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Full Length Research Paper

Application of reverse osmosis membrane system for treatment of effluent in textile knitted fabric dyeing

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The world's water is found in oceans, seas, lakes, reservoirs, rivers and streams, glaciers and snowcaps in the Polar Regions, in addition to ground water below the land areas. The water locked up in the oceans and seas are too salty and cannot be used directly for human consumption, that is, for domestic, agricultural or industrial purposes. The textile industry consumes a vast quantity of water and generates an equally vast quantity of waste water. This work mainly focused on the treatment of wastewater from the textile knitted fabric dyeing industry. The membrane selection process was theoretically designed using well known design software, like KOCH and ROSA. To design the treatment plant system based on the analytical report and software membrane, reverse osmosis (RO) system was used. To compare the experimental and theoretical (KOCH and ROSA software) values for the characteristics of knitted fabric dyeing effluent, the results revealed that the KOCH software membrane shows more recovery, high TDS reduction, less power consumption and low investment cost than ROSA type membrane in the treatment of effluent from knitted fabric dyeing.

Key words: KOCH and ROSA software membrane, knitted fabric dyeing, reverse osmosis, textile effluent, water treatment.

INTRODUCTION

Textile industry is one of the main pillars of Indian economy constituting approximately 14% of industrial production and 20% of total export earnings. It is the second largest employment generator after agriculture. Currently, it accounts for about 8% of gross domestic product (GDP), 20% of industrial production and over 30% of export earnings of India with 2 to 3% import intensity.

Various treatment techniques such as: coagulation/ flocculation (Hasani et al., 2009), activated carbon adsorption (Kadirvelu et al., 2003), oxidation (Malik and (Selcuk, 2005), Saha, 2003), ozonation electrochemical oxidation (Radha et al., 2009), membrane separation (Chiu et al., 2009), biological degradation (Gopinath et al., 2009), etc., have been applied for the treatment of dye containing effluents, and most of the techniques are reported as expensive and not environment friendly (Crini, 2006). In recent years, the use of reverse osmosis (RO) technique in wastewater treatment has been seen in the works of different authors (Sourirajan and Matsuura, 1985; Sugita, 1989; Abdul et al., 2003) and they found that the RO technique is a highly efficient process, in terms of high recovery, low operating cost (Shahid et al., 2006; Garcia-Figueruelo et al., 2009) and easy operation and maintenance. In membrane technology, the theoretical design of membranes plays a vital role in the effluent treatment process.

RO membranes have a retention rate of 90% or more for most types of ionic compounds and they produce a high quality of permeate (Tinghui et al., 1983). Decoloration and elimination of chemical auxiliaries in dye house wastewater can be carried out in a single step. However,

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Abbreviations: RO, Reverse osmosis; **APHA,** American public health association; **CPCB,** central pollution control board; **BOD,** biological oxygen demand; **TFC,** thin film composite membrane.

RO permeates the removal of all mineral salts, hydrolyzed reactive dyes and chemical auxiliaries, but the problem involved is that the higher the concentration of salts, the more important the osmotic pressure becomes and consequently, the greater the energy required.

Nanofiltration membranes retain organic compounds of low molecular weight, divalent ions or large monovalent ions, such as hydrolyzed reactive dyes and dyeing auxiliaries. The effect of the concentration of dyes, as well as the concentration of salt and pressure, has been frequently reported in dye house effluents (Erswell et al., 1988). In most published studies concerning dye house effluents, the concentration of mineral salts does not exceed 20 gL^{-1} and the concentration of dyestuff does not exceed 1.5 gL^{-1} (Tang and Chen, 2002). Generally, the effluents are reconstituted with only one dye, and the amount of volume studied is low (Abari and Remigy, 2002). The treatment of dyeing wastewater by nanofiltration, thus, represents one of the rate applications possible for the treatment of solutions with highly concentrated and complex solution (Freger and Arnot, 2000).

Ultrafiltration enables the elimination of macromolecules and particles, but the elimination of polluting substances, such as color, is never complete (between 31 and 76%) (Watters et al., 1991). Moreover, even in the best of cases, the quality of the treated wastewater does not permit its reuse for feeding sensitive processes, such as the dyeing of textile (Rott and Minke, 1993). As such, ultrafiltration can only be used as a pretreatment for RO (Ciardelli and Ranieri, 2001) or in combination with a biological reactor (Mignani et al., 1999).

Microfiltration is suitable for treating dye baths containing pigment dyes as well as subsequent rinsing baths (Al-Malack and Anderson, 1997). Although, the auxiliaries remain in the retentant, microfiltration can be used as a pretreatment for nanofiltration or RO (Sadr et al., 1998).

Commercial polyamide nanofiltration (NF) RO and ultra-low pressure RO (ULPRO) membranes [NF-90, NF-200, thin film composite membrane (TFC)-HR, and XLE], as well as a cellulose triacetate RO membrane (CTA), were employed to investigate the effect of fouling on transport of organic micropollutants. Membrane fouling also resulted in an increased adsorption capacity and reduced mass transport through partitioning and diffusion of solutes across the membrane. These effects led to an increase in rejection of hydrophobic non-ionic solutes (for example, disinfection byproducts and chlorinated solvents) by fouled membranes (Tae-Uk and Christopher, 2006).
Hollow fibres used in membrane filtration units submerged into the biological stage of a municipal wastewater treatment plant, called membrane bioreactors (MBR), and are investigated in terms of pore structure, membrane morphology and membrane material characteristics. This paper's initial results of membrane characterization are discussed and the next steps to develop a membrane characterization protocol are outlined (Buetehorn et al., 2008).

The textile industry uses valuable dyes, which are clearly visible if discharged into public water ways. Thus, these disposals create both aesthetic and environmental wastewater problems. At the same time, the textile industry continually seeks to conserve water and would economically benefit from recovered and reused dyes. Secondly, water way pollution is avoided, and thirdly, reusable water is produced (Akbari et al., 2002).

The reagents used in textile industries are very diverse in chemical composition. Over 700,000 tons of approximately 10,000 types of dyes and pigments are produced to be discharged as industrial effluent during the textile dyeing processes. Conventional bio-treatment methods are not effective for most of the synthetic dyestuffs due to the complex polyaromatic structure and recalcitrant nature of the dyes (Azbar and Yonar, 2004).

RO membranes are widely used in drinking water, wastewater and industrial applications. The use of RO membranes in advanced wastewater reclamation using secondary treated wastewater effluent to produce water for indirect potable use has also increased over the past few years (Drewes et al., 2003). A major impediment in the application of RO membrane technology for desalination and wastewater reclamation is membrane fouling. In advanced water reclamation, secondary effluent from wastewater treatment plants contains dissolved organic matter, commonly known as effluent organic matter. When the second wastewater effluent is introduced to the RO membrane processes as feed water, the presence of effluent organic matter contributes to organic fouling (Barker et al., 2000). Most of the effluents from different industrial sources were discharged directly into the soil or into ground water, but due to stringent environmental restrictions, the Central Pollution Control Board (CPCB) has become stricter and has imposed very stringent methods for recovering pure water from such industrial effluents. However, for the treatment of an effluent by conventional methods like aerobic and non-aerobic digestion, the ration of biological oxygen demand (BOD) to COD should be >0.6 (Chain and Dewalle, 1977).

MATERIALS AND METHODS

M/S Sakthi Knitting Limited is located at Perundurai, Erode, Tamil Nadu, India. Ten soft flow reactors (batch process) and four Winches dyeing machines were used for knitted fabric dyeing with different machines' capacities. They were used for the purpose of dyeing to include desizing, scouring, bleaching and mercerization. The processed knitted fabric is about 2000 to 2500 kg/day and the volume of effluent generated is 500 to 600 m^3/day.

The sampling effluent (input data) and effluent characteristics were analyzed as per American Public Health Association (APHA) and CPCB standards (APHA, 1998; CPCB, 2001) in the knitted fabric dyeing industry for the following parameters: pH, TDS, BOD, COD, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, $NH4^+$, HCO_3^-, SO_4^{2-}, NO_3^- and SiO_2.

Using KOCH software

For KOCH software membrane 'ROPRO', TFC 8040 XR 375

Table 1. KOCH software membrane details.

S/N	Parameter	KOCH software
01	Membrane	ROPRO
	RO Stage I	TFC 8040 XR 375
	RO Stage II	TFC 8040 SW 335

Table 2. ROSA software membrane details.

S/N	Parameter	ROSA software
01	Membrane	FILMTEC
	RO Stage I	BW 30 – 365 FR
	RO Stage II	SW 30 HR – 380

Table 3. Comparison of reverse osmosis (RO) feed, permeate of theoretical (KOCH, ROSA) versus experimental for knitted fabric dyeing.

Parameter	RO feed ppm (before)	Theoretical value for RO permeate ppm		Experimental value for RO permeate ppm (after)
		KOCH software (after)	ROSA software (after)	
pH	7.70	4.92	5.28	7.14
TDS	4039.92	93.62	324.47	202.32
COD	46.00	7.42	9.62	3.71
BOD	8.00	4.33	5.73	2.43
Cl^{-}	2010.00	51.31	172.12	81.00
Ca^{2+}	35.00	0.15	0.87	0.36
Mg^{2+}	15.00	0.06	0.38	0.11
Na^{+}	1500.00	36.22	121.10	61.36
K^{+}	5.00	0.16	0.45	0.21
NH_4^{+}	0.70	0.05	0.22	0.07
HCO_3^{-}	350.00	8.12	17.40	11.16
SO_4^{2-}	280.00	1.03	10.30	2.96
NO_3^{-}	0.80	0.09	0.59	0.13
SiO2	17.00	0.40	0.90	0.69

membrane was used in RO stage-I and TFC 8040 SW 335 membrane was used in RO stage-II. For array classification, 5X6:3X6 was used in RO stage-I and 2X5:1X5 in RO stage-II. The number of elements used in RO stages I and II is 48 and 15, respectively and the total number is 63 elements. Although, RO feed flow is 30.0 m^3/h, permeate flow is 27 m^3/h, reject flow is 3 m^3/h and RO recovery is 90.00%, the pressure required in RO stages I and II is 11.6 and 14.7 kgs/cm^2, respectively. Table 1 presents the KOCH software membrane.

Using ROSA software

For ROSA software membrane 'FILMTEC', BW 30 - 365 FR membrane was used in RO stage-I and SW 30 HR - 380 membrane was used in RO stage-II. For array classification, 5X6:3X6 was used in RO stage-I and 2X5:1X5 in RO stage-II. The number of elements used in RO stages I and II was 48 and 15, respectively and the total number was 63 elements. Although, RO feed flow is 30.0 m^3/h, permeate flow is 27.10 m^3/h, reject flow is 2.99 m^3/h and RO recovery is 90.03%, the pressure required in RO stages I and II is 11.2 and 14.3 kgs/cm^2, respectively. Table 2 presents the ROSA software membrane.

From Tables 1 and 2, which show the KOCH and ROSA software membrane for RO stages I and II, TFC indicates thin film composite membrane; XR, extra rejection; SW, sea water; 375, membrane active area 375 feet square; 335, membrane active area 335 feet square; BW, brackish water; FR, fine rejection; 365, membrane active area 365 feet square; and 380, membrane active area 380 feet square.

RESULTS AND DISCUSSION

The total quantity of fabric processed in the knitted fabric dyeing unit is 1500 to 2000 kg/day and the volume of effluent generated is 500 to 600 m^3/day. A comparison was also made between theoretical KOCH design and experimental design values which are shown in Table 3

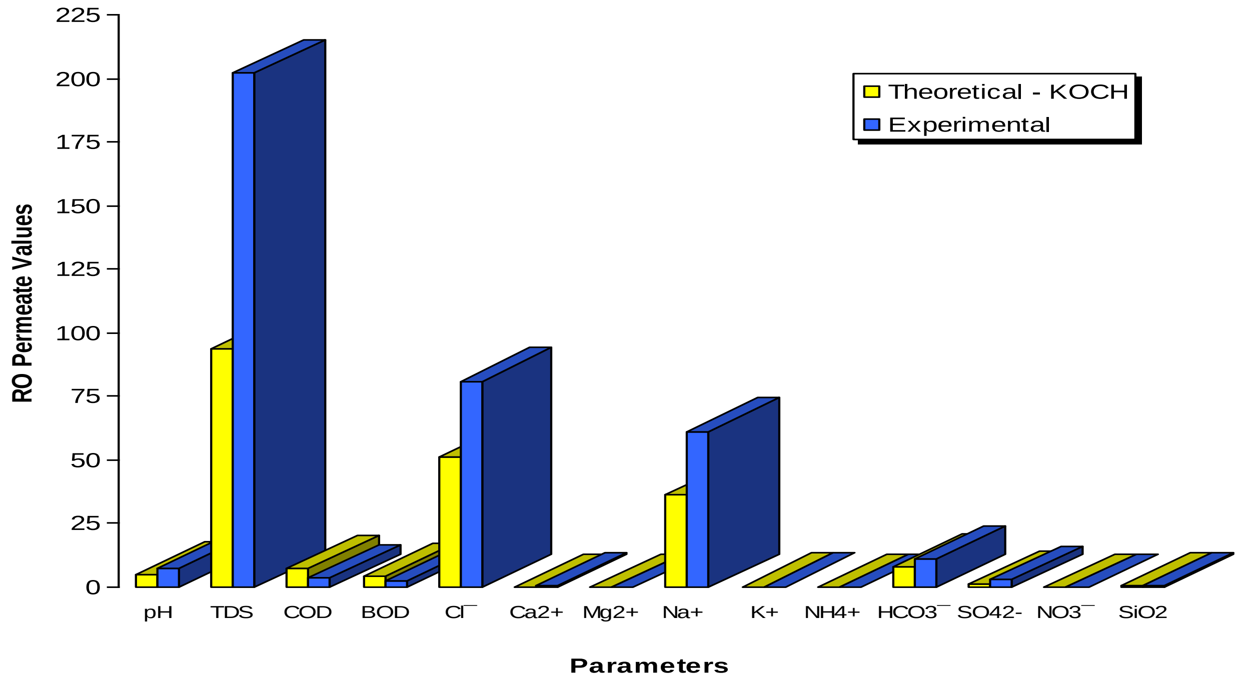

Figure 1. Comparison of reverse osmosis (RO) permeate, theoretical - KOCH versus experimental for knitted fabric dyeing.

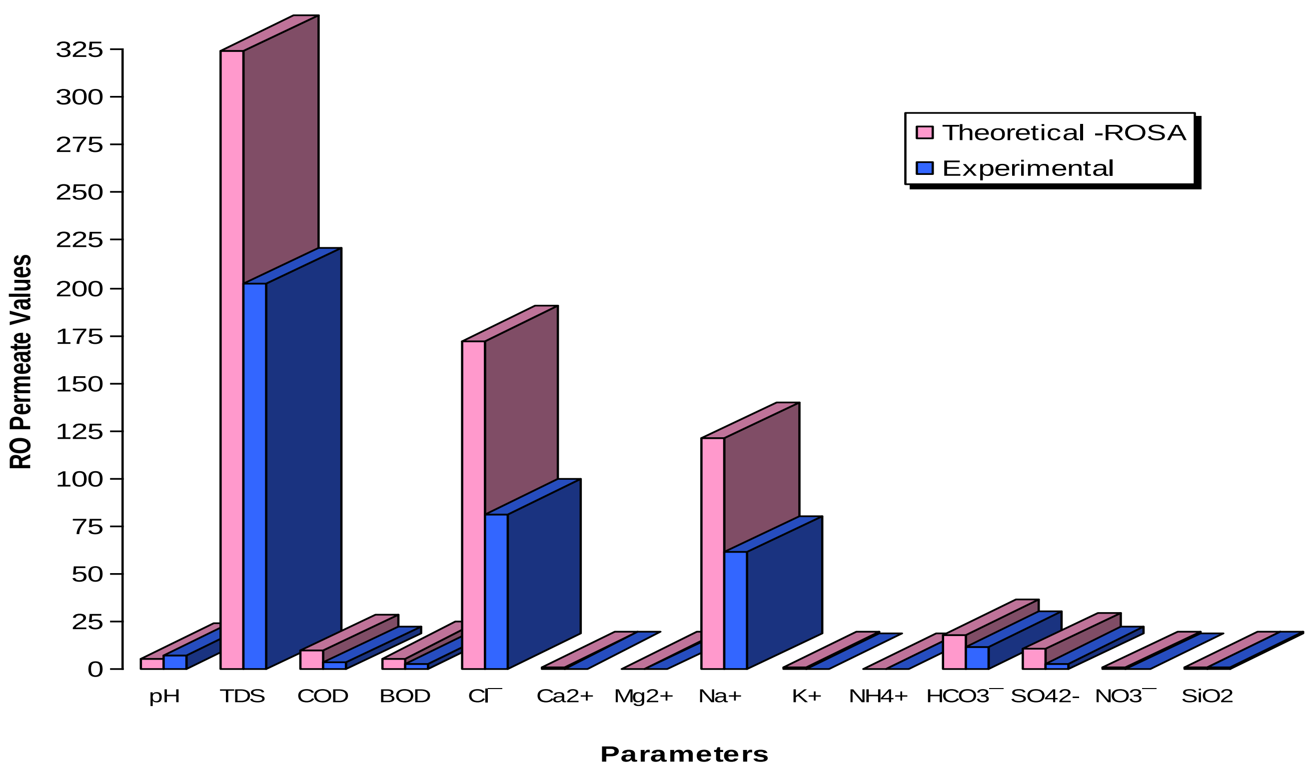

Figure 2. Comparison of reverse osmosis (RO) permeate, theoretical - ROSA versus experimental for knitted fabric dyeing.

and Figures 1, 2, 3 and 4. From these results, it can be seen that TFC 8040 XR 375 and TFC 8040 SW 335 for RO stage I and II, respectively are used to treat the wastewater irrespective of the textile industrial sector. From the treated effluent characteristics, it can be seen that the level of parameters is in line with the pollution

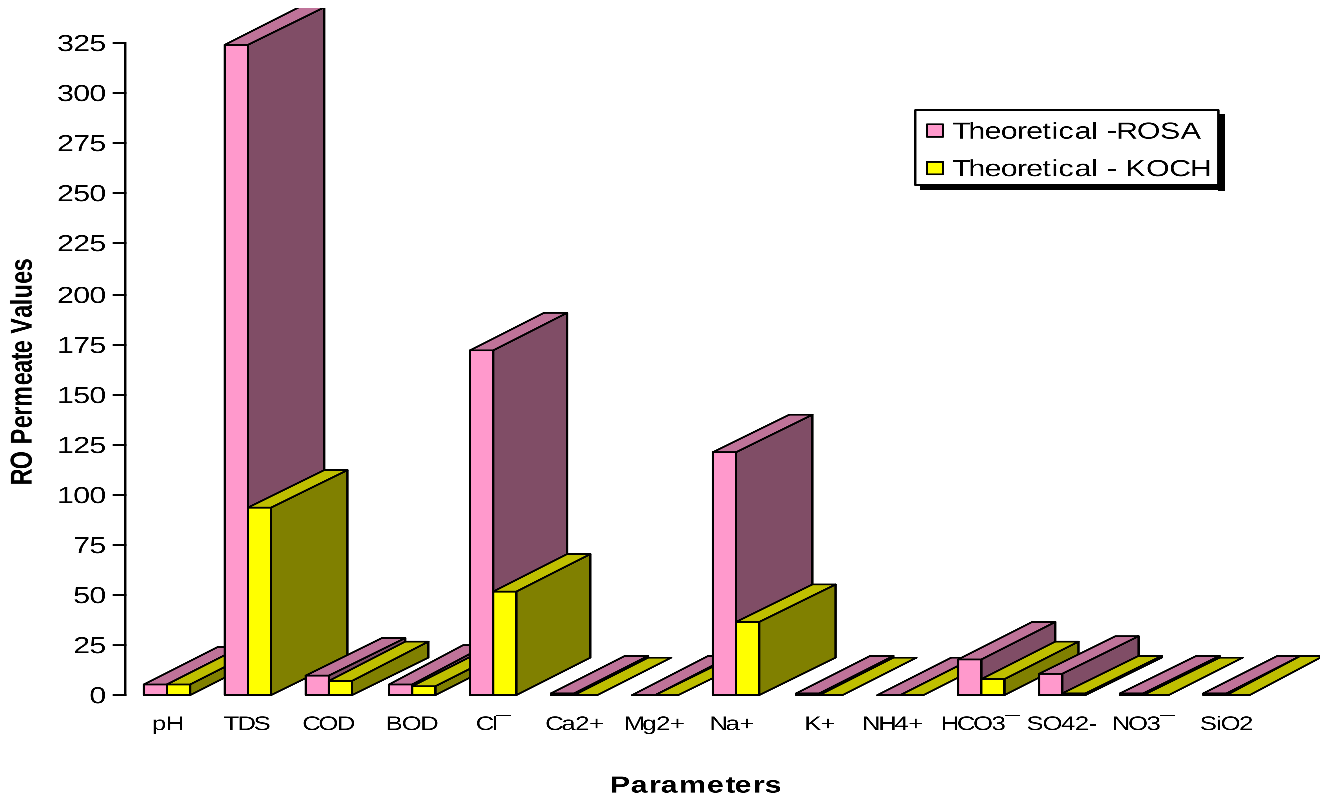

Figure 3. Comparison of reverse osmosis (RO) permeate, theoretical ROSA versus theoretical KOCH for knitted fabric dyeing.

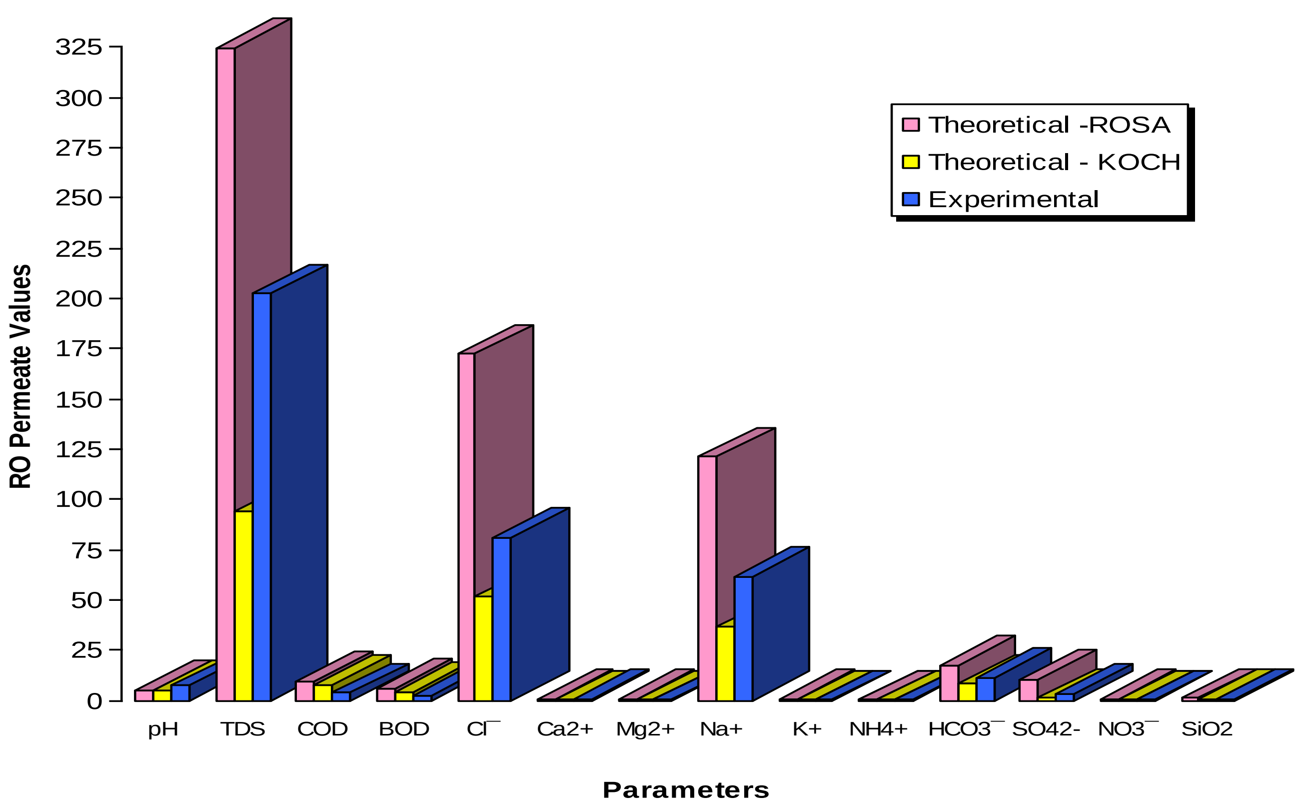

Figure 4. Comparison of reverse osmosis (RO) permeate, theoretical (KOCH, ROSA) versus experimental for knitted fabric dyeing.

Table 4. Comparison between KOCH and ROSA software membrane in 600 KLD capacities for Knitted fabric dyeing.

S/N	Parameter	KOCH software	ROSA software
01	Membrane	ROPRO	FILMTEC
	RO stage I	TFC 8040 XR - 375	BW 30 – 365 FR
	RO stage II	TFC 8040 - SW 335	SW 30 HR – 380
02	**Array classification**		
	RO stage I	5 X 6 : 3 X 6	5 X 6 : 3 X 6
	RO stage II	2 X 5 : 1 X 5	2 X 5 : 1 X 5
03	**Number of elements used**		
	RO stage I	48 elements	48 elements
	RO stage II	15 elements	15 elements
	Total	63 elements	63 elements
04	Number of working hours in RO	20 h	20 h
05	Recovery	90.00%	90.03%
06	Feed TDS	4039 ppm	4039 ppm
07	Permeate TDS	93.62 ppm	324.47 ppm
08	TDS reduction %	97.68 %	91.96%
09	Average membrane flux	9.6 LMH	12.52 LMH
10	Power consumption in Kw	19.33 KW	32.12 KW
11	RO feed flow	30 m³/h	30.00 m³/h
	RO permeate flow	27 m³/h	27.10 m³/h
	RO reject flow	3 m³/h	2.99 m³/h
	RO recovery %	90.00%	90.03%
12	**Pressure**		
	RO 1st stage	11.6 Kgs/cm²	11.20 Kgs/cm²
	RO 2nd stage	14.7 Kgs/cm²	14.30 Kgs/cm²

board norms.

The results obtained from the knitted fabric dyeing industry are shown in Table 4. From the experimental results, it can be seen that KOCH type membrane shows more recovery, high TDS reduction, less power consumption and low investment cost than ROSA type membranes. Hence, the theoretical data obtained from KOCH type were used for fabrication and sizing of the treatment plant for the aforementioned industry. However, RO recovery was about 90.00%, TDS reduction was 97.68%, and power consumption for the treatment process was 19.33 KW. These results also reveal that the KOCH software membrane is recommended to treat the effluent from the knitted fabric dyeing.

Conclusions

The following conclusions were drawn from this study:

1. Sampling and characteristics of effluents were carried out as per APHA and CPCB standards. Theoretical design of membrane was studied using commercial software like KOCH and ROSA before carrying out real time implementation.
2. From the comparison between theoretical and real time (experimental) value, the results were within the range of 10 to 40%.
3. In KOCH software membrane, the following were observed: (a) higher TDS reduction, (b) higher RO recovery %, (c) less power consumption and (d) less investment cost as compared to ROSA software.
4. From theoretical and experimental studies, the following membranes: RO stage I (TFC 8040 XR 375) and RO stage II (TFC 8040 SW 335), were found to be more effective for improvement of the textile sector.
5. It is also found that approximately 90 to 92% of treated (permeate) water can be used for recycling purposes in houses and the remaining 8 to 10% of rejected waste can be sent to solar evaporation/multiple evaporation for salt recovery. The recovered salt can also be used in the dyeing process for making dark color shade.
6. From the treated effluent characteristics, it can be seen

that the level of parameters is in line with the pollution board norms.
7. RO was successfully used in membrane for the treatment of knitted fabric effluent.

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