Application of Forward Osmosis Coupled with Reverse Osmosis in Industrial Wastewater Treatment

[1]Kruti Bhatt, [2]Dr.Reshma L Patel, [3]Anand Vegda

[1]M.Tech Environmental Engineering student, [2]Associate Professor, [3]Process Engineer

[1]Civil Department, Birla Vishwakarma Mahavidyalaya,Vallabh Vidyanagar,, India

Abstract: Forward Osmosis is the sustainable way to treat wastewater resources, specifically for industrial wastewater treatment. In this work, the concept of forward osmosis-reverse osmosis (FO-RO) was demonstrated and applied to textile wastewater. This work was done by a couple of experiments. The first experiment was performed by a lab-based forward osmosis set-up where textile wastewater was taken as a feed solution and NaCl as a draw solution. An experiment was done at a batch mode with the draw solution (NaCl) having different concentrations like 1, 1.5, 2, 2.5, and 3 M. After each batch with different concentration of NaCl the Total Dissolved Solids (TDS) of diluted draw solution and concentrated feed solution as well as Chemical Oxygen Demand (COD) of concentrated feed solution was measured. Results indicated that; feed solution gets more concentrated as the concentration of draw solution increases in the draw stream which means high rejection of solutes could be achieved by increasing the concentration of draw solution. In the second experiment, reverse osmosis was attached after the forward osmosis set-up. The same feed been applied to this hybrid process but at continuous mode where RO was kept to recover water from diluted draw solution and RO reject from this process was returned to the draw stream to reuse as a draw solution. By this coupled process, 75% of water recovery and 97% of TDS removal could be achieved.

***Index Terms*:** Forward Osmosis; Reverse Osmosis; Total dissolved solids; Chemical Oxygen Demand; draw solution; feed solution; water flux

I. INTRODUCTION

Wastewater is basically the liquid waste produced by the community after it has been used in various applications. Wastewater treatment is the process to remove undesirable solutes from wastewater and produce effluent that can be disposed to the water sources.

Membrane process is one of the most efficient physical treatments of wastewater. Membranes act like a cell wall which allows water to pass through but restrict unwanted substances from passing through it. In membrane process, fluid is passed through the membrane due to difference in pressure between both the sides of membrane. Some of the membrane technologies are as follow:

- Forward Osmosis
- Reverse Osmosis
- Microfiltration
- Ultrafiltration
- Nanofiltration

II. FORWARD OSMOSIS

Forward Osmosis is the membrane process that has been used to treat industrial wastewater as well as leachate. It is also a sustainable solution as it is used for desalination of seawater and purifying water for relief during an emergency. Recent development also uses FO for controlling drug released into the body. Forward Osmosis is advantageous because it is being operated at nearly zero hydraulic pressure that means FO uses natural osmosis for the separation of water from solutes. It leads to high efficiency in the removal of contaminants and it has lower membrane fouling than other membrane processes. FO involves only one pressure which is due to the flow resistance within the membrane module. Forward osmosis process involves feed solution and draw solution where draw solution has higher solute concentration with compared to feed solution. Due to high concentration difference, osmotic pressure has taken place naturally and therefore feed water moves towards draw solution. This movement results in dilution of draw solution and up-concentration of feed solution. In the forward osmosis process, NaCl, $MgCl_2$, $CaCl_2$, etc. are used as a draw solution.

III. FO-RO TREATMENT:

The forward osmosis-reverse osmosis (FO-RO) integrated system is a newly approached membrane-based technology. FO-RO process is beneficial for the concept of ZLD or minimal liquid discharge as this hybrid technology has high parameters removal efficiency and high water recovery. This newly developed technology is energy beneficial which is ultimately been proved as a cost-beneficial process.

In this membrane process, as the concentration of draw solution increases, the feed solution gets more concentrated; which means that a high amount of solutes are rejected from the feed water. During this process, the draw solution gets diluted by the separated water from the solutes by the FO membrane. This diluted draw solution is been applied to RO which gives high-quality recovered water. The reject from the RO system consists of a high amount of salts therefore, this reject is returned and reuse as a draw solution.

IV. MATERIALS USED IN FO-RO SYSTEM:

In this work, the FO membrane module is made up of Thin Film Composite (TFC) hollow fibers. A positive displacement pump was been used for applying desirable flow to the draw solution and feed solution. Various concentrations of NaCl like 1M, 1.5M, 2M, 2.5M and 3M were used as a draw solution. Wastewater from the textile industry was taken as a feed solution for the FO process. Commercially available RO was used in the FO-RO system for draw recovery after the FO process.

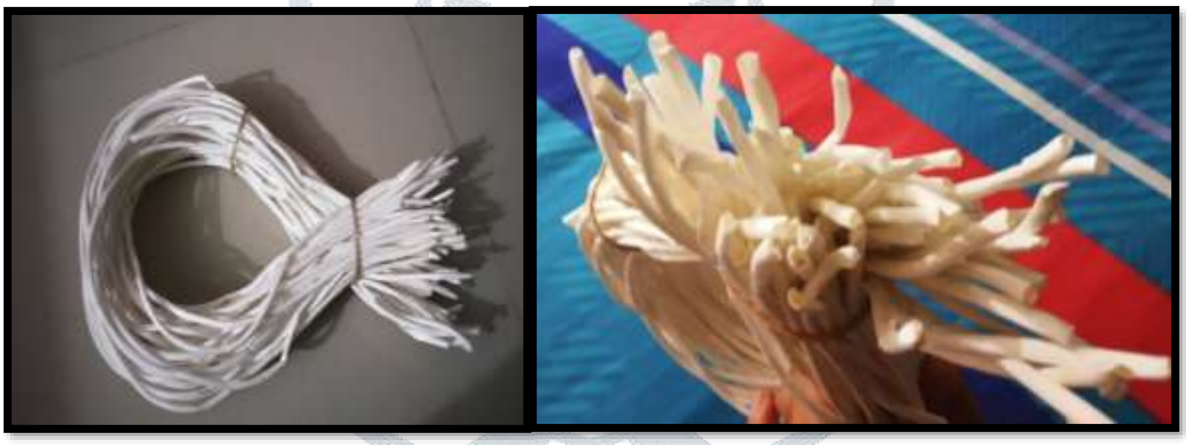

Figure 1 Thin Film Composite (TFC) hollow fibers

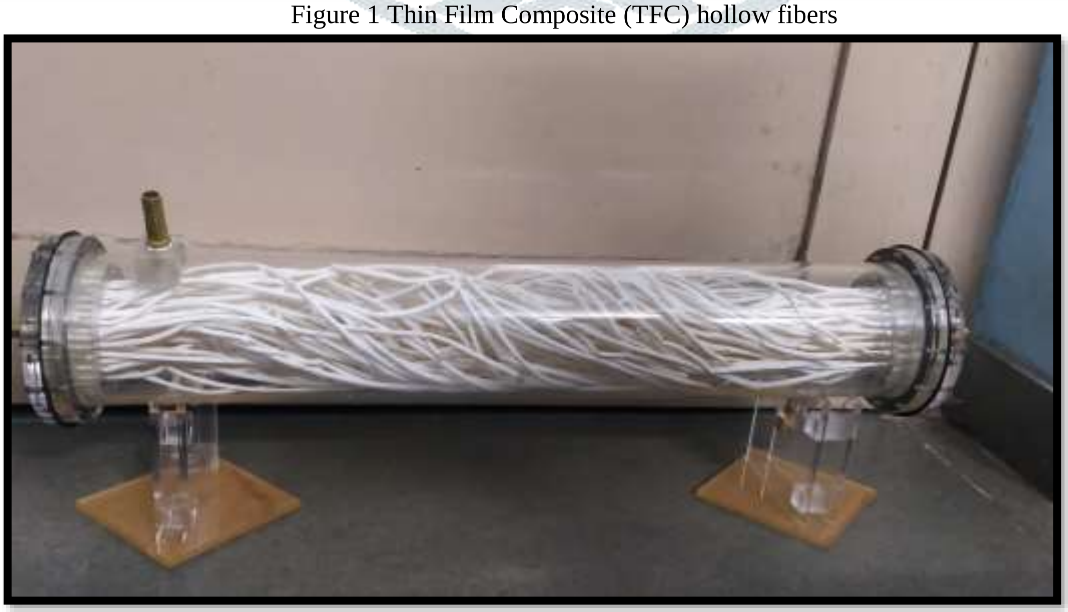

Figure 2 FO Membrane Module

V. EXPERIMENTAL PROCEDURE:

This work was divided into two experiments; the first experiment was done to analyze the performance of the FO process and the second experiment was conducted by attaching FO and RO system for checking water recovery and TDS removal.

1. FO Performance Observation:

In this experiment, a lab-scale FO module was kept with a draw and feed solution container. The flow rate of draw solution and feed solution was kept at 5 L/hr and 2 L/hr respectively. This process was done in batch mode and each batch was performed for an hour. We had taken NaCl solution as a draw solution for the FO process. NaCl was been taken with different concentrations like 1M, 1.5M, 2M, 2.5M and 3M.

After 1 hour of a batch, concentrated feed solution and diluted draw solution were analyzed. Total Dissolved Solids (TDS) and Chemical Oxygen Demand (COD) of concentrated feed solution and Total Dissolved Solids (TDS) of diluted draw solution was been measured after 1 hour of each batch.

Table 1 Initial Quality of Textile wastewater (Feed Solution)

pH	6.96
TDS	2800 mg/L
EC	4.68 ms
COD	1760 mg/L

Figure 3 Forward Osmosis (FO) set-up

2. FO-RO System Performance:

In a lab-scale FO-RO integrated system, we had attached a commercially available RO system after the FO module. RO was been kept in a way that it can recover the water from the diluted draw solution coming from the FO system as well as RO reject can be returned to the draw stream for reuse as a draw solution.

This hybrid process was done in a continuous mode. Flow for the draw and feed solution was kept at the same rate as in the individual FO process. Water recovery from applied diluted draw solution and TDS removal were measured.

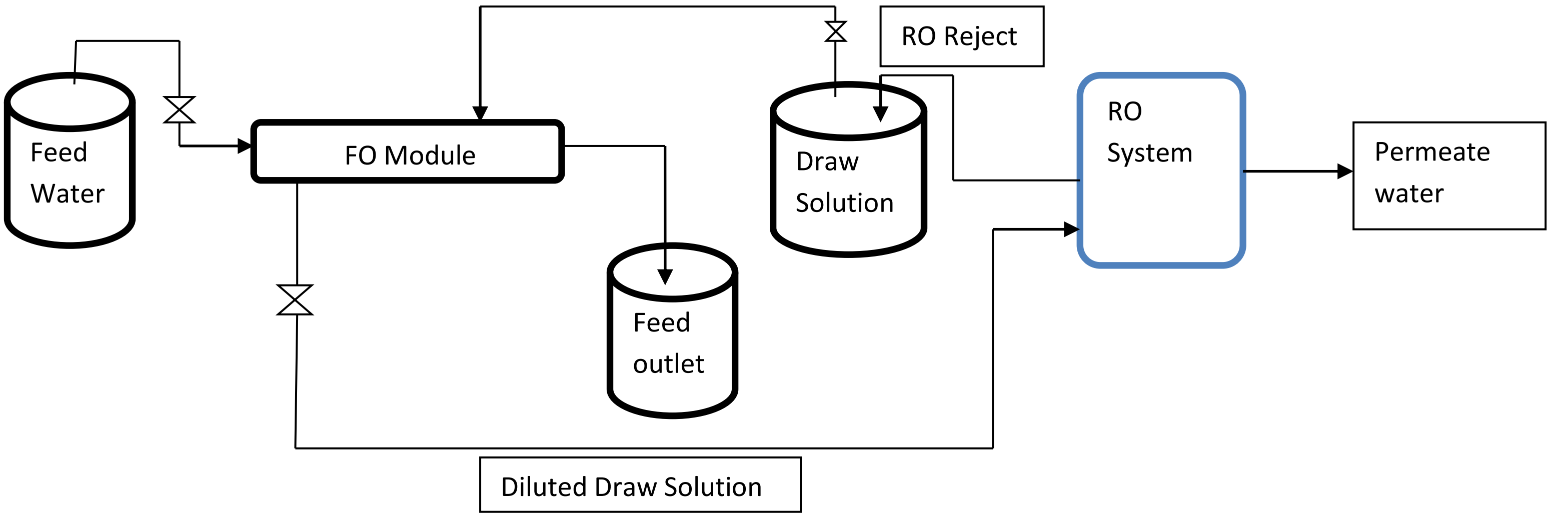

Figure 4 FO-RO Lab-scale System

VI. RESULTS AND DISCUSSION:

Results noted after both the experiments are as follows:

1) FO Performance Observation:

This work was been performed with different concentrations of NaCl. Firstly initial TDS of NaCl having various concentrations were measured. After 1 hour of every batch, the TDS of diluted draw solution were noted. From that, we could able to know the percent decrease in TDS of draw solution or how much draw solution had been diluted after an hour.

Table 2 Initial and final (after 1 hour) TDS of Various Concentration of NaCl

NaCl Concentration (M)	**Initial TDS of Draw solution (mg/L)**	**TDS of Draw solution after 1 hour (mg/L)**	**% decrease in TDS of draw solution**
1	58440	41500	28.98
1.5	87660	65810	24.92
2	116880	81816	30
2.5	146100	104000	28.81
3	175320	122520	30.11

This FO process was done at a batch mode and during the process, the feed solution gets concentrated. Therefore, we measured the TDS of concentrated feed solution after 1 hour of a batch. From results, we could able to know the increment in TDS of feed having initial TDS 2800 mg/L. Increased TDS in feed after an hour indicates solutes rejection from the feed.

Table 3 TDS of feed after 1 hour of batch with various concentrations of NaCl

NaCl Concentration (M)	TDS of concentrated feed solution (mg/L)
1	20320
1.5	24550
2	39864
2.5	44900

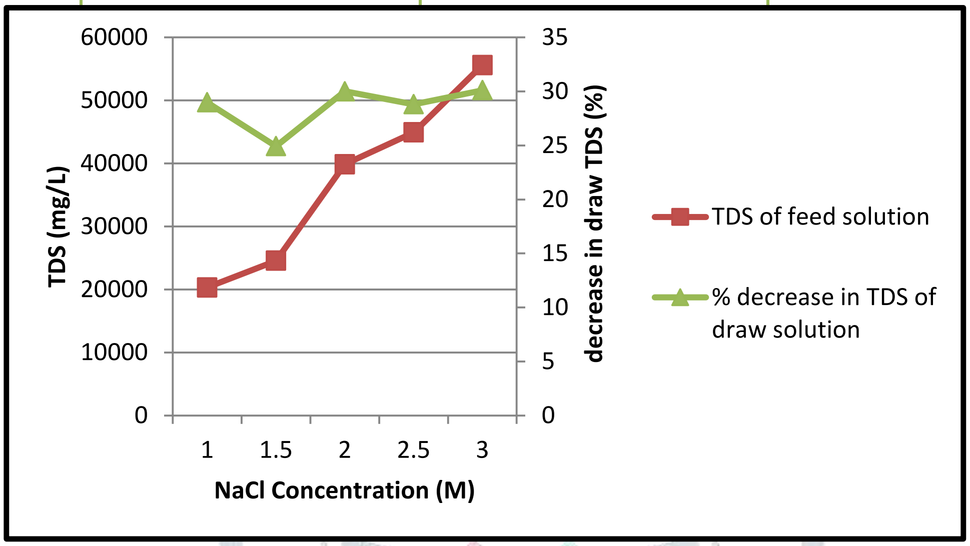

Figure 5 Changes in TDS of Feed and Draw solution after 1 hour

Figure 5 represents that the TDS of feed solution increases with increasing concentration of NaCl. As the concentration of the draw solution increases, the osmotic pressure between the two solutions is also increases. Therefore feed solution gets more concentrated which leads to the higher rejection of solutes. Percent decrease in draw solution represents that draw solution gets diluted after 1 hour of FO process.

Chemical Oxygen Demand (COD) of feed solution was been measured after each batch. Changes in COD of the feed sample after 1 hour were noted. The initial COD of feed sample was 1760 mg/L.

Table 4 COD of Feed sample after 1 hour

NaCl Concentration (M)	COD of concentrated feed after 1 hr (mg/L)
1	5400
1.5	6655
2	7536
2.5	8680
3	10276

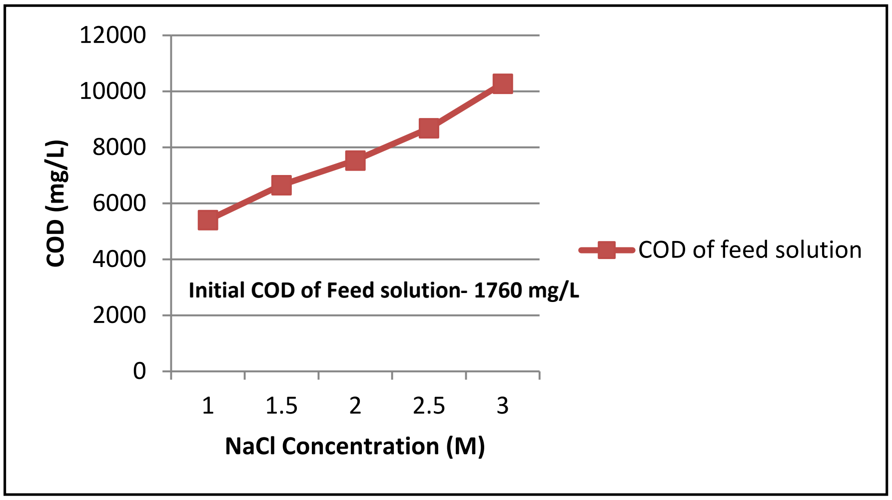

Figure 6 Changes in COD of feed solution after 1 hour

The above Graph (Figure 6) indicates that the COD of the feed sample is increased after 1 hour. Figure 6 represents that COD of feed sample increases with increasing concentration of NaCl, which means feed sample is being concentrated more with an increase in the concentration of draw solution. Therefore high solute rejection can be achieved by increasing the concentration of draw solution as a high concentration of draw solution leads to create high osmotic pressure.

Water flux is an important factor in the performance of any membrane process and it also affects FO performance. Therefore, water flux was observed in every batch with various concentrations of NaCl. Water flux (J_w) in the process is permeated water passing through the effective membrane surface area in a unit of time.

$$J_w = \frac{\Delta v}{A_m \, \Delta t}$$

Where Δv=

Permeate water over 1 hour (L)

A_m= Effective membrane surface area

Table 5 Water Flux achieved with different concentration of NaCl

NaCl concentration (M)	Wat1er Flux (L/m^2h)
1	31.81
1.5	34.47
2	33.4
2.5	33.94
3	34.47

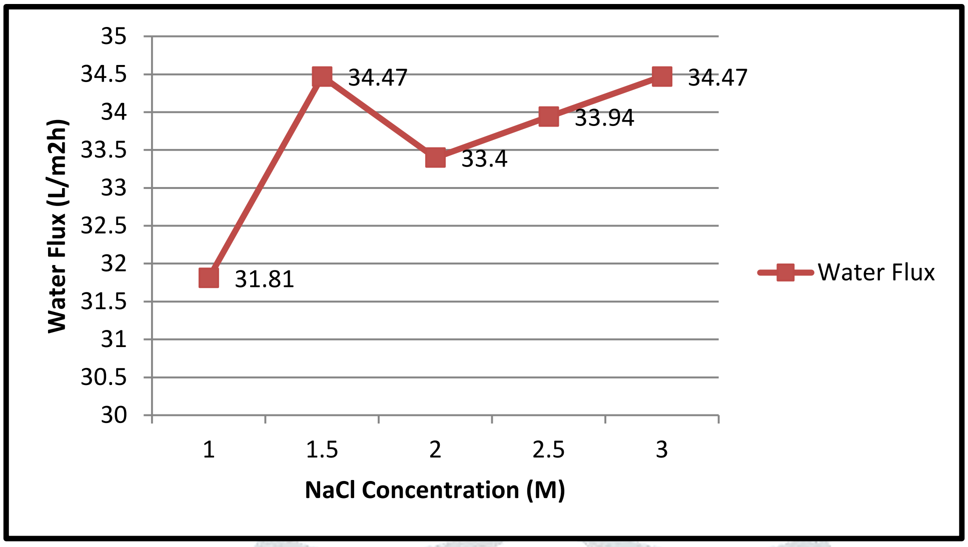

Figure 7 Changes in water flux with different concentrations of draw solution

The above Figure shows that in most cases water flux increases with increasing concentration of NaCl. Here, we observed that a sudden increase took place for 1.5M concentration and it decreased for 2M concentration. After that water flux uniformly increased with increasing concentration of draw solution.

2) FO-RO System Analysis:

RO system was kept after the FO system. A diluted draw solution had been sent to the RO system for water recovery. As we estimated, 75% of water was recovered from the diluted draw solution. RO reject from this process was returned to the draw stream for using it again as a draw solution. From this integrated system, 97% of TDS can be removed from the diluted draw applied to the RO. Due to high water recovery and TDS removal; water can be reused for other purposes.

VII. CONCLUSION:

From this work we concluded:

- Rejection of solutes from the applied wastewater sample is highly dependent on the concentration of draw solution used.
- Low fouling of membrane is the major benefit of the FO process therefore ultimately this integrated process is being proved as cost-beneficial process.
- FO needs very low energy as it works on the natural osmosis principle and it is efficient in rejection of solutes therefore we can also conclude that the FO process is an energy beneficial process.
- FO-RO coupled process is very efficient when water recovery is the main aim. As per the analysis that was been done in this work, FO-RO integrated process is a great approach in the zero liquid discharge or minimal liquid discharge areas.

REFERENCES

i. Tzahi Y. Cath, Amy E. Childress, Menachem Elimelech “Forward osmosis: principles, applications and recent developments” Journal of membrane science 281 (2006), 70-87.

ii. Sherub Phuntsho, Ho Kyong Shon, Seungkwan Hong, Sangyoup Lee, Saravanamuthu Vigneswaran “A novel low energy fertilizer driven forward osmosis desalination for direct fertigation: Evaluating the performance of fertilizer draw solutions” Journal of Membrane Science 375 (2011), 172-181.

iii. Shuaifei Zhao, Linda Zou, Chuyang Y. Tang, Dennis Mulcahy “Recent developments in forward osmosis: Opportunities and challenges” Journal of membrane science 396 (2012), 1-21.

iv. Tai-Shung Chung, Xue Li, Rui chin Ong, Qingchun Ge, Honglei Wang and Gang Han “Emerging forward osmosis (FO) technologies and Challenges ahead for clean water and clean energy consumption”Current Openion in Chemical Engineering 1(2012), 246-257.

v. Keri L. Hickenbottom, Nathan T. Hancock, Nathan R. Hutchings, Eric W. Appleton, Edward G. Beaudry, Pei Xu, Tzahi Y. Cath "Forward osmosis treatment of drilling mud and fracturing wastewater from oil and gas operations" Desalination 312 (2013), 60-66.

vi. Keri L. Hickenbottom, Nathan T. Hancock, Nathan R. Hutchings, Eric W. Appleton, Edward G. Beaudry, Pei Xu, Tzahi Y. Cath "Forward osmosis treatment of drilling mud and fracturing wastewater from oil and gas operations" Desalination 312 (2013), 60-66.

vii. Kerusha Lutchmiah, A.R.D. Verliefde, K. Roest, L.C. Rietveld, E.R. Cornelissen "Forward osmosis for application in wastewater treatment: A review" Water research 58 (2014), 179-197.

viii. Bryan D.Coday, Pei Xu, Edward G. Beaudry, Jack Herron, Keith Lampi, Nathan T. Hancock, Tzahi Y. Cath "The sweet spot of forward osmosis: treatment of produced water, drilling wastewater, and other complex and difficult liquid streams" Desalination 333 (2014), 23-35.

ix. Gang Han, Can-Zeng Liang, Tai-Shung Chung, Martin Weber, Claudia Staudt, Christian Maletzko "Combination of forward osmosis (FO) process with coagulation flocculation (CF) for potential treatment of textile wastewater." Water Research 91 (2016), 361-370.

x. Yan Sun, Jiayu Tian, Zhiwei Zhao, Wenxin Shi, Dongmei Liu, Fuyi Cui "Membrane fouling of forward osmosis (FO) membrane for municipal wastewater treatment: A comparison between direct FO and OMBR" Water research (2016).

xi. Seetha S Manickam, Jeffrey R. McCutcheon "Understanding mass transfer through asymmetric membranes during forward osmosis: A historical perspective and critical review on measuring structural parameter with semi-empirical models and characterization approaches" Desalination 421(2017), 110-126.

xii. Siavash Darvishmanesh, Brian A. Pethica, Sankaran Sudaresan "Forward osmosis using draw solutions manifesting liquid-liquid phase separation" Desalination 421(2017), 23-31.

xiii. Jiaqi Huang, Qingwu Long, Shu Xiong, Liang Shen, Yan Wang "Application of poly (4-styrenesulfonic acid-co-maleic acid) sodium salt as novel draw solute in forward osmosis for dye-containing wastewater treatment" Desalination 421(2017), 40-46.

xiv. A. Haupt, A. Lerch "Forward osmosis treatment of effluents from dairy and automobile industry – results from short-term experiments to show general applicability" Water Science & Technology 78(3-4), 467-475.

xv. Mattia Giagnorio, Francesco Ricceri, Alberto Tiraferri "Desalination of brackish groundwater and reuse of wastewater by forward osmosis coupled with nanofiltration for draw solution recovery" Water Research 153(2019), 134-143.

xvi. Meng Li, Kun Li, Lianjun Wang, Xuan Zhang "Feasibility of concentrating textile wastewater using a hybrid forward osmosis-membrane distillation (FO-MD) process: Performance and Economic evaluation" Water Research 172 (2020), 115488.

xvii. Jiandong Lu, Shijie You, Xiuheng Wang "Forward osmosis coupled with lime-soda ash softening for volume minimization of reverse osmosis concentrate and CaCO3 recovery: A case study on the coal chemical industry" Springer 15(1), 9.