourth largest oil producer in the world, Iran has nine active oil refineries, Kermanshah's being one of them, with an annual water consumption rate of approximately 205 million m^3 resulting in a total production rate of nearly 14 million m^3 of wastewater per year (Marcel. 2006; Mohammadnejad et al. 2011) proving the necessity for wastewater reclamation. Being a tailor-made problem in many cases, here, wastewater reuse management focuses on Kermanshah's oil refinery. This case study demonstrates that the integration of innovative post treatment technologies such as hybrid ultrafiltration (UF) and reverse osmosis (RO) can lead to overall water savings and is possibly able to attain the "almost zero discharge" concept under technical and economic viewpoints.

2. Materials and methods

2.1. Water allocation network of Kermanshah's oil refinery

As aforementioned, due to the variety of the size, crude oil products, and complexity of operations, no two oil refineries are alike and each oil refinery can be a large consumer of water, relative to the other water consumers in a given region. As a matter of fact, the water network within an oil refinery is as distinctive to the oil refinery as its processes. The present case study zeroes in on optimizing the water network of Kermanshah's oil refinery. Therefore, this section starts by describing the typical sources of water supplied to Kermanshah's oil refinery, their subsequent uses, and the typical discharges of water. It also provides an overview of the quantitative and qualitative characteristics of all types of water and wastewater within the refinery.

2.1.1. Sources of water

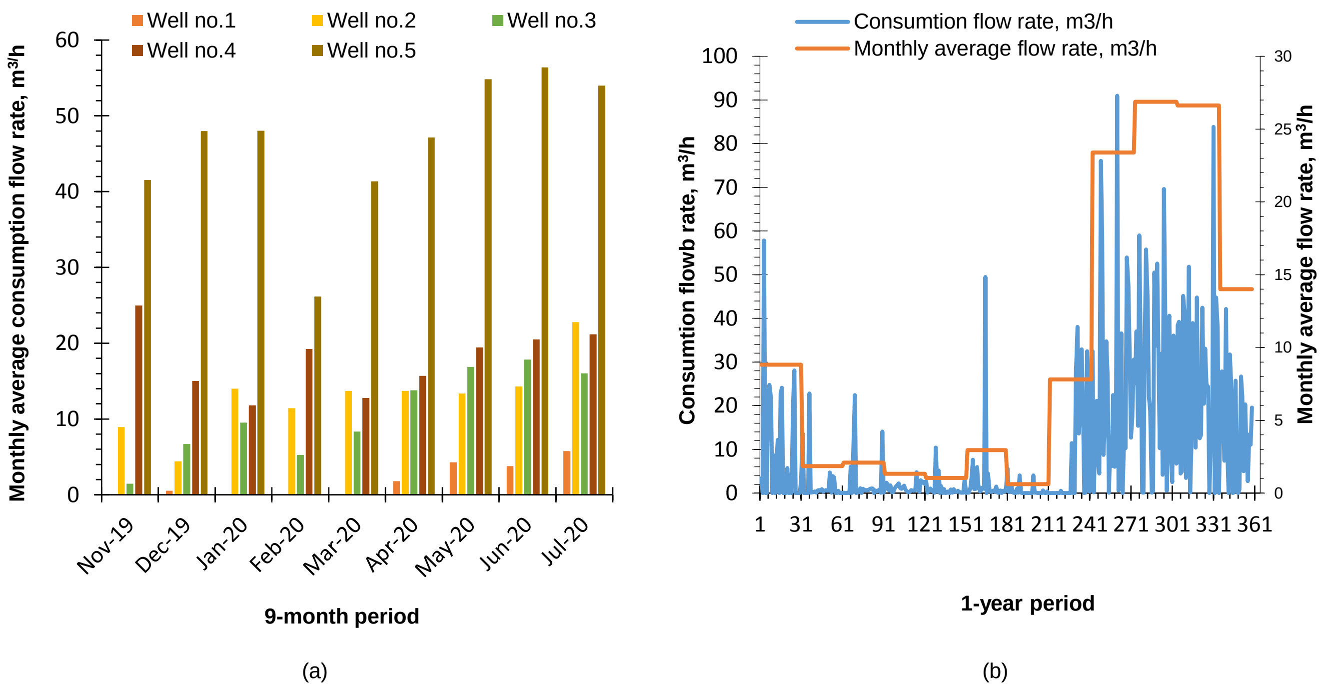
Typically, the water sources in Kermanshah's refinery can be classified in four types: ground water (wells) located in aquifers, surface water from Qarahsu River, municipal water, and the mixture of cooling tower blowdown and biologically treated wastewater coming from wastewater treatment plant (WWTP). Fig. 1 provides the detailed data profiles for water consumption flow rates supplied by these water sources.

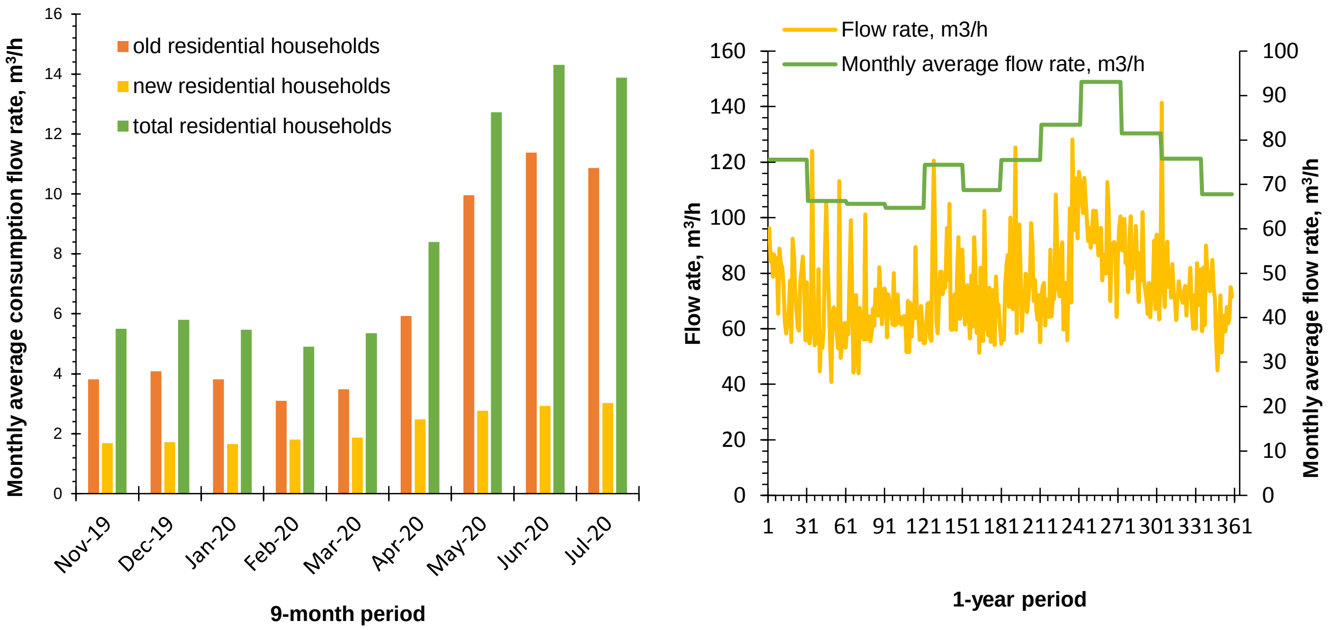
- Groundwater (wells)

Due to the existence of five accessible wells, the water supplies for cooling tower (CT), demineralization (DM) unit, and sanitary units including employee locker rooms, kitchens, and washrooms within the refinery's site are provided. Table 1 contains the typically similar characteristics of the raw water coming from these wells.

Table 1. Characteristics of wells water.

Types of wells	pH	Electric Conductivity (EC), μs/cm	TDS, mg/L	Total Hardness (TH), mg $CaCO_3$/L	M. Alkalinity, mg$CaCO_3$/L
No. 1	6.9	1042	704	530	45
No. 2	6.6	1030	701	550	45
No. 3	6.5	985	670	530	40
No. 4	6.6	995	677	545	40
No. 5	6.6	1030	701	550	45





(c) (d)

Fig. 1. (a) 9-month period data profile of wells water consumption, (b) 1-year period data profile of Qarahsu river water consumption,(c) 9-month period data profile of municipal water consumption, (d) 1-year period data profile of treated wastewater consumption.

In order to meet the water requirements of CT and DM units, wells no. 2 and 5 are switchably applied, while, wells no. 3 and 4 supply the water for sanitary uses within the refinery's site. As illustrated in Fig. 1a, during the 9-month period from November 2019 to July 2020, while well no.1 was barely used, well no.5 contained the highest average of water consumption, resulting in the highest amount of 56.38 m^3/h in July 2020. According to the fact that during this period, well no.5 has been used to meet the CT requirement, it is safe to claim that CT is the most water-consuming unit in the refinery.

- Surface water (Qarahsu river)

In some emergency conditions, specifically in summer time of the year, the water from Qarahsu River has a share in meeting the water requirements of irrigation, fire protection and desalting in the refinery. Table 2 contains the characteristics of the Qarahsu River obtained from three different sampling stations. The high mean value of COD in this specific sampling date, relative to the effluent of the refinery WWTP, indicates that Qarahsu River contains considerable contamination load. Based on further investigations, the relatively high value of ammonia also proves the sanitary wastewater leakage in to the river. Furthermore, the high values of DO, Coliform, and turbidity are enough proofs indicating algae growth. Consequently, any further utilization of this river, specifically in dry seasons, needs significantly cautious proceedings. The maximum water consumption flow rate of 91 m^3/h and the maximum average of 26.87 m^3/h were derived from the 1-year period data profile of the river presented in Fig. 1b.

- Municipal water

In order to meet the potable water (drinking and sanitary water) demands of all residential households within the refinery, Kermanshah's oil refinery is frequently purchasing potable water from Kermanshah's municipality. The maximum average consumption flow rate of 14.3 m^3/h in May 2020 is obtained from Fig. 1c.

- Biologically treated wastewater

As shown in Fig. 1d, the biologically treated wastewater with the one-year period average flow rate of 74.6 m^3/h is ultimately combined with CT blowdown in order to meet the water requirements of irrigation, desalting and fire protection.

2.1.2. Uses of water leading to wastewater generation

In fact, required level of water purity depends on its particular use. Kermanshah's oil refinery water supply is distributed into cooling, demineralization, desalting, potable, utility, irrigation, and fire water. Brief descriptions of the refinery's water usages resulting in ultimate wastewater generation are given as follows.

- Cooling

As aforementioned, a significantly high portion of fresh water provided by wells is used for cooling in the refinery. Therefore, it also accounts for a considerable portion of the refinery's total wastewater. Kermanshah's oil refinery uses an evaporative recirculating cooling tower that rejects the picked-up heat through evaporation. Fig. 2a represents the data profile for CT makeup water throughout the one-year period, resulting in an average makeup flow rate of 47.2 m^3/h. In order to avoid the build-up of dissolved solids, some part of the circulating water in the CT is removed as blowdown. The average quantity of blowdown is 27.2 m^3/h according to the CT mass balance, depending on the quality of the makeup water, the roughly constant evaporation value of 20 m^3/h, and the cycles of concentration (COC) that the CT is currently operated at (1.68).

- Demineralization

Demineralization (DM) unit aims at providing the purified boiler feedwater required for the generation of steam in the refinery by implementing ion exchange resins. Based on Fig. 2b, during the 9-month period, an average water consumption flow rate of 13.4 m^3/h (nearly 14 m^3/h) is obtained for DM unit leading to the generation of approximately 4 m^3/h wastewater.

- Desalting crude oil

Being used to wash out the salts present in the crude oil in order to prevent or lessen the further plugging, fouling, and corrosion of the process equipment, desalting is the first operation in the refinery's crude oil unit (IPIECA. 2010). An average flowrate of 7 m^3/h of the previously mentioned combination of industrial wastewaters, sometimes joining in by the river water meets the requirements of this unit, also resulting in the same average flow rate of wastewater effluent.

- Potable

Portable water (sanitary and drinking water) consumption in the refinery is related to both its site and residential households. It contains the water required for bathrooms, kitchens, wash areas, and safety showers stations (IPIECA. 2010). The generated potable wastewaters contain average flow rates of 5 and 7.2 m^3/h, respectively, originating from the site and residential households and ultimately routing to the municipal wastewater network.

- Utility

Utility water accounts for miscellaneous washing operations such as cleaning and cooling the operating area (IPIECA. 2010). With an estimated average of 36.4 m^3/h (according to the water mass balance in the refinery), the utility uses result in a similar quantity of wastewater finding its way to the WWTP.

- Irrigation

Given an estimated average water consumption rate of 5 L/m^2 per day for the green space area of 45000 m^2 (4.5 hectares), approximately 225 m^3/day (9 m^3/h) water is required for irrigation. Currently, this requirement is met with the combination of biologically treated wastewater and CT blowdown, joining in by the Qarahsu River water in dry seasons.

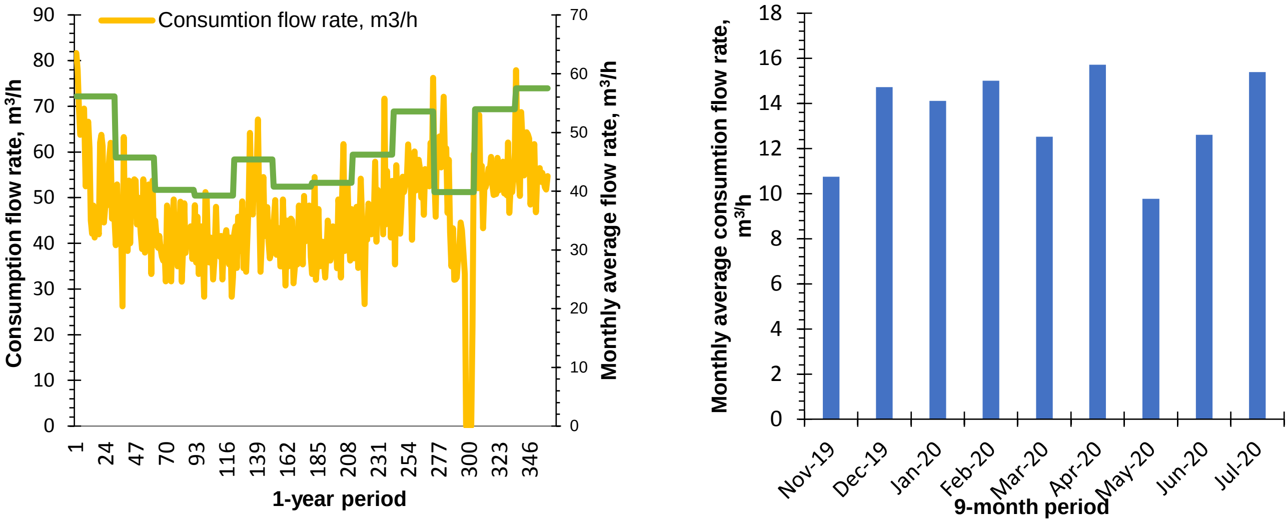


Fig. 2. (a) 1-year period data profile of CT makeup water consumption, (b) 9-month period data profile of DM water consumption.

Table 2. Qarahsu river characteristics based on the results from three sampling stations (Date: 2019/12/14).

Sampling location	COD, mg/L	NO_3, mg NO_3/L	NO_3, mg N-NO_3/L	DO, mgO_2/L	Turbidity, NTU	Ca, mgCa-$CaCO_3$/L	Mg, mgMg-$CaCO_3$/L	NH_4, mg /L	Coliform, CFU/100cc	BOD_5, mg/L	PO_4, mg/L	K, mg/L	Na, mg/L
Under Lab-e-Ab Bridge	54	6.19	1.39	6.2	180	194	32	15.7	10000	14	0.98	8.30 ± 0.1	41.00 ± 0.2
Under Belt Bridge	70	27.97	6.31	5.3	126	166	134	23.5	100000	70	1.4	8.16 ± 0.2	31.23 ± 0.2
Under Kohneh Bridge	44	7.69	1.73	6.8	13	186	142	19	100000	8	0.79	5.14 ± 0.2	23.11 ± 0.3

Table 3. Quantitative and qualitative characteristics of consuming waters.

Types of water usage		Cooling	DM	Site sanitary	Households sanitary		Irrigation	Fire fighting	Desalting	Raw water
Sources		Wells no. 2 and 5	Wells no. 2 and 5	Well no.3	Well no.4	Municipal	Biologically treated wastewater +blowdown + river water effluent			-
Consumption flowrate, m^3/h		47.2	13.4	28.5-34		8.48	-	-	-	-
Quality	pH	7.261	6.6	6.5	6.6	-		7.7		7.2
	T.Hardness, mg$CaCO_3$/L	614.332	550	530	545	-		1610		610
	EC, µs/cm	894.553	1030	985	995	-		1546		1111
	Ca.Hardness, mg$CaCO_3$/L	355.437	370	330	360	-		920		320
	TDS, mg/L	-	701	670	677	-		584		758
	M. Alkalinity, mg$CaCO_3$/L	-	45	40	40	-		48		300
	P. Alkalinity, mg $CaCO_3$/l	-	-	-	-	-	-	-	-	Nil
	TSS, mg/L	-	-	-	-	-	-	-	-	T
	Turbidity, NTU	-	-	-	-	-	-	-	-	0.43
	Cl_2, mg/L	-	-	-	-	-	-	-	-	Nil
	CO_2, mg/L	-	-	-	-	-				65
	SiO_2, mg/L	-	-	-	-	-	-	-	-	20
	S^{2-}, mg/L	-	-	-	-	-	-	-	-	Nil
	Ca^{2+}, mg/L	-	-	-	-	-	-	-	-	320
	Mg^{2+}, mg/L	-	-	-	-	-	-	-	-	280
	Fe^{2+}, mg/L	-	-	-	-	-	-	-	-	0.033
	Mn^{2+}, mg/L	-	0.48	-	-	-	-	-	-	-
	Zn^{2+}, mg/L	-	2.2	-	-	-	-	-	-	-
	NH_4^+, mg/L	-	-	-	-	-	-	-	-	T
	Na^+, mg/L	-	-	-	-	-	-	-	-	13
	K^+, mg/L	-	-	-	-	-	-	-	-	T
	SO_4^{2-}, mg/L	-	62.15	-	-	-	-	-	-	117
	NO_3^-, mg/L	-	-	-	-	-	-	-	-	5
	PO_4^{3-}, mg/L	-	-	-	-	-	-	-	-	0.13
	F^-, mg/L	-	-	-	-	-	-	-	-	-
	Cl^-, mg/L	-	-	-	-	-	-	-	-	110
	TOC, mg/L	-	-	-	-	-	-	-	-	2

Fire protection

The requirements for fire water in the refinery are intermittent; therefore, provisions need to be made in case of the emergency situations. Currently, the mixture of biologically treated wastewater and blowdown and in some cases river waters are applied to meet the fire water demands. As indicated in Tables 3 and 4, the qualities and quantities of the consumed waters and generated wastewaters from different units vary widely, depending on the feed source and process requirements. The perspective offered by these tables further lights the way to set the main goals and manage the possible post treatment scenarios in this case study.

2.1.3. The adaptability of current biological WWTP

Similar to a typical refinery WWTP, Kermanshah's oil refinery WWTP consists of primary and secondary separation of oil and water, followed by biological treatment. As can be seen in the water flow diagram of the refinery WWTP illustrated in Fig. 3, the oil removal is attained by implementing an API separator followed by the equalization tank tending to dampen out the variations in wastewater flow and concentration routing to the dissolved air floatation (DAF) unit. The wastewater is then directed to the biological system including aeration tank/clarifier. Ultimately, it finds its way to the chlorination unit followed by the collection basin. Some important qualitative characteristics of the wastewater flow is also shown in Fig. 3.

As aforementioned, currently, no segment of the sanitary wastewater originating from refinery site and residential households is routed to the refinery WWTP. Nevertheless, as shown in Table 4, according to the qualitative analysis of the wastewater flowing to the aeration tank, the current WWTP has the potential and capacity to adapt to the changes followed by the addition of sanitary wastewaters coming from the refinery site and residential households. Consequently, this approach results in increasing the amount of accessible wastewater seeking to be recycled/reused after the post treatment.

2.2. Water Application Value Engine (WAVE) software

In the present case study, the Water Application Value Engine (WAVE) software program version of 1.72.724 (calculation engine version: 01.11.05.00, database version: 14.5) was applied to design and simulate the operation of wastewater post treatment scenarios using the ultrafiltration (UF), ion exchange (IX, with or without degasification (DG)), and reverse osmosis (RO) technologies by providing a comprehensive platform. As a fully integrated tool using a powerful hydraulic modeling calculation, WAVE enabled us to deliver accurate water quantity and quality predictions for wastewater post treatment designs. As shown in Fig. 3, considering the addition of sanitary wastewaters to the WWTP, the current combination of biologically treated wastewater and CT blowdown acts as the influent to the suggested post treatment scenarios. Therefore, all the initial quantitative and qualitative analysis done by WAVE is set upon this combined wastewater flow rate of 79.8 m^3/h and its related quality obtained from Table 4.

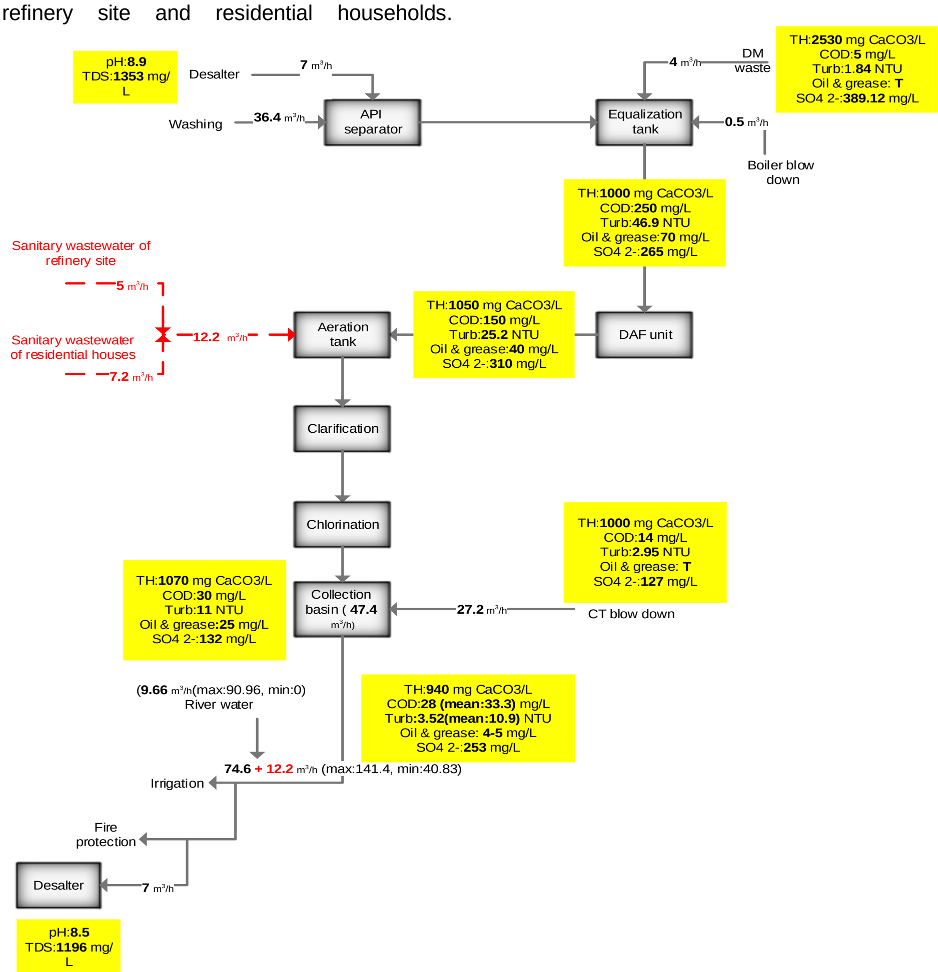


Fig. 3. Water flow diagram of Kermanshah's oil refinery WWTP.

3. Results and discussion

The thorough quantitative and qualitative investigation of the water allocation network in Kermanshah's oil refinery set the research path straight and led us to the potential options for wastewater reuse. As can be seen in the flowchart illustrated in Fig. 4, the hybrid post treatment scenarios are all established based on RO and IX techniques, while sharing the UF unit as pretreatment. Two main approaches are considered that result in attaining the same fresh water quality applied currently and the improved quality of softened water. As aforementioned, the WAVE software program played a major role in providing economic and technical analysis of the potential scenarios. According to the results obtained from the analysis, the integration of UF+RO (+bypass) system is the superior option among them. However, what led us to final selection between two available approaches is the main target the treated water will be used for. Given its high fresh water requirement, CT is considered as one of the main post treatment effluent water consumers. One of the main goals of water use management revolves around improving makeup water quality that consequently increases COC leading to lower blowdown flow rate and ultimately lower makeup water requirement. Therefore, the final selection of the main approach relies heavily on its impact on the cycles of concentration (COC) in CT. Table 5 describes the qualitative and quantitative characteristics of existing CT makeup water and blowdown. It also contains the values of Langelier Saturation Index (LSI) representing the water potential for corrosion/saturation. Crossing the borderline of LSI (-1.5<LSI<1.5) results in undesirable corrosive/saturated situations, thus decreasing the performance of CT. Table 6 provides an opportunity to compare the important qualitative parameters, corrosion/saturation indexes, and COCs related to all the investigated scenarios in details. As can be seen after one post treatment loop, UF+RO (+bypass) with the softened water as the effluent results in a significant increase in COC and ultimately not only minimizes its makeup water requirement by 47.24% but also decreases its chemical requirement by 16.67 %.

Table 4. Quantitative and qualitative characteristics of generated wastewaters.

Types of wastewaters		WWTP					CT blowdown					
		Influent	Before aeration tank	After equalization tank	Effluent	Biologically treated wastewater + blowdown	Utility unit	Pentane unit	DM	Desalter	Washing	Potable
Flow rate, m^3/h		47.4	-	-	47.4	74.6	27.2	4-5	4	7	36.4	7.225
	pH	8.304	8.2	8.4	8.2	7.9	8.2	-	7.1	8.9	7.9	7
	Oil and Grease, mg/L	47.89	40	70	25	4-5	T	-	T	-	-	100
	PO_4^{3-}, mg/L	1.881	0.71	0.78	0.68	0.71	2.41		0.15	-	-	2
	NH_3, mg/L	0.892	-	-	-	0.178	-	-	-	-	-	20
	S^{2-}, mg/L	0.115	7.8	15.8	1.5	2.1	1.8	-	0.8	-	-	-
	Cl_2, mg/L	Nil	Nil	Nil	Nil	Nil	0.2	-	Nil	-	-	-
	DO, mg/L	Nil	2.6	3.2	6	5.9	6.4	-	6.4	-	-	-
	COD, mg/L	176.4	150	250	30	28	14	-	5	-	-	500
	BOD_5, mg/L	110.4	77	45	5	8	10	-	-	-	-	300
	Turbidity, NTU	25.1	25.2	46.9	11	3.52	2.95	-	1.84	-	-	-
	TSS, mg/L	66.27	78	158	9	8	3	-	T	-	-	300
	MLSS, mg/L			2075.185			-	-	-	-	-	-
	MLVSS, mg/L			2075.185			-	-	-	-	-	-
	T. Hardness, mgCaCO_3/l	-	1050	1000	1070	940	960.601	-	2530	-	1260	-
	Ca. Hardness, mgCaCO_3/L	-	720	620	820	640	616.579	-	1730	-	740	-
	EC, µs/cm	-	2890	2750	2900	2890	2830		736	-	1668	-
Quality	M. Alkalinity, mgCaCO_3/L	-	190	180	100	190	160		100	-	54	-
	P. Alkalinity, mgCaCO_3/L	-	Nil	10	Nil	Nil	Nil		Nil	-	-	-
	Total Fe, mg/L	-				-	0.198	-		-	-	-
	SiO_2, mg/L	-	35	33	29	35	28	-	30	-	-	-
	Cl^-, mg/L	-	372	389	360	324	185	-	298	-	-	-
	Total Phosphonate, mg/L	-	-	-	-	-	9.388	-	-	-	-	-
	TDS, mg/L	-	1968	1867	1970	1227	1927	-	501	1353	1134	-
	TOC, mg/L	-	75	60	37	5	4	-	3		-	-
	SDI	-	-	-	-	-	-	-	-	-	-	-
	CO_2, mg/L	-	20	28	11	22	5	-	45	-	-	-
	Ca^{2+}, mg/L	-	720	620	820	640	740	-	1730	-	-	-
	Mg^{2+}, mg/L	-	330	380	250	300	260	-	800	-	-	-
	Fe^{2+}, mg/L	-	0.388	0.194	0.35	0.204	0.262	-	0.2	-	-	-
	Mn^{2+}, mg/L	-	-	-	-	-	-	-	2.3	-	-	-
	Zn^{2+}, mg/L	-	-	-	-	-	-	-	16.3	-	-	-
	NH_4^+, mg/L	-	0.2	0.3	0.2	0.1	0.1	-	0.3	-	-	-
	Na^+, mg/L	-	68	51	75	66	31	-	90	-	-	-
	K^+, mg/L	-	T	T	T	T	T	-	T	-	-	-
	SO_4^{2-}, mg/L	-	310	265	132	253	127	-	389.1	-	-	-
	NO_3^-, mg/L	-	4	10.8	3.8	3	9.7	-	32.7	-	-	-

Table 5. Characteristics of current CT makeup water and blowdown.

CT makeup water flow rate, m^3/h		47.2
Qualitative parameters of makeup water	TDS, mg/L	758
	Cl^-, mg/L	110
	pH	7.2
	Temperature, °C	40
	T. Alkalinity, mg$CaCO_3$/L	95.13
	Ca. Hardness, mg$CaCO_3$/L	320
	T. Hardness, mg$CaCO_3$/L	600
	LSI	-0.142 Non-corrosive
Current Ct blowdown flow rate, m^3/h		25-30
Qualitative parameters of CT blowdown	TDS, mg/L	1927
	Cl^-, mg/L	185
	pH	8.2
	Temperature, °C	40
	T. Alkalinity, mg$CaCO_3$/L	160
	Ca. Hardness, mg$CaCO_3$/L	740
	T. Hardness, mg$CaCO_3$/L	1000
	LSI	1.586 Slightly saturated, non-corrosive
Current COC=[Cl^-] in blowdown /[Cl^-] in makeup water		1.681

Moreover, it is estimated that feeding the softened water into DM unit results in minimizing both DM wastewater and chemical requirement by 70%. The specific energy requirement and operating cost for the selected scenario with a total recovery efficiency of 82.0% are estimated at 0.27 $ and of 0.71 per each m^3 of the treated effluent, respectively. The detailed information presented in Figs. 5a and b deal with the overall water balances obtained after two calculation loops. It also describes the predicted diverse operating conditions required based on the weather as well as the potential options to manage the wastewaters generated in the selected scenario and attain a zero liquid discharge system.

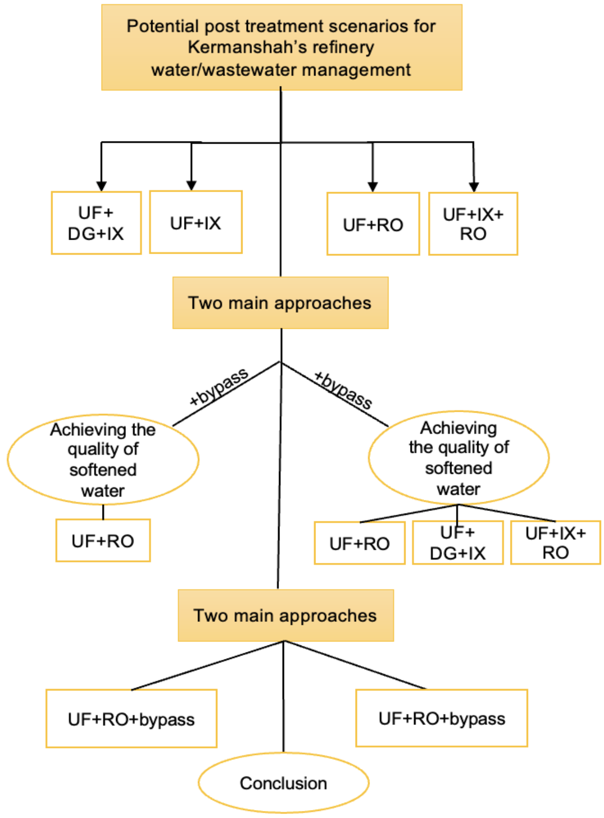
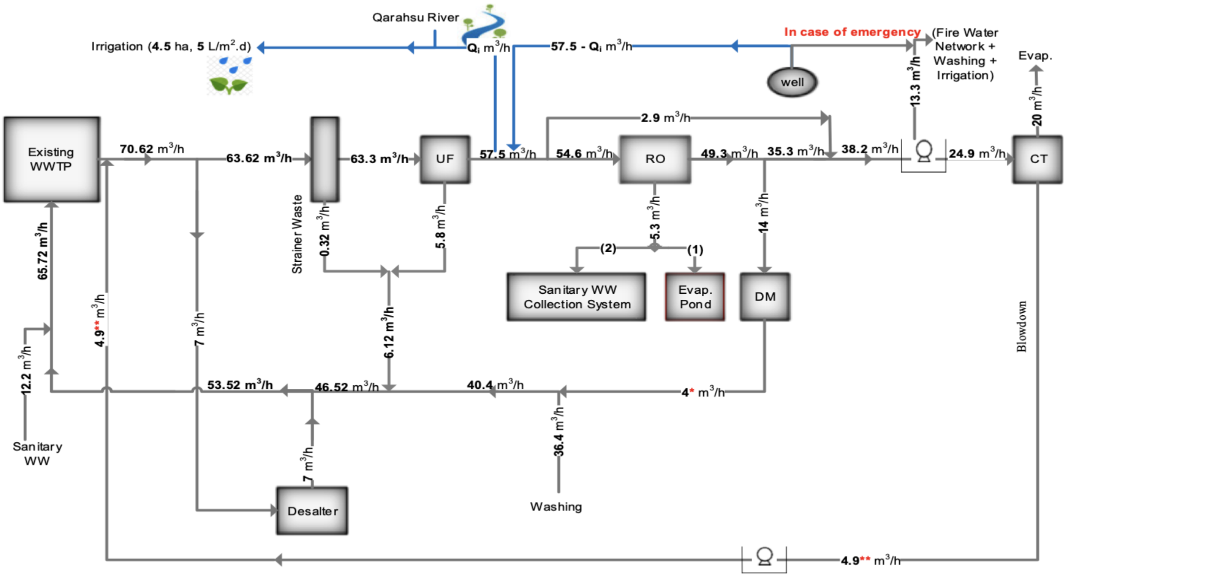


Fig. 4. Post treatment scenarios investigation procedure.

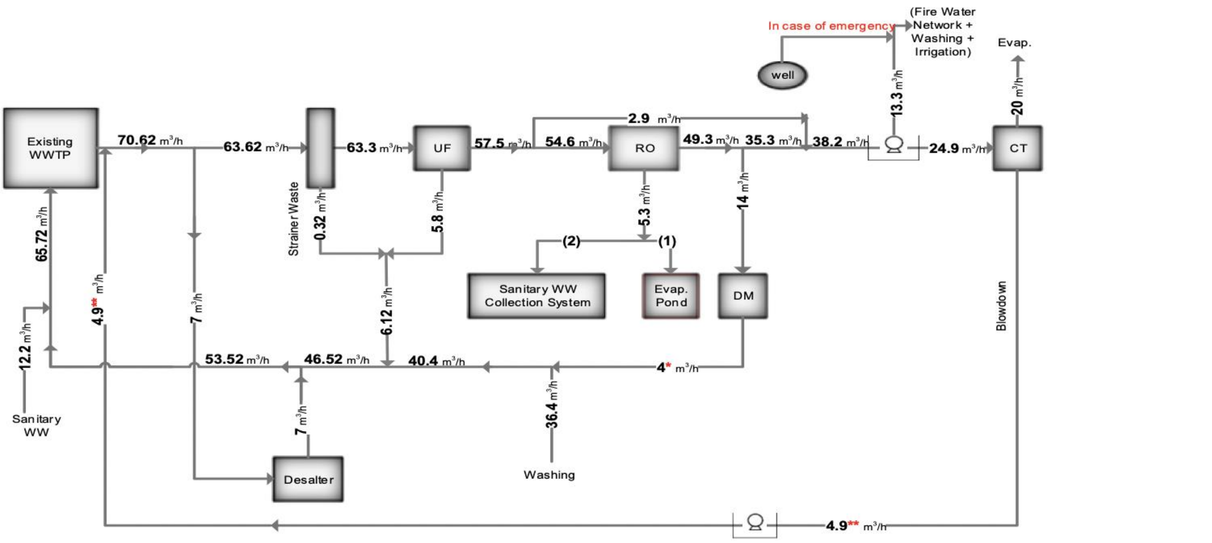
Table 6. Overall comparison of post treatment scenarios.

Post treatment scenarios		**UF + DG + IX**	**UF + IX**	**UF + RO**	**UF + IX + RO**	**UF + RO (bypass)**	**UF + DG+ IX (bypass)**	**UF + IX+RO (bypass)**	**UF+RO (bypass) with the new feed flowrate of 57.5 m3/h and a pH of 6**	
Effluent flow rate, m^3/h		50.8	69.7	68.1	60.3	70.5	61.9	64.6	47.1	47.1
Effluent quality	TDS, mg/L	0.018	1470	28.17	27.3	745.75	750.5	726.4	187.6	187.6
	Cl-, mg/L	0.01	442.29	13.29	8.47	207.61	242.69	219.1	34.05	34.05
	pH	7.72	7.93	4.5	6.3	7.5	7.95	7.6	6	6
	pH_s (Saturation)=(9.3+A+B)-(C+D)	15.184	9.5134	10.03	12.7640	7.0369	7.0747	7.0846	8.1780	8.1780
	$pH_{eq.}$ =1.465log [T. Alkalinity] +4.54	1.61	7.8899	5.125	5.6211	7.8237	7.5070	7.4493	7.1182	7.1182
	A= (log [TDS]-1)/10	-0.274	0.2167	0.0449	0.0436	0.1872	0.1875	0.1861	0.1273	0.1273
	B=13.12*[log(T+273)] +34.5						1.7584			
	C=log [Ca^{2+} as $CaCO_3$]-0.4	-2.4	-0.525	0.6700	-2.4	1.9673	2.1459	2.1740	1.2478	1.2478
	D=log [Alkalinity as $CaCO_3$]	-2	2.2866	0.3996	0.7379	2.2414	2.0253	1.9858	1.7598	1.7598
	Temperature, °C				40					
	T. Alkalinity, mg$CaCO_3$/L	0.01	193.5	2.51	5.47	174.38	106	96.8	57.53	57.53
	Ca. Hardness, mg$CaCO_3$/L	0.01	0.75	11.75	0.01	232.975	351.55	375	44.45	44.45
	T. Hardness, mg$CaCO_3$/L	0.01	1	14.63	0.01	299.25	515.5	475	57.15	57.15
TDS of the new blowdown		-	-	-	-	1123.9	1184.06	1159.96	1928.53 - 2204.3	if 1800 - 2000
New blowdown LSI (if pH of BD:8.2)		-	-	-	-	1.4999~1.5	1.4998~1.5	1.4998~1.5	1.94 – 1.93 (for COC=10.28), 2.06 – 2.05 (for COC=11.75)	1.89 – 1.88 (for COC=9.6), 1.98 – 1.97 (for COC=10.66)
COC (based on TDS)		-	-	-	-	1.5070	1.5776	1.5968	10.28 - 11.75 (if Cl^- :350 - 400)	9.6 - 10.66 (Cl^-:326.88 - 362.97)
New blowdown flow rate, m^3/h (based on the cons. Evap. of 20 m^3/h)		-	-	-	-	39.4420	34.6203	33.5086	2.15 - 1.86	2.32 - 2.19
Saturation/Corrosion indexes	Langelier Saturation Index (LSI) LSI=pH-pH_s	-7.464	-1.583	-5.5337	-6.4641	0.4630	0.8752	0.5153	-2.1780	-2.1780
			LSI<0, corrosive				LSI>0, slightly saturated, non-corrosive		LSI<0, corrosive	
	Ryznar Stability Index (RSI) RSI=2pH_s-pH	22.648	11.097	15.5674	19.2281	6.5738	6.1994	6.5693	10.3560	10.3560
			RSI>8-8.5, Corrosive				5.5<RSI<8.5, slightly saturated, non-corrosive		RSI>8-8.5, Corrosive	
	Puckorious Scaling Index (PSI) PSI=2pH_s-pH_{eq}	28.758	11.136	14.9419	19.9070	6.2500	6.6423	6.7200	9.2377	9.2377
			PSI>7, corrosive				PSI<7, non-corrosive		PSI>7, corrosive	
	Aggressive Index (AI) AI=pH+log T. Hardness*T. Alkalinity	3.72	10.217	6.0649	5.0379	12.2175	12.687	12.262	9.5169	9.5169
			AI<12, corrosive				AI>12, non-corrosive		AI<12, corrosive	



*Compared to the current situation, applying the effluent with an improved quality, originating from post treatment units, may result in reducing the DM wastewater from 4 to 1.5 m^3/h or lower quantities. However, this upcoming gap will not affect the design of post treatment units.
**Following each arrival of the treated effluent with an improved quality into the CT, the increase in COC may result in further reduction of CT blowdown from 4.9 to 2 m^3/h or lower quantities. However, this upcoming gap will not affect the design of post treatment units.

(a)



*Compared to the current situation, applying the effluent with an improved quality, originating from post treatment units, may result in reducing the DM wastewater from 4 to 1.5 m^3/h or lower quantities. However, this upcoming gap will not affect the design of post treatment units.
**Following each arrival of the treated effluent with an improved quality into the CT, the increase in COC may result in further reduction of CT blowdown from 4.9 to 2 m^3/h or lower quantities. However, this upcoming gap will not affect the design of post treatment units.

(b)

Fig. 5. Overall water balance in (a) rainy months, (b) dry months.

4. Concluding remarks and outlook

In recent years, water has become an increasingly scarce commodity and a potentially limiting factor specifically in oil refineries. The crisis of rising expenditures of water supply and wastewater treatment as well as diminishing and discharging wastewater into the environment, are further prompting oil refineries to zero in on water conservation by adopting water use minimization through reusing and recycling of wastewaters. Consequently, sustainable management of water and wastewater in oil refineries should be given the highest priority in efforts to overcome this challenge and lessen the existing imbalance in water resource demand versus its supply. The present state-of-the-art wastewater reclamation case study suggests a great opportunity for major industrial wastewater reuse/recycle and assists in solving some water-related problems in Kermanshah's oil refinery. Besides estimated economic feasibility, the selected post treatment scenario involving hybrid membrane technology (UF + RO) could result in overall fresh water savings of approximately 70% and 50%, respectively in summer and winter times of the year, proving the benefit of water management optimization. We strongly hope that, by implementing the aforementioned design and achieving success, this study serves as a model to other oil refineries with similar water and wastewater management problems. Given the significance of wastewater reuse, oil refineries should realize their major responsibility for environmental preservation and keep in mind that whenever an opportunity arises for water reuse, a thorough investigation must be conducted. Thus, the future of fresh water conservation in refineries lies in the ability of the scientific and engineering community to investigate and develop sustainable approaches for optimizing the use of available water. To balance the costs of these approaches, future trends in designing and constructing post treatment scenarios should focus on hybrid technologies to improve the treatment potential and capacity without any significant increase in design and operational costs.

Acknowledgement

The authors wish to thank Kermanshah’s Oil Refinery for their financial support and Razi University for lab equipment provided for this project.

References

Aghababaei N., Reverse osmosis design with IMS design software to produce drinking water in Bandar Abbas, Iran, Journal of Applied Research in Water and Wastewater 4 (2017) 314-318.

Akhoundi A., and Nazif S., Sustainability assessment of wastewater reuse alternatives using the evidential reasoning approach, Journal of Cleaner Production 195 (2018) 1350-1376.

Alderson M.P., dos Santos A.B., Mota Filho C.R., Reliability analysis of low-cost, full-scale domestic wastewater treatment plants for reuse in aquaculture and agriculture, Ecological Engineering 82 (2015) 6-14.

Alva-Argáez A., Kokossis A.C., and Smith R., The design of water-using systems in petroleum refining using a water-pinch decomposition, Chemical Engineering Journal 128 (2007) 33-46.

Alves R., Guardani R., Bresciani A., Nascimento L., Nascimento C., Computer Aided Chemical Engineering (2006) 1845-1850.

Asano T., and Cotruvo J.A., Groundwater recharge with reclaimed municipal wastewater: health and regulatory considerations, Water Research 38 (2004)1941-1951.

Bagajewicz M., A review of recent design procedures for water networks in refineries and process plants, Computers & Chemical Engineering 24 (2000) 2093-2113.

Barthe P., Chaugny M., Roudier S., Delgado Sancho L., Best available techniques (BAT) reference document for the refining of mineral oil and gas, European Commission 754 (2015).

Baskaran K., Palmowski L., Watson B., Wastewater reuse and treatment options for the dairy industry, Water Science and Technology: Water Supply 3 (2003) 85-91.

Bonnelye V., Sanz MA., Durand JP., Plasse L., Gueguen F., Mazounie P., Reverse osmosis on open intake seawater: pre-treatment strategy, Desalination 167 (2004) 191-200.

Bush KE., Refinery wastewater treatment and reuse, Chemical Engineering Journal 83 (1976) 113.

Chatla D., Padmavathi P., Srinu G., Wastewater treatment techniques for sustainable aquaculture, Waste Management as Economic Industry Towards Circular Economy, Springer: Singapore: (2020) p.159-166.

Ciardelli G., Corsi L., Marcucci M., Membrane separation for wastewater reuse in the textile industry, Resources, conservation and recycling 31 (2001) 189-197.

Diepolder P., Is zero discharge realistic? Hydrocarbon Processing 71 (1992) 129-160.

Feng X., and Chu K., Cost optimization of industrial wastewater reuse systems, Process Safety and Environmental Protection 82 (2004) 249-255.

Goldblatt M.E., Eble K.S., Feathers J.E., Zero discharge: what, why, and how, Chemical Engineering Progress: (United States): (1993) 89 (4).

Goldblatt ME., Gucciardi JM., Huban CM., Vasconcellos SR., Liao WP., New polyelectrolyte emulsion breaker improves oily wastewater cleanup at lower usage rates, Water and Process Technologies Article number TP382en0603 (2006).

IPIECA, Petroleum Refining water/wastewater Use and Management, IPIECA Operations Best Practice Series, London, United Kingdom, 2010.

Into M., Jönsson AS., Lengdén G., Reuse of industrial wastewater following treatment with reverse osmosis, Journal of Membrane Science 242 (2004) 21-25.

Jafarinejad S., Petroleum waste treatment and pollution control, Butterworth-Heinemann (2016).

Jafarinejad S., Jiang SC., Current technologies and future directions for treating petroleum refineries and petrochemical plants (PRPP) wastewaters, Journal of Environmental Chemical Engineering 7 (2019) 103326.

Jimenez B., and Asano T., Water reclamation and reuse around the world, Water Reuse: an international survey of current practice, issues and needs 14 (2008) 3-26.

Kanarek A., and Michail M., Groundwater recharge with municipal effluent: Dan region reclamation project, Israel, Water Science and Technology 34 (1996) 227-233.

Karimi Pashaki M. H., Khosrojerdi A., Sedghi H, Virtual water strategy and its application in optimal operation of water resources, Journal of Applied Research in Water and Wastewater 4 (2017) 349-353.

Lazarova V., and Bahri A., Water reuse for irrigation: agriculture, landscapes, and turf grass, CRC press (2004).

Marcel V., Oil titans: National oil companies in the Middle East, Brookings Institution Press: (2006).

Meidl J.A., Responding to changing conditions: how powdered activated carbon systems can provide the operational flexibility necessary to treat contaminated groundwater and industrial wastes, Carbon 35(9) (1997) 1207-1216.

Meneses M., Pasqualino J.C., Castells F., Environmental assessment of urban wastewater reuse: Treatment alternatives and applications, Chemosphere 81 (2010) 266-272.

Metcalf Eddy I., Asano T., Burton F.L., Leverenz H., Tsuchihashi R., and Tchobanoglous G., Water reuse, McGraw-Hill Professional Publishing: (2007).

Mohammadnejad, M., Ghazvini, M., Mahlia, T. and Andriyana, A. 2011. A review on energy scenario and sustainable energy in Iran, Renewable and Sustainable Energy Reviews 15 4652-4658.

Mohsen M.S., Jaber J.O., Potential of industrial wastewater reuse, Desalination 152(1) (2003) 281-289.

Mujeriego R., and Asano T., The role of advanced treatment in wastewater reclamation and reuse, Water Science and Technology 40 (1999) 1-9.

Nair C., Pollution control through water conservation and wastewater reuse in the fish processing industry, Water Science and Technology 22 (1990) 113-121.

Nikazar M., and Jamshidi M., Reuse of refinery treated wastewater in cooling towers, Iranian Journal of Chemistry and Chemical Engineering 27 (2008) 1-7.

Northey S.A., Mudd G.M., Werner T.T., Haque N., Yellishetty M., Sustainable water management and improved corporate reporting in mining, Water Resources and Industry 21 (2019) 100104.

Owusu-Boateng G., and Adjei V., The potential utilization of grey water for irrigation: A case study on the Kwame Nkrumah University of Science and Technology, Kumasi Campus, Journal of Applied Research in Water and Wastewater 1 (2014) 28-34.

Pombo F., Magrini A., Szklo A., Technology roadmap for wastewater reuse in petroleum refineries in Brazil, Environmental Management in Practice (2011) 425.

Rajkumar K., Muthukumar M., Sivakumar R., Novel approach for the treatment and recycle of wastewater from soya edible oil refinery industry—an economic perspective, Resources, Conservation and Recycling 54 (2010) 752-758.

Rosain R.M., Reusing water in CPI plants. Chemical Process Industries. Chemical Engineering Progress: United States: (1993) 89 (4).

Salahi A., Badrnezhad R., Abbasi M., Mohammadi T., Rekabdar F., Oily wastewater treatment using a hybrid UF/RO system, Desalination and water treatment 28 (2011) 75-82.

Speight J.G., The chemistry and technology of petroleum, CRC press: (2014).

Vazquez-Montiel O., Horan N.J., Mara D.D., Management of domestic wastewater for reuse in irrigation, Water Science and Technology 33 (1996) 355-362.

Wang Y., and Smith R., Wastewater minimization. Chemical Engineering Science 49 (1994) 981-1006.

Yan H., Liu L., Yang F., Takaoka D., Wang C., Operational optimization of air conditioning cooling water system with UF–RO desalination, Desalination 251 (2010) 53-57.

Yan H., Liu L., Yang F., Takaoka D., Wang C., Operational optimization of air conditioning cooling water system with UF–RO desalination, Desalination 251 (2010) 53-57.