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The Applications of Membrane Operations in the Textile Industry: A Review

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Authors' contributions

This work was carried out in collaboration between both authors. AG designed the study and wrote the first draft of the manuscript. AO managed the literature searches. Both authors read and approved the final manuscript.

Review Article

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ABSTRACT

Water reuse continues to rise as demand for fresh water supplies increases worldwide. By recycling and reusing treated wastewater, communities and industries can save on the costs of clean water, ensure adequate supplies and help to preserve a diminishing natural resource. The increase in water reuse has been driven largely by innovative treatment technologies that are both cost effective and reliable in removing harmful bacteria and pathogens. Membrane technology offers several varied applications covering many aspects of the textile processing. These applications are unique because they provide a return on investment (ROI) while abating a water pollution problem. This paper presents descriptions of some of the uses membranes have in textile operations and their benefits, it also delivers a scientific and technical overview and useful information to scientists and engineers who work in this field.

Keywords: Textile; membrane; microfiltration; ultrafiltration; nanofiltration; reverse osmosis.

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1. INTRODUCTION

Access to safe drinking water is a basic human need and a fundamental human right, crucial for poverty reduction. Even at that, 1000 million people worldwide live without access to drinking water and nearly 50% of them, suffer from health problems due to lack of safe drinking water sources and sanitation (Giwa et al., 2008). According to a report (United Nation, 2003), this situation forces people to consume water straight from rivers and ponds and represents a high risk to their health causing most of waterborne diseases as hepatitis, typhoid, cholera, diarrhea, dysentery, polio, trachoma and parasitic infections. Water pollution due to toxic organic compounds is a serious problem nowadays which has necessitated the legal regulations concerning disposal of chemicals into the natural environment being more and more restrictive (Pieter and Nazar, 2011). This problem also concerns the colored wastewaters (Giwa et al., 2006).

For the last two decades, engineering designers have been incorporating membranes into industrial water treatment systems to remove soluble ions. Industrial plants are expanding the use of membranes in water treatment applications as membrane technology becomes more robust. Membranes are replacing ion-exchange systems, filters, clarifiers, deaerators and wastewater bioreactors (Robert and Graeme, 2011).

This paper presents descriptions of some of the uses membranes have in textile operations and their benefits, it also deliver a scientific and technical overview and useful information to scientists and engineers who work in this field.

2. THE FUNDAMENTALS OF MEMBRANE TECHNOLOGY

The methods of purification of colored wastewaters can be generally divided in two groups: chemical (reduction, oxidation, ion exchange, neutralization) or physical (precipitation, adsorption, filtration, reverse osmosis (RO)) methods and biological methods (Giwa, 2009; Giwa et al., 2011a; Mohamed, 2011). Pressure driven membrane processes, like microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and RO have found numerous applications in water treatment and wastewater purification for many years (Curcio et al., 2010; Molinary et al., 2010). Separation by a membrane is achieved by creating a boundary between different bulk gas or liquid mixtures. As different solvents and solutes flow through a membrane at different rates, separation is achieved as shown in Fig. 1.

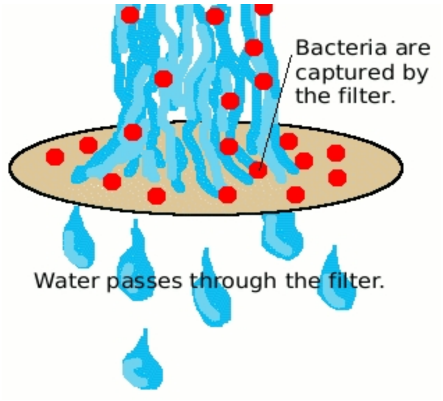

Fig. 1. Membrane filtration process

The spiral wound membrane element configuration (Fig. 2) is the most widely used due to its high packing density and relatively low price. A sandwich consisting of two membrane sheets with an inserted permeate carrier is glued together and to complete the membrane package a feed spacer is inserted between the opposing membrane surfaces. The membrane package is wound around a perforated central tube through which the permeate exits the element. The physical shape of a membrane element is secured by applying a suitable outer wrap. The physical and chemical properties of the various materials, including the membrane, are chosen according to the operating parameters.

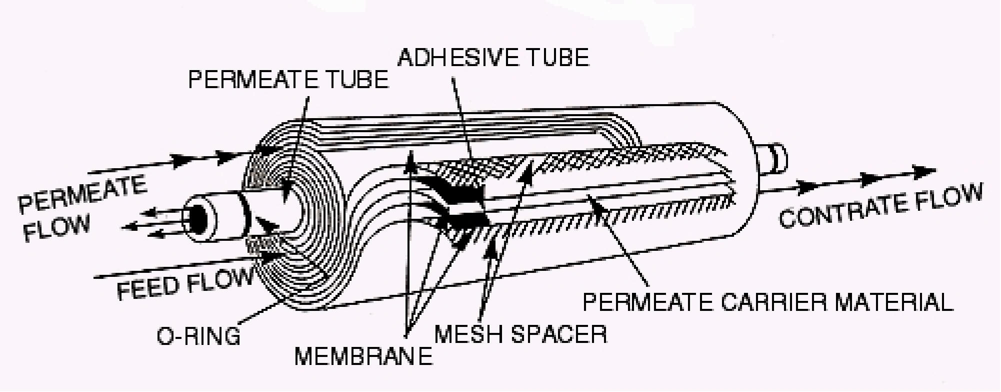

Fig. 2. A spiral-wound membrane

Membrane systems have several advantages. They are compact and modular in addition to their high selectivity (that can provide substance concentrations as low as parts per billion) and low energy consumption. Therefore, membrane units can relatively easily be implemented on existing production sites (Mahmoud, 1997). Furthermore, modern membranes present high resistance to heat, to acid and alkaline conditions, to a number of other aggressive chemicals and to micro-organisms (Mattioli et al., 2002). Membrane processes do not destroy pollutants, they only separate them into permeate and concentrate. It is possible to clarify, to concentrate, and to separate a diluted dye stream continuously from an effluent by membrane filtration.

Membrane technology (or membrane filtration) covers four different membrane groups: Microfiltration, Ultrafiltration, Nanofiltration and Reverse Osmosis depending on the rejection capability of the membrane. Figure 3 depicts the Membrane Filtration Spectrum. A difference in pressure between the two sides of the membrane is the driving force for the separation of all mentioned membrane types (Scott, 1998). The term “membrane operation” is used rather than the term “membrane process”. In general, a process is supposed to consist of two or more operations. A membrane operation is here defined as an operation where a feed stream is divided into two streams; permeate containing substances that have passed through the membrane and a concentrate containing the non-permeating substances (Peter, 1996).

Membrane technology is widely accepted as a means of producing various qualities of water from surface water, well water, brackish water and seawater. Membrane technology is also used in industrial processes and in industrial wastewater treatment, and lately membrane technology has moved into the area of treating secondary and tertiary municipal wastewater and oil field produced water. In many cases one membrane process is followed by another with the purpose of producing water of increasing purity and quality for various purposes.

One type of membrane may thus enhance the function of another to meet goals ranging from disposal of wastewater to production of drinking water from unexpected sources. In this way membrane technology offers the possibility of managing the total water resources in a region, which is of special interest in geographical areas where the natural water resources are scarce.

Membrane technology has thus emerged as a feasible alternative to conventional treatment processes of dye wastewater and has proven to save operation costs and water consumptions by water recycling (Sójka-Ledakowicz et al., 1998; Koyunco et al., 2001; Koyunco et al., 2004). Usually this technique is applied as a tertiary/final treatment after biological and/or physical-chemical treatments (Ciardelli et al., 2000; Marcucci et al., 2001). It has also been used to concentrate and purify dyes in the manufacture of these compounds (Crossley, 2002; Koyuncu et al., 2004). These techniques allow, when not applied as end-of-pipe solutions, the recovery and reuse of some reagents (Sójka-Ledakowicz et al., 1998; Koyuncu et al., 2001; Marcucci et al., 2001; van der Zee et al., 2003). The existing types of filtration are shown and characterized in Fig. 3.

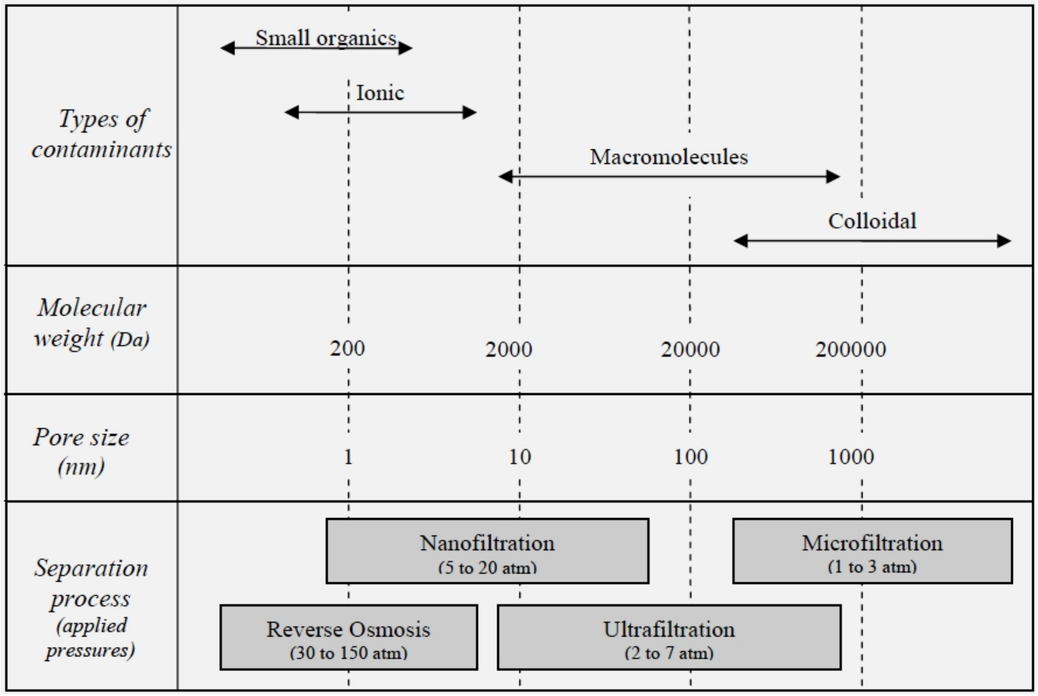

Fig. 3. Membrane filtration spectrum

2.1 Pressure Driven Membrane Operations

This is traditionally divided into four different types:

> Microfiltration is a way of removing contaminants in the size range of 0.1 to 10.0 µm from fluids or gases by passage through a microporous medium such as a membrane. There are two techniques used in microfiltration: dead-end filtration, where microfiltration is widely used and cross-flow filtration, using a tangential flow

for the fluid being filtered. Larger colloidial particles, bacterial iron, bacterial reduction, algae and limited viruses typically 5 microns to 0.1 micron.

Ultrafiltration is a process similar to microfiltration. The main difference is the "tighter" retention behavior: the ultrafiltration membrane retains much smaller particles from passage through the membrane than does microfiltration membranes. Typically the particle size is measured by molecular weight and ultrafiltration membranes have retention ranges from 1,000 to 1,000,000 molecular weight. There is excellent reduction of colloidal properties, viruses, endotoxin, pyrogen and VOC and TOC to typically between 0.1 to 0.05 microns. It comes in “Dead End” or Crossflow configurations.

Nanofiltration is a process similar to microfiltration. It is applied when separation in the area between RO and UF membranes is required and high sodium rejection is not needed, but where other salts such as Mg and Ca (i.e. divalent ions) or ions from solutes such as small molecules of sugar are to be removed including hardness reduction, TOC, VOC, endotoxin, and pyrogen typically 0.01 to 0.001 micron.

Reverse osmosis (RO) is typically used for separation of dissolved salts and other ionic solutes from solution; normal RO operation pressure is from 15 to 75 bars. In some applications of high salt concentration and high osmotic pressure, RO of up to 150 bar is used.

Membrane filtration of rinsing water has been investigated in parallel projects (Koltuniewicz, 2010; Gray et al., 2011; Hashim et al., 2010; Qiang et al., 2011; Fu et al., 2011). It is documented that this technology is able to separate dissolved components from water and implies opportunities for producing clear hot water for reuse. Thus membrane filtration can imply savings in water, chemicals and production time, and also can give large savings on energy (Mattioli et al., 2002; Scott, 1998).

2.2 Other Types of Membrane Operations

2.2.1 Pillow-shaped membranes

Membranes that consist of flat plates are called pillow-shaped membranes. The name pillow-shaped membrane comes from the pillow-like shape that the two membranes have when they are packed together in a membrane unit. Inside the ‘pillow’ is a supporting plate, which attends solidity. Within a module, multiple pillows are placed with a certain distance between them, which depends on the dissolved solids content of the wastewater. The water flows through the membranes inside out. When treatment is done, the permeate is collected in the space between the membranes, where it is carried away through drains.

2.2.2 Tubular membranes

Tubular membranes are not self-supporting membranes. They are located on the inside of a tube, made of a special kind of material. This material is the supporting layer for the membrane. Because the location of tubular membranes is inside a tube, the flow in a tubular membrane is usually inside out. The main cause for this is that the attachment of the membrane to the supporting layer is very weak. Tubular membranes have a diameter of about 5 to 15 mm. Because of the size of the membrane surface, plugging of tubular membranes is not likely to occur. A drawback of tubular membranes is that the packing density is low, which results in high prices per module.

2.2.3 Capillary membranes

With capillary membranes, the membrane serves as a selective barrier, which is sufficiently strong to resist filtration pressures. Because of this, the flow through capillary membranes can be both inside out and outside in. The diameter of capillary membranes is much smaller than that of tubular membranes, namely 0.5 to 5 mm. Because of the smaller diameter the chances of plugging are much higher with a capillary membrane. A benefit is that the packing density is much greater.

2.2.4 Hollow fiber membranes

Hollow fiber membranes are membranes with a diameter of below 0.1 µm. consequentially, the chances of plugging of hollow fiber membranes are very high. The membranes can only be used for the treatment of water with a low suspended solids content. The packing density of a hollow fiber membrane is very high. Hollow fiber membranes are nearly always used merely for nano filtration and Reverse Osmosis (RO).

2.3 Membrane Fouling

Fouling is probably the most frequently encountered problem with membrane processes, and especially with processes involving liquid feeds. SM's e-Home (2012) defined fouling as the coating of the membrane surface or blocking of the pores with a solid or gelatinous material which creates a barrier through which the permeating components must pass. The effective pore size distribution of the membrane is reduced. The net effect of blockage is to reduce the flux passing through the membrane.

Fouling materials can enter the module in the feed as particulates, gels or soluble, high molecular weight species, or they may precipitate from solution as part of the feed permeates. Because there is a flux towards the membrane surface, caused by the flow of materials through the membrane, these fouling substances tends to migrate towards the membrane surface.

However, fouling can be reduced by:

- Pre-filtration of feed to remove concentration of particles, gels, etc before entering a module. Relatively simple dead-end filtrations are often used.
- Choice of proper form of membrane module, e.g. hollow-fibre is most susceptible while plate-and-frame configurations are the least.
- Maintaining high velocities on the feed side of the membrane, without exceeding the module's velocity limit.

2.4 Membrane Module Selection

The types of modules generally used in some of the major membrane processes are listed in Table 1.

Table 1. Types of modules in major membrane processes

S/No.	Application	Module type
1	Reverse Osmosis: Seawater	Both hollow fine-fibres and spiral-wound modules
2	Reverse Osmosis: Industrial and brackish water	Spiral-wound modules used almost exclusively, fine-fibres too susceptible to scaling and fouling
3	Ultrafiltration	Tubular, capillary, and spiral-wound modules all used. Tubular generally limited to high fouling feeds (e.g. automotive paint) and spiral-wound to clean feeds(e.g. ultrapure water)
4	Gas Separation	Hollow fibre for high-volume applications with low-flux, low selectivity membranes in which concentrations polarization is easily controlled (e.g. nitrogen from air) Spiral-wound when fluxes are higher, feed gases more contaminated, and concentration polarization a problem (e.g natural gas separations, vapour permeation)
5	Pervaporation	Most evaporation systems are small so plate and frame were used. Spiral-wound and capillary modules are being introduced.

From: Table 3.8, "Membrane Technology and Applications", R.W. Baker, p.150

The choice of the most suitable membrane module type for a particular membrane separation must balance a number of factors, as shown in Table 2.

Table 2. Types of membrane module for specific membrane separation

S/No.	Parameter	Hollow fibres	Capillary fibres	Spiral-wound	Plate-and-frame	Tubular
1	Manufacturing costs ($/m^2)	2 – 10	5 – 50	5 – 50	50 – 200	50 – 200
2	Concentration polarization fouling control	Poor	Good	Moderate	Good	Very good
3	Permeate-side pressure drop	High	Moderate	Moderate	Low	Low
4	Suitability for high pressure operations	Yes	No	Yes	Marginal	Marginal
5	Limitation to specific types of membrane material	Yes	Yes	No	No	No

From: Table 3.7, "Membrane Technology and Applications", R.W. Baker, p.149

3. APPLICATIONS IN THE TEXILE INDUSTRY

3.1 Characterization of Textile Wastewaters

Wet processing in textile industry generates large amounts of wastewater whose pollution load arises not only from the removal of impurities from the raw materials themselves but also from the residual chemical reagents used for processing (Table 3), (Giwa et al., 2007a). The extreme diversity of raw materials and production schemes employed poses problems in assessing effluent characteristics and subsequently defining pollution control technologies (Giwa et al., 2011b). Colour is one of the major problems of these types of wastewaters. During textile processing, inefficiencies in dyeing result in large amounts of dyestuff being directly lost to the wastewater, which ultimately finds its way into the environment. The amount of dye lost is dependent upon the dye application class, varying from only 2% loss when using basic dyes to a 50% loss when certain reactive dyes are used (O'Neill et al., 1999; McMullan et al., 2001; Pearce et al., 2003).

Table 3. Major pollutant types in textile wastewater, chemical types and process of origin (adapted from Delée et al., 1998)

Pollutants	Chemical types	Process of origin
Organic load	Starches, enzymes, fats, greases, waxes, surfactants and acetic acid	Desizing, Scouring, Washing, Dyeing
Colour	Dyes, scoured wool impurities	Dyeing, Scouring
Nutrients (N, P)	Ammonium salts, urea, phosphate-based buffers and sequestrants	Dyeing
pH and salts	NaOH, mineral/organic acids, sodium chloride, silicate, sulphate, carbonate	Scouring, Desizing, Bleaching, Mercerising, Dyeing, Neutralisation
Sulphur	Sulphate, sulphite and hydrosulphite salts, sulphuric acid	Dyeing
Toxic compounds	Heavy metals, reducing agents (sulphide), oxidising agents (chlorite, peroxide, dichromate, persulphate), biocides, quaternary ammonium salts	Desizing, Bleaching, Dyeing, Finishing
Refractory organics	Surfactants, dyes, resins, synthetic sizes (PVA), chlorinated organic compounds, carrier organic solvents	Scouring, Desizing, Bleaching, Dyeing, Washing, Finishing

3.2 Overview of Textile Finishing Baths

The methodology required for integrated water management in a textile finishing company depends largely on the nature of the finishing operations and, consequently, on the composition of the finishing baths and wastewater (Giwa et al., 2005; Giwa et al., 2007b). The term 'finishing' covers pre-treatment as well as post-treatment of textiles (Centexbel, 2003). Pre-treatment includes many possible activities (desizing, boiling off, bleaching, etc.) on textiles in view of subsequent treatments. Also textile dyeing and printing are part of the textile finishing activities. Post-treatment comprises a series of finishing activities (other than dyeing) to obtain or improve textile properties. Examples are the softening of textiles, or treating textiles to become crease-proof, or fire-, water- and oil-resistant. The dyeing step has the largest risk for environmental pollution, because this step often requires high concentrations of organic dyes, additives and salts. Dyes can be classified on the basis of chemical structure or binding with the textile (AATCC, 1971). Dyes with the same structural formula can be used to dye different textiles with different techniques. Different types of dyes are basic (cationic) dyes, direct dyes, sulphur dyes, azoic dyes and ingrain dyes, vat dyes, acid dyes, mordant dyes and metalcomplex dyes; disperse dyes, reactive dyes, and pigments (Giwa et al., 2005). The application technique determines the composition of the dye bath. Hence, not only the dyes are needed for the dyeing process; additives such as surfactants and dispersing agents are also important. Salts are often used as a regulator for the reaction; depending on the mechanism, high or low salt concentrations are used in the dye bath. For vat dyeing, no salts are needed; reactive dyeing uses extremely high salt concentrations (up to 100 g/l); metal-complex dyeing and mordant dyeing use salt concentrations ranging from very low to high. A typical recipe for disperse dyeing would consist of the following components: foam reducing agent (on the base of mineral oil), organic complexing agent (for hardness ions and iron; example: modified Na-polyacrylate); acetic acid; mixture of aromatic hydrocarbons as egaliser; dispersing agent; disperse dyes; base; sodium hydrosulphite. Reactive dyeing usually requires a pre-treatment with a washing agent such as alkanolethoxylate, organic complexing agent, NaOH, hydrogen peroxide; the dye bath consists typically of two or three reactive dyes, dispersing agent, complexing agent and equalizer. The choice between chloride salts and sulphate salts is determined by cost and quality: although sulphates are more expensive, they are preferred because of the better quality.

Finally, it can be stated that a large diversity can be found in textile finishing baths. However, a significant fraction of organic compounds is always present; the inorganic fraction may range from absent to 10 wt%. All further considerations concerning treatment methodologies for an integrated water management system will take this range of concentrations into account.

3.3 Process Water Requirements

Apart from empirical rules of thumb and local standards (Rozzi et al., 1999), no guidelines for process water quality in the textile finishing industry exists. Therefore, requirements for process water in the textile industry depend on individual companies. A few basic conditions are related to water turbidity, which should be less than the turbidity of the ground water that is used as fresh water, and the water hardness, which should be in the normal range for relatively soft ground water (not more than 50–60 mg/l). Of course, all colours should be removed before reuse. Furthermore, no concentration of other components such as heavy metals can be allowed in the water cycle.

Numerous studies claim that water reclamation is feasible with pressure driven membrane technology, because these basic requirements are fulfilled for the obtained permeates (Akbari et al., 2002; Bes-Pia et al., 2002; Koyuncu, 2002; Marcucci et al., 2002; Tang and Chen, 2002). In these studies, a simple sequential treatment is suggested using a combination of traditional processes (coagulation/flocculation, adsorption, sand filtration) and membrane processes (ultrafiltration, nanofiltration, RO). A fraction of the treated water is lost in each of the treatment steps, and solid or liquid waste fractions are produced. Although experimental studies on the practical consequences of full scale water reuse in textile finishing are missing, it can be assumed that it is technically possible to provide reclaimed water leading to a similar quality of the end product, or even to quality improvement. Thus, it will be further assumed that the final water quality obtained using the processes described in the literature (ultrafiltration, nanofiltration, RO) is suitable for reuse.

3.4 Assessment of Integrated Water Management System Using Membrane Technology

A typical sequential treatment system for water reuse in a textile company making use of nanofiltration is represented in Fig. 4.

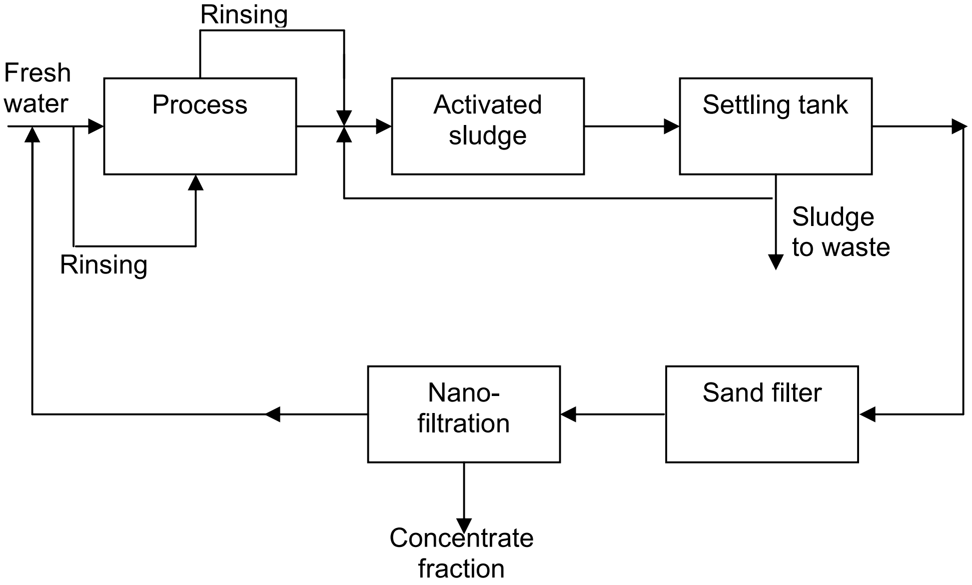

Fig. 4. Typical current methodology for water reclamation in a textile company

The nanofiltration is essentially an extension of the existing treatment system, opening the possibility of (partial) reuse of the process water. However, this methodology generates secondary waste fractions (excess sludge and the concentrate from the nanofiltration unit), and energy from hot process streams gets lost by dissipation in the different treatment steps. Although some attempts have been made to improve this scenario, the use of membrane processes in the textile industry is still limited to designs similar to Fig. 4. An important advance is the simultaneous reclamation of wastewater and energy, by applying membrane operations at elevated temperatures (Voigt et al., 2001). The objective of achieving an integrated zero discharge system has already been formulated using a combination of chemical, biological and membrane processes (Lee et al., 2001).

3.5 Textile Printing

The printing operation uses large quantities of water for washing the continuous rubber belt. The wastewater is ladened with fine pigments and polymeric binders giving the stream high colour and BOD. UF membranes remove the colour and the binder. The clean permeate has a 90% reduction in BOD and 100% reduction in colour. The water can be recycled back to the print machine for reuse. The best membrane for this application is the one inch FEG tube used in a modified batch mode. It readily handles the high viscosity at the end of the run. It can be mechanically cleaned with a sponge ball or pig and it has a long membrane life. Economics are based on the reuse of the water and reduction of BOD. Lower water costs are realized through reduced volumes to be purchased and treated and the lower BOD level can reduce fines and surcharges. A two year payback can be realized if the water and sewer costs are $10/1000 gal.

3.6 Scouring Operations

Scouring operations generate large BOD, oil and grease loadings on the sewer system. Heavy metals in cotton greige goods sometimes cause a problem also. Typically, these emulsions are stable and are hard to treat by traditional means. UF retains and concentrates the emulsion to 30-50% oil which can be economically hauled away. At these concentrations the O/W emulsion supports combustion and can be used as fuel. Heavy metals are reduced to their solubility limit, usually less than 1 ppm. Scouring operations are best with ceramic or hollow fibre membranes. The driving force in this application is pollution control. Water reuse of permeate is possible, along with the heat savings. Water reuse gives a two year payback if the water price is $6/1000 gal.

3.7 Dyestuffs and Dyebaths

Most dye baths have three major pollutants: the dye which presents an aesthetics problem in waters used for recreation, heavy metals incorporated in the dye, and the salt which can present a toxicity problem when discharged to small streams. UF is capable of completely separating many dyes such as: vat, acid, premetallized, dispersed and direct dyes from the brine. Some dye manufacturers use UF to wash excess salt out of the dyes. NF can be used to separate fibre reactive dyes and cationic dyes from the salt. The salt is recovered for reuse, and the dye can be discarded. Cost savings are generated from the reuse of the salt, reuse of the water (less water purchased, lower sewer charges), recovery of heat from the water and the value of the dyes if the dye is reused. Salt recovery from the dyebath alone has 50% returns on investment while reducing 99% salt toxicity by about 75%. A system to remove colour and recover salt from fibre reactive dyeing has a two year payback if the water price including purchase, sewer charges and fines is $5/1000 gal.

3.8 Latex Recovery

Latex is an expensive material used as the binder in carpet manufacturing. In general, latex is mixed with an extender such as calcium carbonate. The waste stream is too dilute to reuse and is discarded causing an aesthetics and BOD/COD problem. Latex recovery by UF is a standard operation for the many latex manufacturers and users. Latex recovery produces several principal benefits. Two benefits are: decreased purchase of latex and BOD reduction. The permeate is laden with surfactant, making excellent process or cleaning water. A two year payback from latex recovery is possible from a 0.5% latex waste stream.

3.9 Size Recovery

PVA size recovery has long been used in large, integrated weaving plants to recover and concentrate the size from the desizing bath. Size recovery can be used economically on small streams to remove the size from desizing baths. The size can be reused in-house or sold to a nearby weaving company. As a last resort, the size can be hauled off as waste. The hot permeate can be recycled back to the desizing bath. Poly(acrylic acid) and polyester sizes can be recovered this way also. Cost savings are generated from lower PVA purchases, lower BOD surcharges, heat recovery, and water reuse. In most cases, the recovered size may be reusable. If the size is sold to a weaving company, this eliminates hauling costs and improves the return on investment for an integrated weaving company practicing size recovery, the payback is several months.

3.10 Indigo Dye Recovery

Indigo dye is only 80% fixed onto the fabric with the remainder being washed away. In the quinone form it is highly insoluble in water and can be readily concentrated by UF. The concentrate can be blended with fresh Indigo, reduced with hydrosulfite and caustic and reused. It has exceptionally long life of several years. The high cross flow velocity gives high stable fluxes keeping system and operating cost low. The typical payback on a continuous rope dyeing operation is about one year or less.

3.11 Water Softening

Nanofiltration is an excellent alternative to ion exchange or green sand water softening. Many communities use NF to soften, decolorize and eliminate bacteria and viruses from the drinking water supply. The principal advantages are low maintenance, no regeneration costs, and low discharge volume.

3.12 Feed Water Pretreatment

Water quality is paramount in high quality dyeing operations. Hollow fibre UF removes colour bodies which interact with the dye and compete for sites on the cloth. It also removes the colloidal material which causes spotting. In this way a higher consistency dyehouse operation can be maintained.

4. CONCLUSION

The textile industry is advancing toward a more closed operation. Strategically, membrane systems will play an important role in recovering chemicals which used to go to the sewer, and in providing the high quality water needed to produce top quality goods. In conclusion, the following suffices:

- Because membrane processes can separate at the molecular scale up to a scale at which particles can actually be seen, this implies that a very large number of separation needs might actually be met by membrane processes.
- Membrane processes generally do not require a phase change to make a separation (with the exception of pervaporation). As a result, energy requirements will be low unless a great deal of energy needs to be expended to increase the pressure of a feed stream in order to drive the permeating component(s) across the membrane.
- Membrane processes present basically a very simple flowsheet. There are no moving parts (except for pumps or compressors), no complex control schemes, and little ancillary equipment compared to many other processes. As such, they can offer a simple, easy-to-operate, low maintenance process option.
- Membranes can be produced with extremely high selectivity for the components to be separated. In general, the values of these selectivities are much higher than typical values for relative volatility for distillation operations.
- Because of the fact that a very large number of polymers and inorganic media can be used as membranes, there can be a great deal of control over separation selectivity.
- Membrane processes are able to recover minor but valuable components from a main stream without substantial energy costs.

- Membrane processes are potentially better for the environment since the membrane approach require the use of relatively simple and non-harmful materials.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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