Forward Osmosis Process for the Treatment of Wastewater from Textile Industries

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ABSTRACT

This paper was aimed to study the efficiency of forward osmosis (FO) process as a new application for the treatment of wastewater from textile effluent and the factors affecting the performance of forward osmosis process.

The draw solutions used were magnesium chloride ($MgCl_2$), and aluminum sulphate ($Al_2(SO_4)_3 .18 H_2O$), and the feed solutions used were reactive red, and disperse blue dyes.

Experimental work were includes operating the forward osmosis process using thin film composite (TFC) membrane as flat sheet for different draw solutions and feed solutions. The operating parameters studied were : draw solutions concentration (10 – 90 g/l), feed solutions concentration (5 – 30 mg/l), draw solutions flow rate (10 – 50 l/hr), feed solutions flow rate (20-60 l/hr), constant pressure and temperature were maintained at 0.5 bar and 30°C respectively. And includes operating the forward osmosis process using cellulose triacetate (CTA) membrane as flat sheet for different draw solutions and feed solutions. The operating parameters studied were : draw solutions concentration (10 – 90 g/l), and feed solutions concentration (5 – 30 mg/l), constant temperature at 30°C. It was found that water flux increases with increasing draw solution concentration, and feed solution flow rate and decreases with increasing draw solution flow rate and feed solution concentration for TFC and CTA. It was found $MgCl_2$ given water flux larger than Alum. And also found that reactive red given water flux larger than disperse blue.

The experiments also show that CTA membrane gives higher water flux than TFC membrane for forward osmosis operation. The increase in water flux for CTA is about 12.85% than TFC.

KEYWORDS: Forward Osmosis; Textile Wastewater; Membranes.

عملية التناضح الامامية لمعالجة مخلفات المياه من الصناعات النسيجية

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الخلاصة

يهدف هذا البحث الى دراسة كفاءة عملية التناضح الامامي كتطبيق جديد لمعالجة الفضلات الخارجة من الصناعات النسيجية والعوامل التي تؤثر على اداء عملية التناضح الامامي .
محاليل السحب المستخدمة هي : كلوريد المغنيسيوم و كبريتات الالمنيوم المائية و محاليل اللقيم المستعملة هي : الاحمر المتفاعل و الازرق المنتشر .
العمل التجريبي يتضمن تشغيل عملية التناضح الامامي باستخدام اغشية (TFC) على شكل صفيحة مستوية لمحاليل سحب مختلفة و محاليل لقيم مختلفة. العوامل التشغيلية التي تم دراستها : تركيز محاليل السحب (10-90غرام / لتر)، تركيز محاليل اللقيم (5-30ملغم / لتر) ، معدل الجريان الحجمي لمحاليل السحب (10-50لتر / ساعة) ، معدل الجريان الحجمي لمحاليل اللقيم (20-60لتر / ساعة). الضغط و درجة الحرارة ثابتين عند0.5 بار و30 ^{o}م على التوالي . وكذلك يتضمن تشغيل الوحدة التناضحية بأستخدام اغشية من نوع CTA على شكل صفيحة مستوية . العوامل التشغيلية التي تم دراستها : تركيز محاليل السحب (10-90 غرام / لتر) ، و تركيز محاليل اللقيم (5-30ملغم / لتر)عند درجة حرارة ثابتة30^{o} م.
لقد وجد بأن معدل تدفق الماء يزداد بزيادة تركيز محلول السحب و معدل الجريان الحجمي لمحلول اللقيم ويقل بزيادة معدل الجريان الحجمي لمحلول السحب و تركيز محلول اللقيم لكلا الغشائين (TFC) و(CTA) .

لقد وجد بان كلوريد المغنيسيوم يعطي معدل تدفق ماء اعلى من كبريتات الالمنيوم المائية . وايضا وجد بان الاحمر المتفاعل يعطي معدل تدفق ماء اعلى من الازرق المنتشر. اظهرت التجارب ايضا ان اغشية CTA تعطي معدل تدفق ماء اعلى من اغشية TFC في عمليات التناضح الامامي. ان الزيادة في معدل تدفق ماء لاغشية CTA تقريبا 12,85% من اغشيةTFC .

INTRODUCTION

The textile industry can be considered as one of the greatest consumers of water, due to high consumption necessary to adequately treat large quantities of effluents before their discharge to the environment. Some of these effluents are colored despite containing only small amounts of dyes. These dyes are toxic and, in most cases, are not biodegradable or their biodegradation is difficult and they resist well physico-chemical treatment method (Ulsonetal.,2009). Presence of very small amounts of dyes in water(less than 1 ppm for some dyes) is highly visible and undesirable therefore it is necessary to eliminate dyes from waste water before it is discharge (Maryam et al., 2008). Color is the first contaminant to be recognized in the wastewater and has to be removed before discharging into water bodies or on land (Abbas, 2005).

Complex aromatic structures of most dyes make it very difficult for conventional treatment methods such as activated sludge, ozonation and electrochemical techniques to be effective in achieving good color removal. However, excellent results were obtained using membrane processes which are proven to be very successful in removing the undesired color (Mohamed et al., 2007).

Membrane separation processes has the ability to clarify, concentrate and most importantly, to separate dye continuously from effluent (Adul Latif et al., 2002).

Membrane separation has gained increasing popularity in water, wastewater and many other industrial applications(Yuan et al., 2010). The separation of water from aqueous polymeric membranes has been solution usin studied intensely for the past half century. Over this time, pressure – driven membrane separations, namely microfiltration (MF) , ultrafiltration (UF), nanofiltration (NF), and reverse osmoses (RO) have become more popular as a viable separation technique for removing undesired solutes from a solution. These pressure – driven membrane process have been employed heavily in the field of water treatment using forward osmosis (FO) as an alternative to pressure – driven membrane process has been gaining some popularity in the last few years (Jeffry et al ., 2006). In FO the force for mass transport is the difference in osmotic pressure between the the feed solution and a draw solution, water diffuses from the feed solution of higher chemical potential (low osmotic pressure) to a draw solution of lower chemical potential (higher osmotic pressure). As water diffuse through the membrane the feed solution becomes concentration and the draw solution is diluted (Riziero et al., 2009). . The main objective of this work is to study the efficiency of forward osmosis (FO) process as a new application for the treatment of water from textile effluent. In this search using Alum and $MgCl_2$ as draw solution to extract water from textile effluent across a semi – permeable membrane ,and using reactive red and disperse blue dyes as feed solution (which are mainly used in Al-Hilla Textile Company).

EXPERIMENTAL

- **Draw Solution**

Deionized water of (8 – 20 μs/cm) conductivity was used for preparing aluminum sulphate ($Al_2(SO_4)_3 .18 H_2O$), magnesium chloride ($MgCl_2$) solutions which were used as draw solution. Table 1 shows draw solutions concentration and their conductivities at 30 °C temperature and chemical analysis of the draw solutions.

- **Feed Solution**

Deionzed water of 8 – 20 μs / cm conductivity, was used for preparing reactive red and disperse blue. These dyes represented the most commonly used in Al-Hilla. Textile Company as listed in Table 2.

Table1Chemical Specification of Draw solution

Properties	Substance
Magnesium Chloride $MgCl_2$= 95	Assay 98% Maximum limits of impurities (%) Sulfate 0.002 Copper 0.002 Lead 0.005 Iron 0.0005 Zinc 0.0005 Cadmium 0.005

Aluminum Sulphate ($Al_2(SO_4)_3 .18 H_2O$) = 666	Assay 98% Maximum limits of impurities (%) Chloride 0.005 Copper 0.005 Lead 0.0002 Iron 0.005 Zinc 0.005 Cadmium 0.005

Table 2 The wavelength and molecular weight of two dyes

Dye	Molecular Weight	Wavelength
reactive red	875.5	533
disperse blue	420	560

- **The Forward Osmosis Process**

Figure 1 describes the forward osmosis apparatus used in laboratory of chemical engineering department. The feed and draw solutions were pumped by means of a centrifugal pump to pass through channels of osmosis cell. The flow rate of draw and feed solutions was regulated by means of globe valve connected at the discharge of the pumps, and measure with a calibrated rotameters with range flow(3–60 l/hr). One pressure gauge is used in the feed solution. To indicate the feed solution pressure. Both the draw and feed solutions were held at the same temperature and flow rate during the FO tests. Concentration of dye was measured by spectrophotometer. While, the concentration of draw solution was measured by digital laboratory conductivity meter, a digital balance was used to measure the samples weight in experiment. The flat sheet module was designed to serve forward osmosis operation it has two symmetric flow channels on both side of the applied membrane. The diameter of each section is 15 cm it operates with two different streams on both sides of the types of membrane. In this study used two types of (TFC) and (CTA). Thin film composite membrane is an aromatic polyamide consisting of three layers: polyester support web, microporous polysulphone interlayer, and ultra thin polyamide barrier layer on the top surface. The thickness of CTA membrane is less than 50 μm and the structure of cellulose triacetate (CTA) forward osmosis membrane is quite different from standard reverse osmosis membranes. Reverse osmosis membrane typically consist of a very thin active layer (less than 1 µm) and a thick porous support layer.

- **Experimental Procedure**

Draw and feed solutions were prepared in vessels by dissolving the solid salt and solid dye in 25 liter of deionized water, the outlet valve of the feed vessels was open to let the solutions fill the whole pipes of the system. Both feed are fed to the membrane by a centrifugal pump. The feed and draw solution flow tangential to the membrane in the same direction (co – current flow). In the typical orientation of forward osmosis process, the draw solution is placed against the support layer and the feed solution is on the active layer. Through osmosis, water transports from the feed solution (low concentration) across membrane and into the draw solution (high concentration). For every five minute the conductivity (concentration) of draw solution is measured by conductivity meter and the Absorbency (concentration)of feed solution is measured by spectrophotometer. The water flux was calculated by dividing the permeate volume by the product of effective membrane area and time. After recording the results, the solution (remaining in feed vessel), was drained by means of a drain valve.

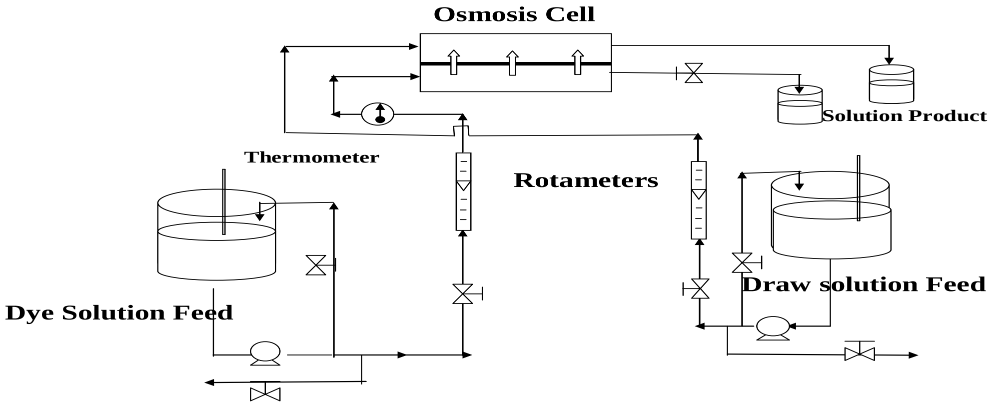

Fig. 1 Schematic Diagram of Forward Osmosis Process

RESULTS AND DISCUSSION

Effect of Thin Film Composite Membrane

The water flux calculated by dividing the volume of pure water which transfers from feed to draw solution on time and active area of membrane. The water flux increases with increasing draw solution concentration because the driving force (osmotic pressure of draw solution – osmotic pressure of dye) increased. An increase as demonstrated in Figure 2 for Magnesium chloride ($MgCl_2$) as draw solution at two types of feed solution. The solution of dye loses quantities of pure water and this leads to increased concentration of dye. The same quantities of pure water transferred across the membrane to the draw solution, as a result, decrease the concentration of draw solution. Thus, increases or decreases in concentrations of draw solution and dye are linked to each other. The effect of draw solution concentration on draw solution outlet concentration (C_{do}) is shown in Figure3. Figure 4 show the effect of draw solution concentration on feed solution outlet concentration(C_{Fo}) at two types of feed solution. Figure 5 show the effect of the types of draw solution on water flux , $MgCl_2$ has a high water flux because it has high osmotic pressure (driving force) than Alum. Increasing of osmotic pressure of draw solution will increase the driving force ($\Delta\pi$) for water flux. At the same concentration of draw solutions, osmotic pressure depends on the molecular weight of solute, and number of dissociates. The increase in water flux resulted from Red is larger than Blue because it has low osmotic pressure (driving force) than Blue. By increasing feed solution concentration (C_{Fi}) driving force decreases. This appears as a decrease of water flux through the membrane. The water flux decreasing with increasing feed solution concentration because the driving force (osmotic pressure of draw solution – osmotic pressure of dye) decreased. This is shown in Figures 6, and 7 for Red and Blue as feed solution at two types of draw solution. Increasing the draw solution flow rate (Q_d) prevents the concentration buildup in the solution at the vicinity of the membrane surface (support layer), and resulting in decreasing the driving force. Thus , water flux decreased with increasing the flow rate .This is shown in Figure 8. Increasing the feed solution flow rate prevents the concentration buildup in the solution at the vicinity of the membrane surface (Active layer), leading to increase a driving force($\Delta\pi$).This behavior contradicts the case of increasing the draw solution flow rate.

Figure 9 show the effect of feed solution flow rate on water flux .

Effect of Cellulose Triacetate Membrane

By increasing the concentration of draw solution, osmotic pressure difference increases and then the driving force increases, this leads to an increase in water flux, inversely when increasing the feed solution concentration osmotic pressure difference ($\Delta\pi$) decreases. This appear as a decreasing in water flow through membrane. This shown in Figures 10, 11, 12, and 13. The effect of feed and draw solution concentrations on the draw solution outlet concentration and feed solution outlet concentration are shown in Figures 14, 15, 16, and 17. Generally , any membrane consists of two layers : active layer and support layer. In RO which operates at high pressure it needs membrane with very thick support layer to withstand this pressure but FO which operates at low or no hydraulic pressure it needs membrane with very thin support layer. Because CTA membrane has thickness less than that of TFC membrane, it is found that for forward osmosis operation CTA membrane is more suitable than TFC membrane. CTA membrane was designed to operate for forward osmosis operation. This can be shown in Figure 18.

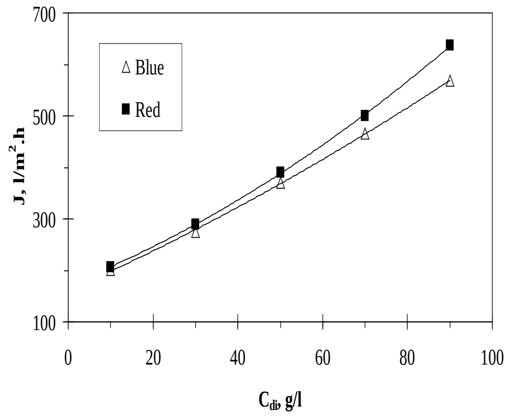

Fig. 2 Water flux with $MgCl_2$ concentration for different types of feed solution (C_{Fi}= 30 mg/l, Q_d = 50 l/hr, Q_F=60 l/hr, p = 0.5 bar).

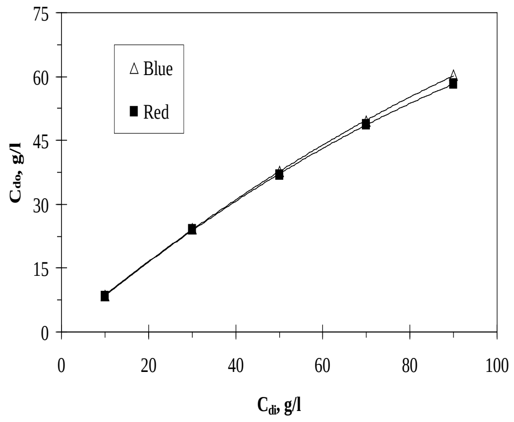

Fig. 3 Draw solution outlet concentration with $MgCl_2$ concentration for different types of feed solution (C_{Fi}= 30 mg/l, Q_d = 50 l/hr, Q_F=60 l/hr, p = 0.5 bar).

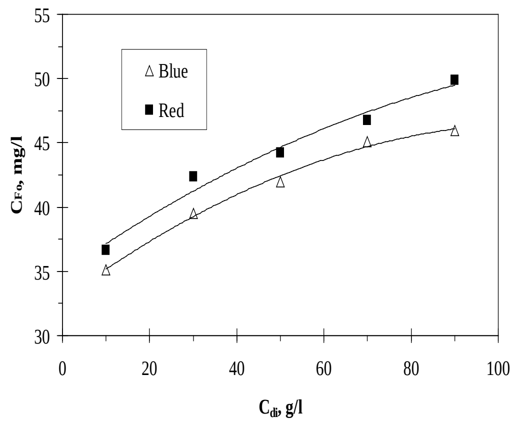

Fig. 4 Feed solution outlet concentration with $MgCl_2$ concentration for different types of feed solution (C_{Fi}= 30 mg/l, Q_d = 50 l/hr, Q_F=60 l/hr, p = 0.5 bar).

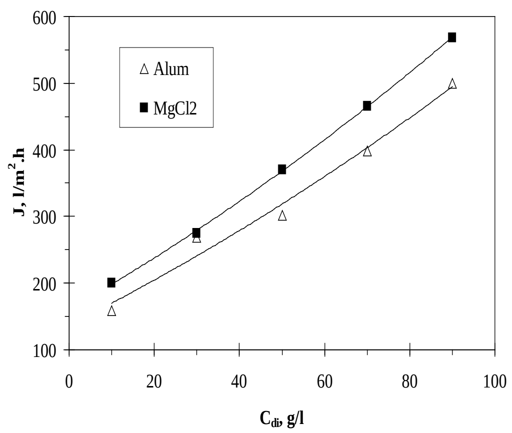

Fig. 5 Water flux with draw solution concentration at feed solution(Blue) (C_{Fi}= 30 mg/l, Q_d = 50 l/hr, Q_F=60 l/hr, p = 0.5 bar).

Fig. 6 Water flux with Red concentration for different types of draw solution (C_{di}= 30 g/l, Q_d= 50 l/hr, Q_F=60 l/hr, p = 0.5 bar).

Fig. 9 Water flux with Red flow rate for different types of draw solution (C_{Fi}= 30 mg/l, C_{di}=30 g/l, Q_d= 50 l/hr, p = 0.5 bar).

Fig. 7 Water flux with Blue concentration for different types of draw solution (C_{di}= 30 g/l, Q_d= 50 l/hr, Q_F=60 l/hr, p = 0.5 bar).

Fig. 10 Water flux with Alum concentration for different types of feed solution (C_{Fi}= 30 mg/l, Q_d = 50 l/hr, Q_F=60 l/hr).

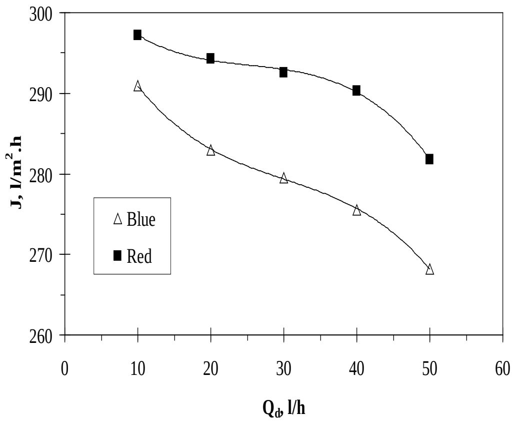

Fig. 8 Water flux with Alum flow rate for different types of feed solution (C_{Fi}= 30 mg/l, C_{di} = 30 g/l, Q_F=60 l/hr, p = 0.5 bar).

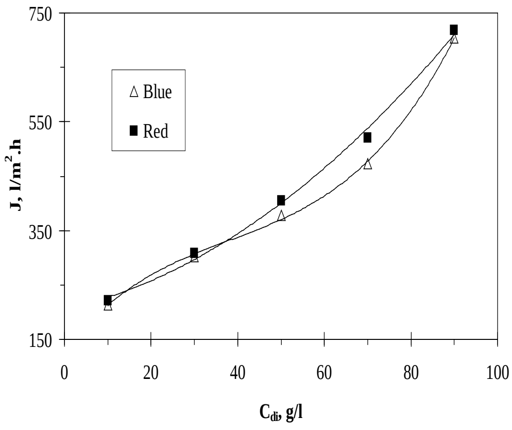

Fig. 11Water flux with $MgCl_2$ concentration for different types of feed solution (C_{Fi}= 30 mg/l, Q_d = 50 l/hr, Q_F=60 l/hr).

Fig. 12Water flux with Blue concentration for different types of draw solution (C_{di}= 30 g/l, Q_d= 50 l/hr, Q_F=60 l/hr).

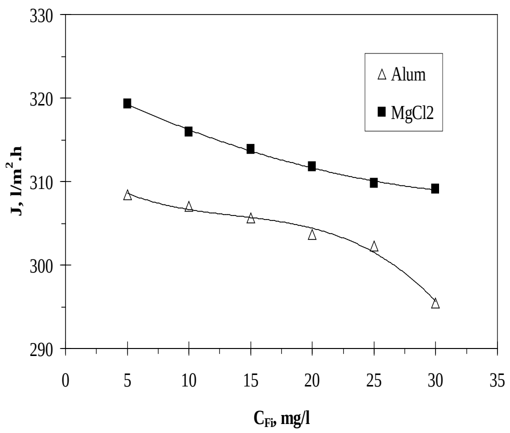

Fig. 13Water flux with Red concentration for different types of draw solution (C_{di}= 30 g/l, Q_d= 50 l/hr, Q_F=60 l/hr).

Fig. 14 Draw solution outlet concentration with $MgCl_2$ concentration for different types of feed solution (C_{Fi}= 30 mg/l, Q_d = 50 l/hr, Q_F=60 l/hr).

Fig. 15 Draw solution outlet concentration with Red concentration for different types of draw solution (C_{di}= 30 g/l, Q_d= 50 l/hr, Q_F=60 l/hr).

Fig. 16 Feed solution outlet concentration with $MgCl_2$ concentration for different types of feed solution (C_{Fi}= 30 mg/l, Q_d = 50 l/hr, Q_F=60 l/hr).

Fig. 17 Feed solution outlet concentration with Red concentration for different types of draw solution (C_{di}= 30 g/l, Q_d= 50 l/hr, Q_F=60 l/hr).

Fig. 18 Water flux with $MgCl_2$ concentration for different types of membrane (C_{Fi}(Red)= 30 mg/l, Q_d = 50 l/hr, Q_F=60 l/hr).

CONCLUSION

- Forward osmosis can be used for the treatment of wastewater from textile industries.
- the draw solutions can be used as coagulants in coagulation-flocculation process which use in water treatment unit.
- The water flux produced from the osmosis cell increases by increasing the concentration of draw solutions and increasing the flow rate of feed solution and decreases by increasing the concentration of feed solution and increasing the flow rate of draw solutions.
- For two types of draw solutions with the same concentration , the water flux is limited by the molecular weight and number of dissociates. Thus, $MgCl_2$ given water flux higher than Alum.
- For two types of feed solution with the same concentration, the water flux is limited by the molecular weight. Reactive red given water flux higher than disperse blue.
- CTA membrane gives higher water flux than TFC membrane. Therefore CTA membrane is more suitable than TFC membrane for forward osmosis operation.

REFERENCES

- Abbas, H.B, 2005, “Removal of Dyes from Wastewater of Textile Industries Using Activated Carbon and Activated Alumina” M.Sc. thesis, Baghdad University.
- Abdul Latif Ahmad, Wan Azlina , Syafiie, and Ooi Boon, 2002, “ removal of dye from wastewater of textile industry using membrane technology ” , Journal Teknologi, 31-44.
- Jeffrey, R., Robert, L., and Menachem, E., 2006, “Influence of concentrative polarization on flux behavior in forward osmosis ”, Journal of Membrane Science, (278), 114-123.
- Mohamed Al-Aseeri, Qais Bu-Ali, Shaker Haji,And Nader Al-Bastaki, 2007, “Removal of acid red and sodium chloride mixtures from aqueous solutions using nanofiltration ”, Desalination, (206), 407-413.
- Maryam Hasani ,Mohammed Reza ,and Mokhtar Arami, 2008, “Removal of acid red 398 dye from aqueous solutions by coagulation –flocculation process ” Gheorghe Asachi Technical University of lasi, Vol.7, No.6, 695-699.
- Riziero Martinetti, Amy E. Childress, Tzahi Y. Cath, 2009, “High recovery of concentrated RO brines using forward osmosis and membrane distillation ”, Journal of Membrane Science , (331), 31–39.
- Ulson, A. De souza, petrus, J, Santos, F.p. , Brandao, H.L., Guelliu. Souza and Juliano, L.N., 2009, “Color reduction in textile effluents by membranes”, Latin American Applied Research, (39), 47-52.
- Yuan Xu , Xiaoyu Peng, Chuyang, Y., Tang, Q., Shiang, Fu., and Shengzhe Nie., 2010,“ Effect of draw solution concentration and operating conditions on forward osmosis and pressure retarded osmosis performance in a spiral wound module”, Journal of Membrane Science, 298–309.

NOMENCLATURE

Symbol	Definition	Units
C_{di}	Draw solution concentration	g/l
C_{do}	Draw solution outlet concentration	g/l
C_{Fi}	Feed solution concentration	mg/l
C_{Fo}	Feed solution outlet concentration	mg/l
J	Water flux	$l/m^2.hr$
P	Pressure	bar
Q_d	Draw solution flow rate	l/hr
Q_F	Feed solution flow rate	l/hr
T	Temperature	^0C

ABBREVIATIO

Symbol	Definition
Alum	Aluminume sulphate
Blue	Disperse blue
CTA	Cellulose triacetate
FO	Forward osmosis
MF	Microfiltration
Red	Reactive red
RO	Reverse osmosis
TFC	Thin film composite
UF	Ultrafiltration