MANUAL ON

RECOVERY OF WATER FROM TREATED EFFLUENT FROM TEXTILE FACTORIES IN BANGLADESH

Prepared for

PROMOTING SUSTAINABILITY IN THE TEXTILE AND GARMENT INDUSTRY IN ASIA (FABRIC)
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FOREWORD

This document is meant for providing an overview of options for recovery of clean water from treated effluent from textile industries of Bangladesh. Bangladesh witnessed rapid industrial growth in the past decades and consumption of water, an important raw material, increased many folds. Bulk of the industry is consuming groundwater for its operations and the over-exploitation resulted in the ground water table going down alarmingly. Since this industry is expected to continue its tremendous growth rate in coming year, additional consumption of water can be expected, even as the present water availability is dwindling fast.

On the other side, in spite of establishing good effluent treatment plants, public complaints about the industry had only gone up. This may be due to the fact that bulk of the treated effluent is discharged into one river and the localised impact is quite high.

It is quite clear that in-order to sustain the industry and continue its growth, water security of the industry need to be ensured. One of the options considered by the industry to manage the issue is recovery of clean water from treated wastewater, considering the fact the textile industry of neighbouring India has been practicing the same with zero liquid discharge (ZLD) concept for over a decade. However, many fear that adoption of ZLD may jeopardise the growth of this industry considering its technical/managerial/logistical/economic challenges. Their suggestion is to consider ZLD in stages and start with partial recovery options.

This document is expected to provide the basic information enabling the stakeholders to assess the viability of effluent recovery. The first 11 chapters deals with the technical details of effluent recovery with some results obtained so far from similar projects as well as the financial aspects. The chapters 12-16 deals with viability challenges and policy requirements needed for implementation of effluent recovery in Bangladesh in a sustainable manner.

The recommendations made herein are based on the views of this author, which may not necessarily be shared by GIZ and author assume complete responsibility for any suggestions and statements made.

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List of Important Abbreviations

APHA	American Public Health Association
BOD	Biological Oxygen Demand
Cm	Centimeters
COD	Chemical Oxygen Demand
CO_2	Carbon dioxide
DO	Dissolved Oxygen
DoE	Department of Environment
ECA	Environment Conservation Act
EC	Environmental Clearance
ECR	Environment Conservation Rules
ETP	Effluent Treatment Plant
GDP	Gross domestic product
GIZ	German International Cooperation
HP	Horsepower
HRT	Hydraulic Retention Time
IEC	International Electrotechnical Commission
Kg	Kilogram
Hrs.	Hours
L, l, lit	Litres
M, Mts	Meters
m/s	Meters per second
µ	Microns
MBR	Membrane Bioreactor
m^2	Square Meter
m^3	Cubic meter
MLSS	Mixed Liquor Suspended Solids
µg/lit	Micrograms per litre
Mm	Milli metre
MOEF	Ministry of Environment and Forests
O & M	Operation & Maintenance
Ppm	Parts per million
PVC	Poly Vinyl Chloride
PTZ	Pan, Tilt, Zoom
RAS	Return activated Sludge
RMG	Ready Made Garments
RPM	Revolutions per Minute
RT-EQMS	Real Time Effluent Quality Monitoring System
S, Sec	Seconds
SMS	Short Messaging Service
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UV	Ultra violet
V	Volt
WAS	Waste activated sludge
ZDHC	Zero Discharge of hazardous Chemicals

1 INTRODUCTION

1.1 Background of the industry in Bangladesh

Industry accounts for about 31% of the total 350 billion dollar GDP of Bangladesh. Major industries include:

- Textile industry
- Pharmaceutical industry,
- Shipbuilding industry,
- Information technology,
- Leather industry,
- Steel and light engineering industry.

Though textile industry was a major industry in Bangladesh from early 90's, an exponential growth of the industry occurred in the past two decades. About 15-20% of GDP is contributed by textile industry, mainly RMG alone. It is clear how important this industry is.

The textile and clothing industries provide a single source of growth in Bangladesh's rapidly developing economy Exports of textiles and garments are the principal source of foreign exchange earnings. By 2002 exports of textiles, clothing, and ready-made garments (RMG) accounted for 77% of Bangladesh's total merchandise exports.

In 1972, the World Bank approximated the gross domestic product (GDP) of Bangladesh at US$6.29 billion, and it grew to $368 billion by 2021, with $46 billion of that generated by exports, 82% of which was ready-made garments. As of 2016 Bangladesh held the 2nd place in producing garments just after China [(1)].

As on date, Bangladesh is the world's second-largest apparel exporter of western fast fashion brands. Sixty percent of the export contracts of western brands are with European buyers and about thirty percent with American buyers and ten percent to others[(2)].In the financial year 2016-2017 the RMG industry generated US$28.14 billion, which was 80.7% of the total export earnings in exports and 12.36% of the GDP[(3)].

Despite the hurdles, riding the growth wave, Bangladesh apparel making sector could reach 60 percent value addition threshold relying on the strong backwardly linked yarn-fabric making factories directly from imported raw cotton, reaching a new height of exports worth of US$30.61 billion in the fiscal year 2018.[(4)]

It can be observed that despite many challenges, textile industry maintained a steady growth rate for the past two decades. It currently stands at No.2 position in the world for RMG exports, steadily catching up with the No.1, i.e., China.

The industry has flourished due to

(a) their high productivity at relatively cheaper labour,
(b) good quality control in production and
(c) trust earned with brands & buyers.

A major reason, often not highlighted, for this growth is the *apparent* availability of copious water. This perception was based on the fact that the country has numerous rivers with good water flow. However, it was entirely ignored that bulk of the industry is *not* using surface water and relies almost entirely on ground water.

1.2 Present water consumption by the industry

The textile processing is a water intensive industry. Depending on process/product, 1 kg of raw material may consume 75-250 litres of water[(6)]. Some reports pegs current total water consumption by the textile industry in and around Dhaka alone is at 4500 million litres per day, which may rise to 7000 million litres per day by 2030[(5)].

1.3 Industry projections on water requirement for 2030

Projections by some agencies which studied the present water consumption pattern predicted the water requirement in the year 2030 as 7500 million litres per day from textile sector alone which would be more than double of all other industry requirement & urban water requirement combined together.

If the increase in water consumption between 2015 and 2020 (reported to be about 35%) is taken as an indication, this projection could be realistic and there are possibilities that it may exceed this figure. [(5)]

1.4 Sources of water and availability

Though there is apparently good quantity of water available in the rivers including the River Turag which flows through the textile belt, the industry uses only ground water.

Main reason, given to this author when queried about it, was that the quality of ground water in the river is too bad and the industry may not be able to keep quality control if they use this water. However, none of the industry management who made this statement could give a correct information on the quality of water in the river and what contaminant they are apprehensive about in it. Apparently, it was based on the visual observation of the factory owners!

The groundwater is falling down at an alarming speed. Industry feed backs indicate that in many parts of Dhaka, groundwater lowering is in the range of 5-8 m.

Factories had installed rain water harvesting systems in their factories. However, this is not very useful to manage the fall in ground water levels.

This is mainly due to following factors:

- Majority of the rain water harvesting systems are not scientifically constructed and maintained. The re-charge wells are not wide enough and often blocked by debris. In most cases, after the first few minutes, the rain water just flows out without percolating.
- The rain water percolation rate is very slow owing to the low permeability of the soil and hence harvesting is not very effective.
- The area occupied by factories are too low to give any significant contribution to its water demand. One of the factories in Dhaka reported that they have collected about 8000 m^3 in the past year through rain water harvesting. While this figure may look impressive, the fact remains that the factory consumes approximately 12 MLD of water and the entire water harvested in this way for a full year is less than one day's consumption!
- The rain water harvesting points are not scientifically selected, resulting in the water percolating tends to drain towards the river. Ideally, the water percolating should get stored in a (nearly) confined aquifer. A proper geological investigation will reveal such spots & locations, but most factories do not bother to do any such checks.

1.5 Importance of water for the industry sustainability & growth.

Even today, it was not recognized by majority of the industry that water is one of the most important raw material for their production and its availability is not perennial. Interestingly, an industry which do all kind of investigation & audits like labour availability, power availability and transport availability etc. to finalise a location for establishing a factory does not bother to check the availability of water before the big decision.

Unless they realize the importance of water as a major raw material and plan for its continued availability in future, the production security may be in jeopardy.

Earlier similar words of caution were made to the industries regarding dwindling supply of gas and about dangers of planning without considering this aspect. However, not many industries took cognizance of such warnings and continued their expansions assuming endless supply of gas.

Even 2019, during factory visits by this author, most factories exuded confidence in continuous supply of gas for their energy needs. Today the situation is quite different and disruptions in gas and power supplies are rampant. Other countries which went through same issues witnessed worsening of situation when public started protests against diverting gas supplies to industries when domestic supply is not adequate. In any case, uninterrupted supply is not a certainty anymore.

Similar fate may occur with water too.

Unless the industry takes the situation in ground water seriously and takes appropriate action immediately, the issue may turn un-manageable.

2 NEED FOR OPTIMIZATION OF WATER USAGE IN THE INDUSTRY

2.1 Options to manage water requirement

2.1.1 Optimization of water through in-house conservation

Reduction of water consumption to less than 50% of the present value is technically feasible through optimisation. Different technologies, process modifications and optimisation is promoted by many organisations including GIZ. These measures should be pursued further. The details are available in public domain and hence not detailed here.

2.1.2 Surface water treatment and usage in the factories

Any surface water source (e.g. Rivers) can be used for the raw water requirement. As already mentioned, at the moment the industry is not keen to use river water.

2.1.3 Zero Liquid Discharge (ZLD)

This is obviously the last option. ZLD enable the industry to almost all water used by the industry to be recovered and re-used. There is a possibility to re-use salt too. Besides water security, full environmental compliance can be obtained through ZLD.

2.1.4 Effluent recycle after only tertiary treatment

Many suppliers claimed that after some polishing treatment like oxidation/adsorption, effluent can be re-used. As per their claims such systems can produce ‘nearly colourless’ water which can be safely used in the dyeing process.

However, the actual experience resulted in poor quality control in dyeing and such systems are so far a failure. Recovery of water from treated effluent without RO may not be safe and it may compromise product quality.

2.1.5 Partial recycling of treated effluent without amounting to ZLD

This option envisages treatment of effluent, recovery of part of water through RO, but discharge the rest. This may be simpler & cheaper than ZLD. Complete environmental compliance is an issue with this option.

2.2 Options for recovering sections of effluent for re-use

2.2.1 Recovery & re-use of caustic soda

Caustic recovery involves concentrating the weak lye through evaporation and then re-use the same. It has been implemented successfully in some units.

A normal composite dyeing factory uses caustic lye of 20-30% in mercerising and discharge weak lye effluent with 3-5% caustic lye concentration. On an average one ton of raw material may generate 5-6 m^3 of weak caustic lye. This caustic lye is discharged into the effluent.

This addition not only results in loss of valuable chemical, but also increases the pH, necessitating neutralisation in the ETP using acid. This stream also increases the TDS of the effluent, which is the biggest factor when the effluent recovery is considered. Caustic soda recovery could thus be integrated with effluent recovery.

To obtain the caustic soda recovery, weak caustic lye effluent can be collected separately, thermally evaporated, purified by oxidation (say with hydrogen peroxide) and used back in process.

The 5-6 m^3 of weak caustic lye is equivalent to 800-1000 litres of lye, which in turn is equal to 200-300 kg of caustic soda flakes. The condensate from caustic recovery can be used in boiler for steam generation. A well operating CRP may give a saving of US $ 18-20 per ton of production.

This saving is without considering the value of water recovered, reduction in cost of effluent treatment (mainly neutralisation and COD removal) and heat potential in the condensate water

2.2.2 Recovery & re-use of salt brine from exhaust dye bath using nano filtration

The nano filtration uses the selective rejection of membranes to get a cleaner saline liquor & re-use it in dyeing. Successfully tested in some units, some stopped using it after encountering few technical challenges.

Concept of salt recovery through nano filtration envisage salt laden exhaust dye bath to be first pre-treated with fine filtration and sometimes chemical oxidation and thereafter passed through a nano membrane. This allows only salt to pass through & remove organics, colour, other impurities. The permeate from nano filter will be a clear salt solution and reject from nano may have all colour and multivalent ions etc. The permeate is then re-used in dyeing after adjustments. However, the recovered brine may not be good for all shades.

Usually, the exhaust dye bath with 4 to 7% salt concentration is taken as the feed. The product, i.e., permeate will be about 6-8% brine. The reject carrying all organic impurities, sulphates etc. are taken for reject handling in RO and/or evaporated to dryness.

Based on molecular size of organics in exhaust dye bath, a nano-filter with 400-500 Daltons (about 0.0008 microns) pore size can give a decent recovery.

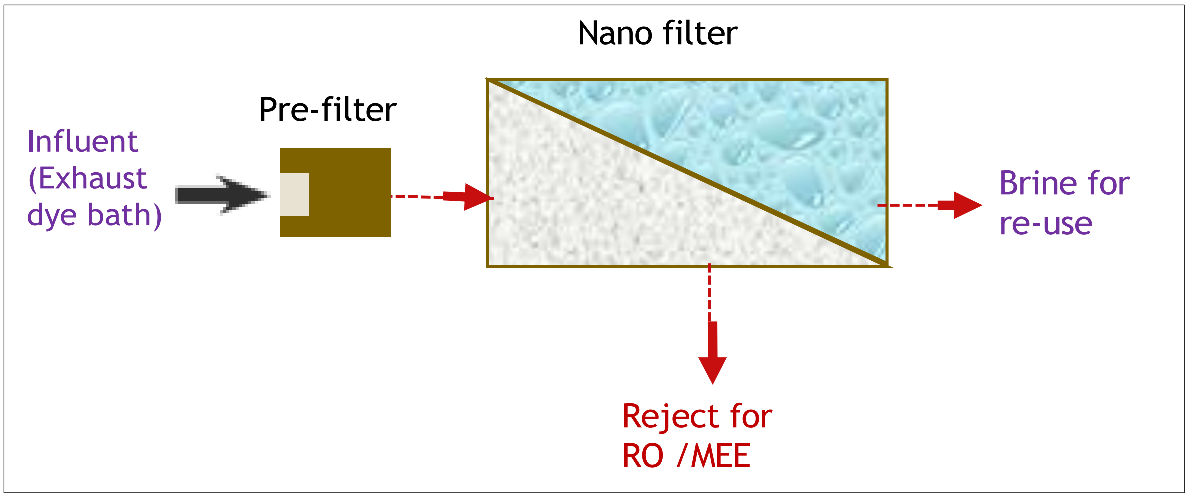

Figure 1: Scheme of nano filtration

Theoretically, nano filtration allows only mono/divalent ions and water to pass through, retains hydrolysed dyes and multivalent salts. Which means theoretically it is possible to recover all salts through the membrane, in practice recovery is affected by a variety of factors.

The pore size of the nano membranes is crucial. Too large a pore size (say >1000 Daltons) ensures good recovery, above 70% of salt liquor, but allows passage of some smaller organic molecules too. Passage of organics makes recovered salt solution coloured and potentially unsafe for re-use. On the other hand, too narrow pore sizes (say <300 Daltons) ensure recovery of clear salt liquor, safe for re-use but then recovery rate could be very low, say less than 35% of input.

The matter is further complicated by the presence of reacted salts, i.e., salts produced due to inter-reaction of acid and alkali used in the textile processing.

2.3 How to estimate water sustainability for 10 years.

In order to estimate the water need for next 10 years, three factors need to be considered:

2.3.1 Any plans for expansion of production capacity

Next 10 years may need expansion of present production capacity, which may show additional water requirement. This, of course depend on the expandability of the capacity in the existing location which depends on many factors including area available, business potential and diversification.

2.3.2 Improvements in water management

In the meantime, the factory may optimise the water requirement by opting for better technologies, machinery and water saving practices. This may compensate the additional water requirements due to expansion to some extent.

2.3.3 Extent of variation in availability of water source

If the availability of water is likely to get affected, that factor need to be considered while estimating water sustainability. For instance, if the groundwater table goes down continuously, it is a matter of serious concern since quantity and quality of water deteriorates when water table goes down. Many factories in Dhaka informed the author that the average groundwater table dropped continuously by more than 5 m per year, which is way too much compared to normal drop in water level in other countries. Also, the hardness and salinity of water is found increasing when the depth of ground water table increases.

All these factors need to be taken into account while estimating their future demand. For a normal factory, it may be practical to assume nominal increase of 30% in water requirement over next 10 years for sustainable operation and growth.

2.4 Treatment and recovery of domestic wastewater from textile factories

The textile industry is one which employ a large number of workers. Some factories have twenty or thirty thousand workers in a single factory. These workers consume a good amount of water for domestic purposes and discharge significant quantity of domestic sewage. Normally this water is mixed with trade effluent and is treated in the ETP.

Since domestic sewage has lower pollution load in terms of chemical contaminants, it can be relatively easier to treat it and recover as clean water. This recovered water, depending on the degree of treatment, can be used for purposes such as irrigation or cooling water make up after softening. Of course, most textile factories in Dhaka have no much area for gardening or irrigation and re-usability of recovered sewage is rather limited.

However, if a new factory considers effluent recovery or ZLD, it will be much better to segregate domestic wastewater, treat it and recover it separately for other re-use options such as cooling water.

3 EFFLUENT TREATMENT FOR ULTIMATE WATER RECYCLE

Since effluent treatment is a subject of detailed discussion and sufficient information is available in many other papers, this paper only focusses on effluent treatment with an intention of ultimate water recycle.

3.1 Logic of recovering water from effluent

Why should we even consider recovering water from effluent? There are some sensible reasons:

3.1.1 Lesser dependency on locations

The lesser the effluent to discharge, the lesser the dependency on water source & wastewater discharge provisions. In fact, a factory with Zero Liquid discharge can even be established in the centre of the city.

3.1.2 Discharge of treated effluent is a waste

Effluent treatment is a costly affair. It is illogical to incur cost to treat the wastewater only to discharge it as waste.

3.1.3 Effluent is one reliable source of water

It is a fact that ground water reserve may be limited and surface water availability may be affected by the seasonal changes. However, as long as a factory uses water, effluent is generated. So, in a way, it is perennial. A factory practicing recovery for water from effluent may never need to worry about stopping production due to unavailability of water.

3.1.4 It is an image booster

The buyers and brands are generally doubtful about the reliability of claims about proper operation of effluent treatment plant by the factories in the region. The ultimate proof of effective effluent treatment is that you are re-using it. This fact gives complete confidence to the buyer that environmental protection is assured.

3.2 Effluent generation: quality & quantity.

The quantity and quality of effluent varies from different type of industry based on their product, process, size and water consumption culture. On an average, water consumption per kg of raw material is 75-225 litres. The pollutants in raw textile wastewater are generally the following:

- Organic pollutants: residues of organic material used both as raw material and process ingredients.
- Salt: Most chemicals used in textile processing contributes to salts.
- Suspended particles: mostly fine fibers and residues of chemicals.

- Heavy metals & hazardous substances: Normally present in dyeing & printing chemicals and discharged in these effluents.
- Colour & temperature: caused by the remnants of the dyes & printing agents. The operation is done at high temperature.

3.3 Basic Effluent Treatment Scheme

General scheme of effluent treatment adopted by the textile industry of Bangladesh is given below. Some of ETPs are only primary and some are only biological treatment and many are combined ETP with primary & secondary treatment.

Table 1: General Effluent Treatment Schemes

Unit operation	Functions	Common unit
Screening	• Removal of large particles (suspended or floating)	Manual/mechanical screens
Grit Removal	• Removal of sand like materials from the effluent	Grit chamber
Equalization	• Homogenizing the quality of effluent • Flow balancing	Equalization tank Aerators, mixers
Coagulation/ flocculation	• Facilitating settling of colloidal solids & allowing the small solids to join to form sludge.	Flash mixer & flocculator
Primary settling	• Removal of part organic/inorganic settleable solids	Primary clarifier/tube settler
Biological treatment	• Removal of organics using microbial action	Aeration tank
Secondary settling	• Settling of bio-sludge, enabling biomass inventory	Clarifier
Tertiary treatment	• Removes suspended solids/increase dissolved oxygen	Multi-grade filter & aeration
Sludge dewatering	• Reducing moisture of liquid sludge to dried sludge	Sludge filter press/centrifuge
Sludge maturation	• Reducing moisture of dewatered sludge further before disposal	Sludge storage

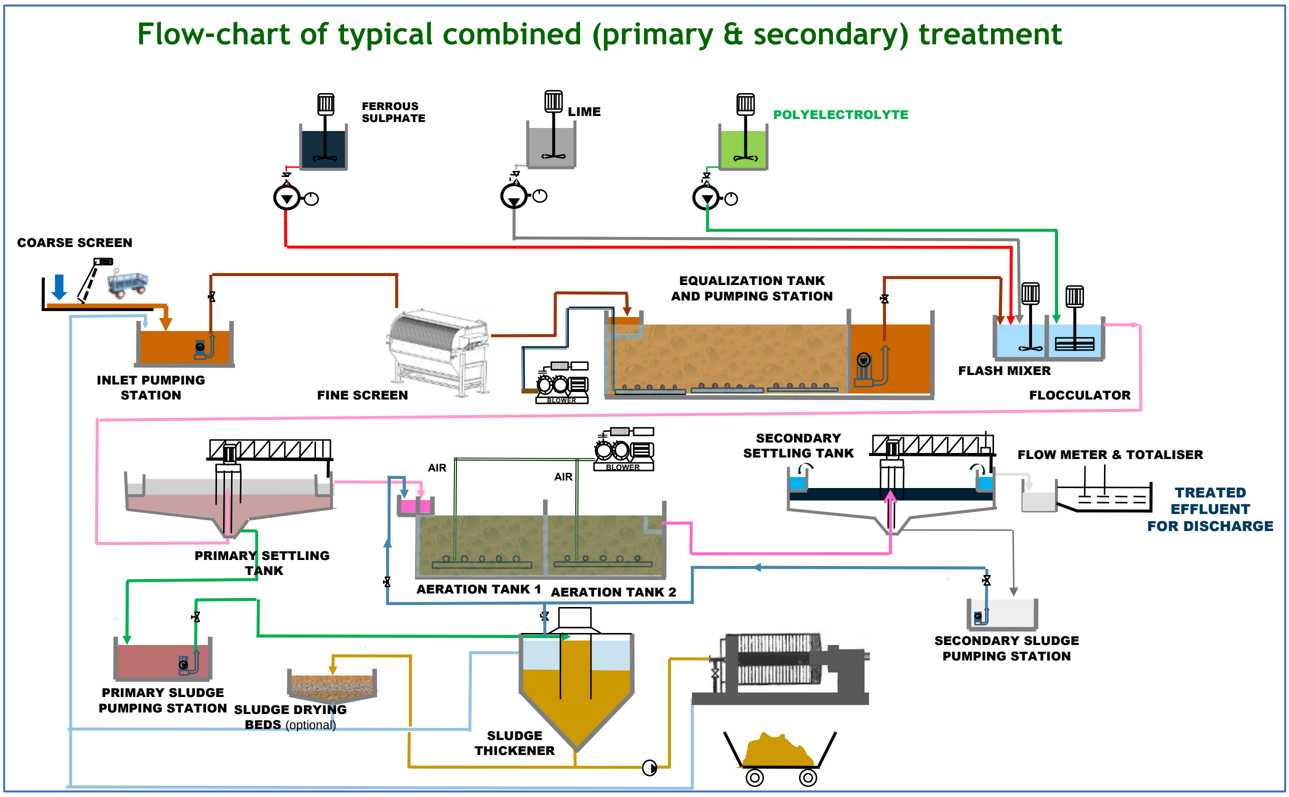

Figure 2: General Scheme of Textile Effluent Treatment

3.4 Treated effluent quality

Clearly, the treated effluent quality will depend on the type of treatment. Generally, the newer ETPs do conform to the norms of EPA.

The treated effluents commonly have some reddish colour, have BOD around 30-50 mg/l, total dissolved solids (TDS) about 2000 mg/l.

In factories which adopted strict water conservation, the TDS values are higher, say up to 4000- 5000 mg/l. Mostly, the suspended solids are very low, but occasional sludge bulking may increase it at times. The treated effluent may also contain some small quantity of heavy metals.

3.5 Disposal of treated effluent

Almost all the textile factories in clusters around Dhaka discharge treated effluent into water bodies, mostly to River Turag.

As such, the treated effluent does not offer much re-use potential. Even with some tertiary treatment such as oxidation or filtration, recovery & reuse in textile operations are not viable. This is because textile processing needs high quality water and any degraded water may affect quality control.

Treated effluent after polishing treatment may be used in floor washing, toilet flushing, gardening etc., but the requirement in these areas is indeed less.

3.6 Advanced wastewater treatment

To overcome the limitations of conventional biological treatment & make it for membranes, improved biological systems developed. Recently, many advanced biological treatment systems are being used for textile effluent treatment.

It comprises of modification of conventional treatment systems such as MBBR/FAB as well as in-situ units such SBR or RBC type units.

While these systems consume relatively lesser space and provide better treatment, it does not effectively address issues such as space constraints, pre-treatment requirement for recycling, sludge generation etc.

Membrane bio-reactors (MBR) are being increasingly considered as an effective biological alternative for this purpose. Since MBR also borders into units commonly used in effluent recovery, it is discussed in little more detail.

3.7 Membrane Bio-reactor

Membrane bio-reactor (MBR) is a modified biological treatment which uses a membrane filter for solids separation. It uses fine filters which can filter out all suspended and colloidal solids.

MBR is basically an activated sludge treatment, except instead of a secondary settling tank to separate bio-solids, a micro or ultra-filtration is used.

An MBR consumes much less space and produces effluent with clarity & no suspended solids. The treated effluent from MBR therefor need much lesser pre-treatment for effluent recovery or ZLD.

Due to its high solids retention, it can treat recalcitrant organics much better. It does not have much of the operational issues in secondary clarification such as sludge bulking. Similarly issues such as maintaining return activated sludge in proportion to the inlet flow is not so prominent in MBR.

It also produces relatively less sludge due to higher solids retention time and possibility of better endogenous respiration. MBR has no limitation due to settling characteristics of MLSS. Since it can obtain much higher MLSS in aeration tank, size of aeration and overall area needed for ETP comes down significantly.

The MBR concept was developed in the late 1960’s, but was not popular due to high power consumption till end of 80’s. Then submerged MBR was developed.

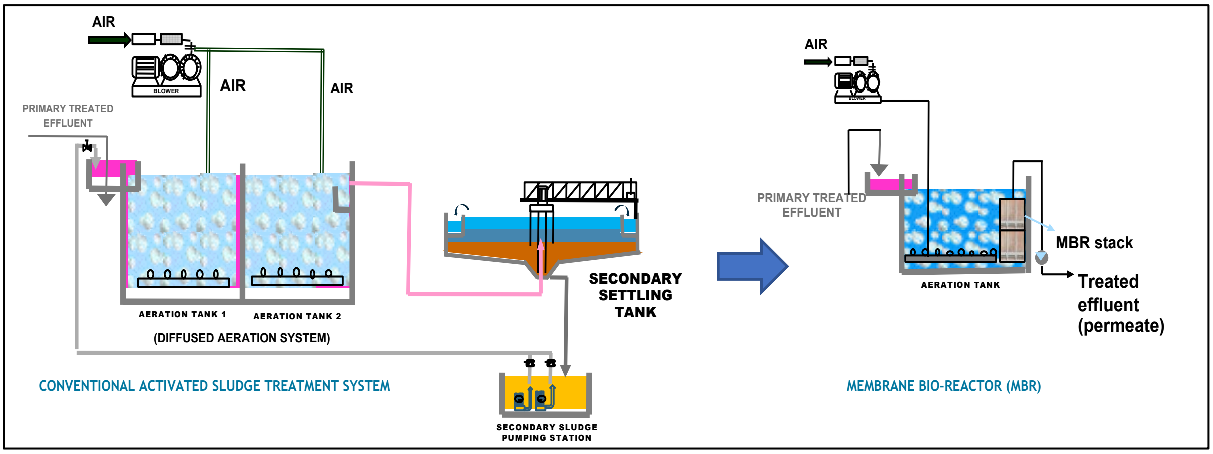

Figure 3: Comparison of MBR with conventional treatment

MBR has basically two components: an aeration tank and a set of micro/ultra-filters to filter out clean water retaining the biomass inside the aeration tank. In case of MBR membrane installed outside, the biomass is pumped back as membrane rejects.

The MBR can have different configurations. Most popular configuration include submerged membranes and side-stream membranes.

Submerged MBR has membranes installed inside the aeration tank. Here the membranes are stacked in cassettes and installed in aeration tank. The filtrate is sucked out using vacuum/ pressure pump, leaving the MLSS in the tank. The membrane stack is scoured by additional airflow frequently to loosen and remove the sludge deposited on the membrane surface.

The submerged MBR has lowest power consumption (in the range of 0.4-0.8 kWh/m^3) among the different MBR configurations. However, this configuration has greater chance of fouling compared to other options.

In side stream MBR, the membranes are installed outside the aeration tank and the concentrated MLSS from the aeration tank is pumped into an external MBR module mounted on a skid. The filtered clear effluent is discharged. Retained MLSS liquor is sent back to aeration tank. While this configuration has lower fouling frequency than submerged MBR, it consumes more power (in the range of 2.5-3.5 kWh/m^3).

A modification of side-stream MBR is called air-lift. In this system, scouring by air for extra backwash is added for smoother operation. This scouring also reduces power consumption to about 0.9-1.2 kWh/m^3.

There are other proprietary variants of MBR using different type and configuration of membranes. The benefits claimed by suppliers of such system include better clarity of treated effluent, lower fouling problems and higher life span of membrane. However, much of these claims are yet to be proven.

3.7.1 Advantages of MBR compared to conventional treatment

Since the treated effluent is a permeate from an ultrafilter/fine microfilter, it will have practically no suspended solids. Usually, the suspended solids in treated effluent would also be organic, mostly the fragments of MLSS, and they may contribute to BOD & COD. Thus the MBR ensures better removal of BOD/COD.

Since the treated effluent passes through a membrane, significant amount of pathogens too would be removed.

With no suspended solids, the effluent from MBR will be clear and less turbid than normal treated effluent. Hence lesser pre-treatment is required on this effluent when effluent recovery is considered.

The unit needs much less area compared to conventional ASP. In countries like Bangladesh where area is an issue MBR would be a sensible option.

3.7.2 Disadvantages of MBR compared to conventional treatment

The MBR system is higher in capital cost, compared to conventional effluent treatment.

The aeration provided in MBR is for meant to satisfy air requirement both for conventional aeration to supplement dissolved oxygen in water and to provide scouring of membranes submerged in aeration tank. Due to this need, the blower capacity and thus electrical energy needed per m^3 of effluent is higher than conventional treatment.

Also, the MBR has higher O & M cost due to the need for membrane cleaning/replacement. Frequent clean-in-process (CIP) is required (depending on the effluent quality) and cost of such maintenance may be BDT 1-2 per m^3 of effluent treated.

The MBR system is more sensitive and complex in operation vis-à-vis the conventional effluent treatment. The O & M need more skilled and trained personal and many MBR units need fully automatic operation. Besides the cost, much of this control systems are very sensitive and need special care.

Membrane replacement add to the list of consumables of such as membranes and extra modules need to be kept as stock to ensure trouble free operation. This adds to cost and space in store management.

Improper solids control may result in membrane clogging and the maintenance cost of such event could be more complex than conventional effluent treatment.

3.8 Pre-treatment before membranes for effluent recovery

Most effluent recovery systems use membranes for purification of treated effluent to the level fit for any serious re-use.

It should be kept in mind that most membranes are designed to treat saline, but otherwise pure water, as input. Hence treatment of effluent through membranes need extensive precautions and pre-treatment.

Membranes are prone to fouling (plugging) if treated effluent high in:

- Fine suspended solids (silt)
- Organic compounds (BOD/COD)
- Microbial population (mostly bacteria)
- High hardness

To make treated effluent fit for membrane systems such as Reverse Osmosis is a major challenge. Advanced tertiary treatment systems are useful for this purpose. A tertiary treatment designed to comply with norms and make effluent fit for recycle systems such as Reverse Osmosis may be the first requirement of effluent recovery units.

The tertiary treatment can be single stage or using combination of tertiary systems. The focus of tertiary treatment is on:

- ✓ Reduction of color
- ✓ Reduction of turbidity and suspended solids
- ✓ Destruction of pathogens
- ✓ Removal of residual organics
- ✓ sometimes for aesthetic purpose and as precautionary or complimentary measure

4 COMMON TERTIARY TREATMENT SYSTEMS FOR EFFLUENT RECOVERY

The common units of tertiary treatment to achieve better quality treated effluent before subjecting it to effluent recovery system include:

- Disinfection, mainly to kill micro-organisms in treated effluent and some for organic removal
- Filters, using filter media to filter out suspended particles in effluent
- Adsorption filters, most commonly activated carbon filters to remove organics
- Oxidation systems to oxidize residual organics in treated effluent
- Chemical precipitation systems for removal of phosphates/metals

4.1 Disinfection

The treated effluent from the ETP will have pathogens. Since the pathogens can damage the membrane, they need to be removed. To kill micro-organisms, specifically pathogens, disinfection of treated effluent need to be carried out.

Disinfection is usually achieved through addition of a strong oxidant, such as ozone, chlorine (gas, chlorine dioxide, or sodium hypochlorite), chloramine, or potassium permanganate (7) The oxidant is typically dosed at a high enough concentration to allow residual disinfectant through the rest of the pre-treatment system and prevent biological growth. For example, chlorine is typically dosed to allow for a residual concentration of 1-1.5 mg/l.

Chlorination is the most common disinfection system. To do disinfection, mixing effluent with chlorine gas is done in contact chambers or hypo-chlorite is dosed to the treated effluent.

Efficiency of chlorination is increased with higher dosage, lower pH, higher temperature and longer contact time. Though chlorination is simple and cheaper than other options, handling of chlorine is difficult, need safety precautions and chlorination of effluent with aromatic organics may generate toxic chlorinated halogens.

If chlorine is used as the disinfectant, activated carbon filter or sodium bisulfite dosing is used at the end of the pre-treatment system to remove (chemically reduce) the free chlorine. Sodium bisulfite is less expensive and more commonly used for large RO plants. (7)

The majority of RO membranes on the market today are made of aromatic polyamides, and such structures are known to be sensitive to chemical attack by chlorine. Extended chlorine exposure will cause membrane deterioration and a decrease in salt rejection.

All disinfection processes cause the formation of disinfection by- products, which are potentially toxic oxidation products formed by reactions between the disinfectant and organic and inorganic water components. The typical toxic by product formed due to chlorine is chlorinated hydrocarbons which may include highly toxic compounds like penta-chlorophenol.

Alternative to chlorination is UV radiation, which can kill pathogens. UV radiation damages the DNA of the bacteria/virus and destroys them. To carry out UV disinfection, the effluent is passed through a chamber illuminated by UV rays from UV lamp. There are two types of UV lamps commonly used. Low pressure and medium pressure. Medium pressure ones can handle higher flows, but consume more power.

Depending on their wavelength UV rays are classified into UV-A, UV-B, UV-C. The UVA is less powerful, but consumes lower power, UV-B has medium efficiency and consumes medium power and UV-C consumes highest power, but give better efficiency than other variants.

Advantages of UV disinfection include (a) UV disinfection is effective at inactivating most bacteria & viruses and cysts, (b) There is no residual effect that can be harmful to humans or aquatic life, (c) UV disinfection is a physical process rather than a chemical disinfectant, hence there is no need to buy, store and handle dangerous chemicals and (d) UV disinfection has a shorter contact time when compared with other disinfectants (approximately 20 to 30 seconds) and thus UV disinfection equipment requires less space than other.

Disadvantages of UV disinfection include (a) low dosage may not effectively inactivate some viruses, (b) organisms can sometimes survive UV, (c) frequent cleaning is necessary to control fouling of tubes, (d) suspended solids and turbidity reduces efficiency of UV disinfection (TSS levels above 30 mg/l is not suitable) and (e) UV disinfection is costlier in installation than other disinfecting technologies like chlorination.

4.2 Filtration

Since the membranes are susceptible to fouling due to suspended solids, it is desirable to remove the fine suspended solids to the maximum extent.

Removal of suspended solids in treated effluent is commonly done through filtration. Filtration also reduces part of BOD/COD by removing suspended organics (like MLSS particles).

The filtration is done by gravity or pressure filters. Gravity filters are now rarely used in ETPs and may be suitable for only very small textile ETPs.

4.2.1 Common filtration units

There are three types of filtration commonly in use. They are (a) slow/rapid sand filters using gravity (b) pressure sand filters using vessel filled with filter media with effluent being pumped and filter under pressure and (c) fine filtrations (such as pre-treatment of membrane) with cartridge filters.

The slow sand filter/rapid sand filters are not much used in polishing of treated effluent, unless the ETP is very small and has lot of area.

There are three common types of pressure filtration used in wastewater treatment. They are (a) Pressure sand filters, (b) Multi-grade filters and (c) Dual media filters.

The pressure filters are similar in construction and operational pattern, but varies in composition of filter media. The vessels are made of FRP, MS (often rubber lined) and stainless steel. New types of filter media coming to market every year.

Measurement of operational efficiency in pressure filter is done through parameters like filtration rate, head loss and frequency of backwashing needed. Maintenance of pressure filter involves backwashing of the filter whenever the filtration rate falls due to accumulation of filtered suspended solids.

Backwashing is done whenever pressure drop more than 1 bar. Backwashing is sometimes preceded by air scouring for agitating media with scrubbing action and loosens retained solids.

Common filtration media are (a) silica sand and anthracite coal, which is most common and (b) quartz sand, garnet, magnetite. Size and shape of filter media affects efficiency of filtration. As a rule, smooth and rounded media is better than sharp and angular media. Most suspended solids are removed at surface of filter (top 5 - 10 cms), gradually the solids percolate down to prevent rapid pressure drop.

4.2.2 Types of pressure filters

There are three types of pressure filtration. They are pressure sand filters, multigrade filters, dual media filters.

The first type of pressure filtration is pressure sand filters (PSF). Usually the PSF is a cylindrical vessel filled with filter media. It can be shaped vertical or horizontal in orientation. The PSF has set of frontal pipe work and valves, mainly to control the feed and backwash operations. The filter media is graded silica quartz sand. The sand layer is supported by under-bed of pebble/gravel. Feed water is admitted via top distributor. The under-drain collects filtered water and is taken out as filtered water.

The second type of pressure filtration is Multigrade filter (MGF). The MGF is similar to pressure sand filter in construction with cylindrical vessel and identical piping/valves. It has same way of operation and backwashing. The MGF uses coarse and fine media mixed together in fixed proportion. The filtration efficiency of MGF is not as fine as in pressure sand filter but turbidity reduction better than PSF. The MGF can give higher flow rate and better turbidity reduction than pressure sand filter. However, it has less filtration efficiency, more energy and higher backwash than pressure sand filters.

The third type of pressure filtration is Dual Media Filters (DMF). The DMF is similar to pressure sand filter in construction with cylindrical vessel and identical piping/valves. It has same way of operation and backwashing. The DMF uses sand-anthracite filter layer or multi-media which used for removal of turbidity and suspended solids. The DMF removes TSS as low as 10 - 20 microns. It has the highest filtration rate & flow than other pressure filters. The disadvantage include higher need of backwash water quantity. Also, frequency of backwash is higher and the media has lower life compared to other filters.

4.2.3 Efficiency of pressure filtration

Efficiency of pressure filtration varies with respect to the type and characteristics of treated effluent. The average reduction, obtained from multi-grade filter when tried in pilot scale by this author, is given in Table 2, just for reference.

Table 2: Performance of DMF in textile effluent

Effluent from process	Para-meters	Influent to MGF			Outlet of MGF			% redn average
		Value - range	Average value	Std. deviation	Value - range	Average value	Std. deviation	
Combined effluent	TSS	68.5-132	88.4	29.80	8.9-19.8	14.65	4.75	83.43
	Turbidity	175-224	195.2	19.6	32-46	37.2	5.56	80.94
Cotton Dye effluent	TSS	62-98	77.2	26.4	12-21.6	15.2	4.88	80.31
	Turbidity	122-196	178.2	31.3	28.2-37	32.2	7.4	81.93
Garment washing effluent	TSS	71.2-145	106.4	29.2	14.2-26	17.6	5.2	83.46
	Turbidity	222-318	256	31.6	52-74.5	63.66	17.2	75.13

4.3 Options for management of residual organics

Treated effluent contains those organics not removed in biological treatment since they are bio-degradable to lesser extent. For removal of such organics, tertiary treatment systems are used.

The commonly used tertiary treatment for residual organics include:

- Adsorption of organics in adsorbent media, such as activated carbon filters and organic scavengers
- Advanced oxidation systems
- Ozonation of treated effluent
- Fenton treatment: Oxidation catalyzed by iron

4.4 Activated carbon filtration

Adsorption means adhesion of ions or molecules to surface in effluent treatment entrapment of organics (or other contaminants like chlorine) in adsorbent medium. Adsorption of organics in the voids of activated carbon is an effective treatment.

Activated carbon is an inert solid adsorbent material made from almost any carbon containing feedstock (e.g. wood, coconut shells and coal). Activated carbon can also be derived from waste products such as coconut husk, coir pith, waste wood chips. It is porous, inexpensive and high surface area per gram.

Physical entrapment in voids of porous medium or attachment to surface due to surface charge. Due to its high degree of micro-porosity, one gram of activated carbon can have a surface area in excess of 3,000 m^2.

Since there is much information already available on mechanism of organic removal through activated carbon, a detailed discussion on the same is not attempted here.

Results obtained from a typical activated carbon filter treating treated effluent from textile units, as noted by the author, is given below, just for reference.

Table 3: Performance of activated carbon filtration in textile effluent

Parameter	Results obtained from tertiary treatment using granulated activated carbon								
	Combined Effluent			Cotton dyeing			Garment washing		
	Inlet	Outlet	% redn	Inlet	Outlet	% redn	Inlet	Outlet	% redn
BOD	37.2	26.4	29.03	26.4	16.8	36.36	29.3	19	35.15
COD	388.4	265.4	31.67	252	202.5	19.64	412.5	325	21.21
Colour	174	92.2	47.01	162	85.6	47.16	315	165.5	47.46

It can be seen that efficiency of activated carbon is only moderate in removal of residual organics in the treated textile effluent. However, since its installation is not very expensive, it is commonly used as tertiary treatment when effluent recycling is considered. Interestingly, many ETP managements ignore the fact that activated carbon is exhaustible and need replacement after some time. Many do not even know that treatment efficiency has been dropped and continue to pass the effluent through the same without any real benefit.

The activated carbon filter is usually coupled with a pressure filter. Recent effluent recycling units use combination of multi-grade filter/dual media filter followed by activated carbon filter.

4.5 Oxidation of organics treated effluent

Advanced oxidation processes (AOP) is a chemical treatment process for removing organic (and sometimes inorganic) pollutants through oxidation.

Common systems used in tertiary treatment of textile effluent include the following systems: (a) Plain oxidation using Hypochlorite or peroxides, (b) Photochemical oxidation, (c) Hydrogen peroxide with or without UV radiation, (d) Ozone and (e) Fenton treatment.

The concept of oxidation envisage hydroxyl radical (OH-) and nascent oxygen as active reactants. The hydroxyl radicals are produced in water with primary oxidants like oxygen, ozone and peroxides enhanced with energy sources or catalysts.

Generation of oxidation by products is a serious concern. Despite AOPs ability to oxidise and neutralise toxic/hazardous organics present in textile effluent, there are concerns about toxic by-products of AOP. AOP can create oxidation by-products (OBPs) from the partial degradation of dissolved organic matter may create highly toxic substances.

A known by-product is bromate and excess peroxide. If chlorine is used, it may produce halogenated organic by-products. For example, application of chlorine in textile effluent may generate toxic chlorophenols. However, most of such by-products are not due to AOP itself and depend on the composition of effluent. Hence it is advised that an AOP may be considered after adequate lab analysis of treated effluent and AOP effluent.

General advantages of AOP include : (a) small footprint: units of AOP do not require much land area, even for high capacity, (b) Mineralization of organics: AOP can ensure complete degradation of organics into water, carbon dioxide, and salts, (c) Rapid reaction rates : AOP is one of the fastest reaction and hence need much lower retention times than other conventional treatment processes, (d) Wide range: Can treat nearly all organic materials and some heavy metals even, (e) Disinfection: Besides organic degradation, it can also ensure complete disinfection, (f) No sludge production: AOPs does not produce sludge for further processing and disposal of sludge as with chemical or biological processes and (g) Does not concentrate waste: unlike membrane treatments, it does not concentrate the contaminants like salts avoiding special handling of those separately.

General disadvantages of AOP include: (a) Need for expertise: Need highly skilled labour to operate and control (b) high cost: It has relatively high capital and operating/maintenance costs in terms of energy and chemical reagents to operate the system, (c) high variability: It has complex chemistry tailored to specific contaminants, need specific understanding and selection of technology as advanced oxidation processes have several different variants., (d) need for removal of residual oxidants: advanced oxidation process systems utilizing hydrogen peroxide should be designed and operated carefully to minimise residual peroxide. (e) higher need for anti-oxidants: AOP residuals may be dangerous to membranes if proper anti-oxidant control is ensured.

Let us briefly consider the variants of oxidation systems.

4.5.1 Oxidation with hypochlorite

Despite having the risk of generation of chlorinated hydrocarbons, some ETPs tried oxidation using sodium hypochlorite. The result obtained by this author from a typical ETP is given below:

Table 4: Performance of oxidation in textile effluent

Parameter	Results from tertiary treatment using Hypo at dosages of combined effluent								
	Inlet	50 ppm		75 ppm		100 ppm		300 ppm	
		Value	% redn.	Value	% redn.	Value	% redn.	Value	% redn.
BOD	36.5	32.5	10.96	28.8	21.10	26.2	28.22	25.2	30.96
COD	392	342.4	12.65	310.2	20.87	288	26.53	272	30.61
Colour	182	142	21.98	128	29.67	47.16	74.09	44	75.82

Paramet er	Results from tertiary treatment using Hypo at dosages of Cotton Dyeing effluent				
	Inlet	50 ppm	75 ppm	100 ppm	300 ppm

		Value	% redn.	Value	% redn.	Value	% redn.	Value	% redn.
BOD	26.5	22.4	15.47	18.6	29.81	18.8	29.06	17.6	33.58
COD	264	252	4.55	228	13.64	190.4	27.88	186	29.55
Colour	168	142	15.48	162	3.57	47.16	71.93	165.5	1.49

Parameter	Results from tertiary treatment using Hypo at dosages of Garment washing effluent								
	Inlet	50 ppm		75 ppm		100 ppm		300 ppm	
		Value	% redn.	Value	% redn.	Value	% redn.	Value	% redn.
BOD	32.1	29.2	9.03	28.8	10.28	21.2	33.96	19.6	38.94
COD	418	368	11.96	342	18.18	294	29.67	288	31.10
Colour	322	265	17.70	212	34.16	85	73.60	88	72.67

It is quite clear that this oxidation is not very effective, except for the removal of colour.

4.5.2 Photochemical oxidation process

Though any oxidants, or chemicals with extra oxygen atoms, can be used for this process, hydrogen peroxide is the more commonly used oxidant. Here hydroxyl radicals is generated from peroxide and generation of the same is enhanced by radiation with UV rays.

The reaction can be indicated as follows:

$$H_2O_2 + UV \rightarrow 2(OH)$$

Organics pollutants are oxidized by hydroxyl radical and broken into simpler organics and further oxidized into carbon dioxide. The system usually has higher efficiency in acidic conditions and the optimal pH is noted as 3 - 6. Natural organic matter or carbonate species reducing effectiveness. The reduced metal ions (e.g. Ferrous and Manganous) reduces effectiveness since they also consumes the excess oxygen.

Advantages of photochemical oxidation process include (a) low space requirement, (b) complete degradation of organics is possible (c) fast reaction and very lower retention times vis-à-vis others, (d) treatment of wide range of organics, (e) complete disinfection too and (f) There is no sludge production.

Disadvantages of photochemical oxidation process include (a) need for highly skilled labor to operate and control, (b) high capital and operating & maintenance costs, (c) it involves complex chemistry, (d) there is a need to control and remove of product of oxidation and (f) generation of residuals affecting membranes if proper anti-oxidant control not ensured.

4.6 Fenton Treatment

Fenton treatment is a branch of AOP which has evolved to be quite popular in itself. An advanced variant of the same is photo Fenton. In Fenton treatment, the liberation of OH radicals from H_2O_2 is catalyzed by ferrous ions. Photo Fenton uses UV radiation too.

Though there are different theories about active reactant in Fenton treatment, it is widely believed that the oxides of iron produced in the reaction also catalyzes the oxidation of organics by OH radicals.

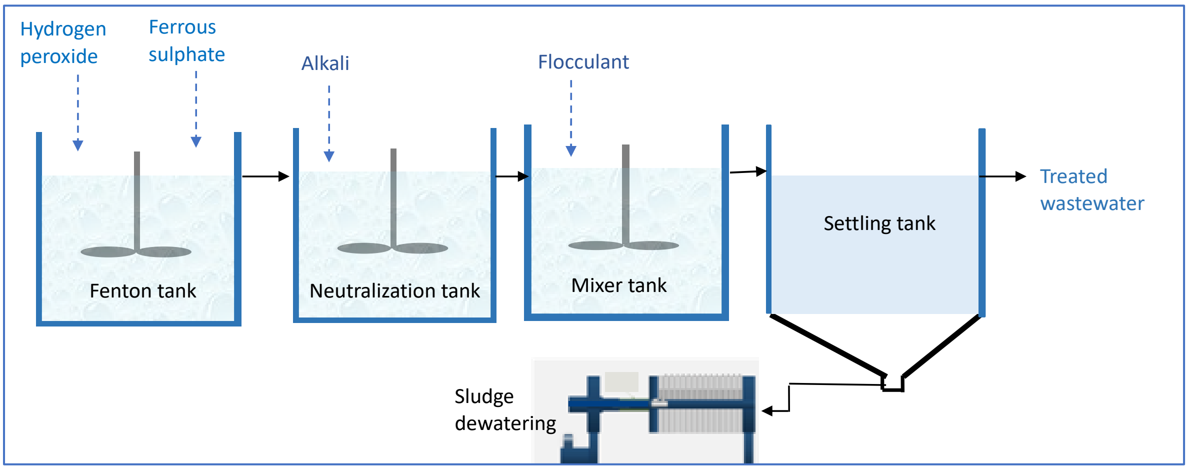

Figure 4: Scheme of Fenton Treatment

Optimum pH for Fenton treatment is 3-5. At higher pH, iron precipitates as ferric hydroxide and the system will be less effective. At lower pH, the $(OH)^-$ radicals are used up by excess H^+ ions and affect the treatment. Curiously, the pH of mixture drops as reaction proceeds. It is prevented to some extent by using ferrous sulphate and by adding H_2O_2 in stages.

Advantages of Fenton treatment include (a) it has relatively lower capital cost, (b) it is simple and easy process, (c) it is suitable for all organic materials and some heavy metals and (d) there occurs no concentration of contaminants like salts.

Disadvantages include (a) generation of ferric sludge for dewatering/disposal, (b) high operation and maintenance costs due to the requirement to add peroxide and to do pH management, (c) There is a need to adhere to strict pH range.

4.7 Ozone treatment

Ozone treatment is often suggested as an ideal tertiary treatment to remove organics from treated textile effluent, though it is quite costly in operation. Ozone (O_3) is basically oxygen gas with additional oxygen atom. It is a pale blue gas with distinctively pungent smell and potentially toxic.

The basic concept of ozonation involve generation of ozone and applying it on effluent through contact chambers. Generation of ozone is commonly done from oxygen-bearing gas subjected to electric field or UV. Ozonation is often done on-site since it is unstable and quickly decompose to oxygen.

The Ozone generators use air or oxygen as source, with occasional oxygen concentrators. Ozone gas when generated from air usually has a concentration 0.5-2% ozone and if done with oxygen gas, the usual concentration is 4 – 7% ozone.

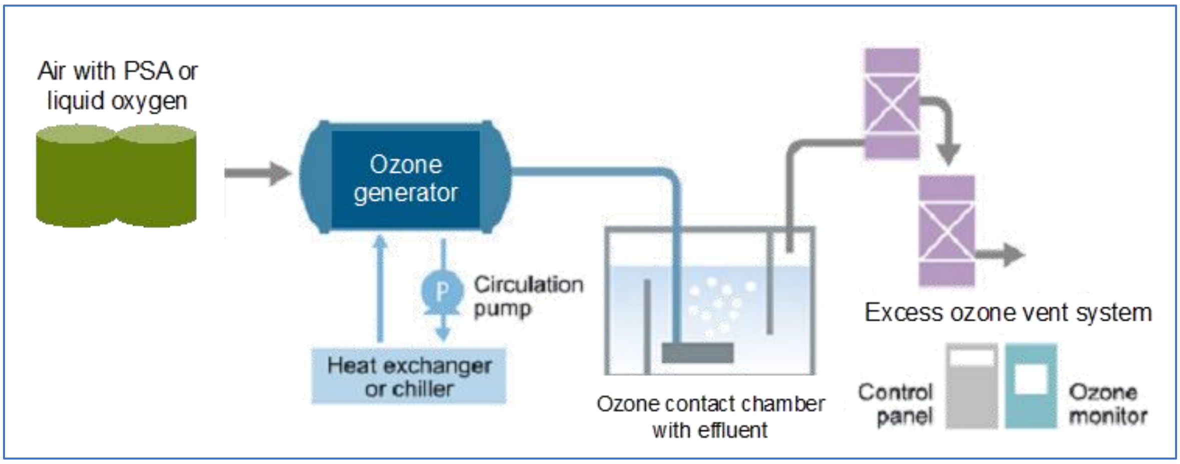

Figure 5: Scheme of Ozone treatment

Electrical discharge method most common source for generating ozone. Electrical discharge method is the most common energy source used to produce ozone. Extremely dry air/pure oxygen is exposed to a controlled, uniform high-voltage discharge.

After generation, ozone is fed into a down-flow contact chamber containing the wastewater to be treated. The main purpose of the contactor is to transfer ozone from the gas bubble into the bulk liquid while providing sufficient contact time for disinfection.

The commonly used contactor types diffused bubble (co-current and counter-current) are positive pressure injection, venture, mechanically agitated, and packed tower.

The off-gases from the contact chamber must be treated to destroy any remaining ozone When pure oxygen is used as the feed-gas, the off-gases from the contact chamber can be recycled to generate ozone or for reuse in the aeration tank.

Advantages of ozone system include : (a) little space required, (b) it can destroy pathogens & organics, (c) reaction is fast: less than 30 min, (d) It does not generate any harmful residuals, € there is no bacteria regrowth, (f) onsite generation of ozone is possible and (g) the increase in dissolved oxygen helps maintain aerobic condition.

Disadvantages include : (a) high capital and operation & maintenance costs, (b) need for highly skilled labor, (c) it is more complex than other systems, (d) need for corrosion-resistant material (e.g. stainless steel), (e) it is not economical for removal of high levels of TSS/COD and (f) it need careful handling as ozone is very toxic.

Efficiency of ozone varies a lot with respect to the type & characteristics of treated effluent and to the type of ozonator used and input used for ozone production.

Result from a study done by this author in an operational ozone treatment system is given in Table 5, just for giving a general idea.

Table 5: Performance of ozone system in textile effluent

Parameter	Results obtained from ozonation of combined effluent at different contact time										
	Inlet	60 seconds		1 minutes		5 minutes		10 minutes		30 minutes	
		Value	% redn.	Value	% redn.	Value	% redn.	Value	% redn.	Value	% redn.
BOD	38.2	39.4	-3.14	36.6	4.19	29.4	23.04	28.5	25.39	29.4	23.04
COD	401.5	399	0.62	399.6	0.47	337.6	15.92	282	29.76	305	24.03
Colour	222.4	234.5	-5.44	221	0.63	182.4	17.99	85.2	61.69	94.6	57.46

Parameter	Results obtained from ozonation of cotton dye effluent at different contact time										
	Inlet	60 seconds		1 minutes		5 minutes		10 minutes		30 minutes	
		Value	% redn.	Value	% redn.	Value	% redn.	Value	% redn.	Value	% redn.
BOD	28.2	27.8	1.42	26.4	6.38	21.4	24.11	20.5	27.30	19.6	28.2
COD	355.6	351.2	1.24	292.6	17.72	238	33.07	211	40.55	208	355.6
Colour	184.6	178.8	3.14	142.5	22.81	87.6	52.55	84.5	54.19	81.2	184.6

Parameter	Results obtained from ozonation of garment wash effluent at different contact time										
	Inlet	60 seconds		1 minutes		5 minutes		10 minutes		30 minutes	
		Value	% redn.	Value	% redn.	Value	% redn.	Value	% redn.	Value	% redn.
BOD	40.8	40.8	0.00	38.65	5.27	29.4	27.94	28.2	30.88	40.8	40.8
COD	421.2	410.8	2.47	367.8	12.68	311.	26.07	289	31.24	421	410.8
Colour	332.6	331.6	0.30	318.4	4.27	285	14.13	202	39.09	332	331.6

It can be seen that ozonation is only moderately effective even when high contact time is provided. The high capital cost & operating cost of ozonation to obtain such moderate efficiency could seldom be justified. Many suppliers who have offered ozonation as a pre-treatment for effluent recycling system had no plant scale experience in operating ozonation in textile effluent.

4.8 Quality of tertiary treated effluent

Quality of tertiary treated effluent depends on efficiency of basic effluent treatment, type of tertiary treatment & its management. Generally, the treated effluent after tertiary is nearly colourless, very low suspended solids and low level of organics.

Still, the quality of this water may not conform to inlet requirements of membrane filtration such as Reverse Osmosis. Hence pre-treatment to membranes are required additionally for any recovery.

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Still, the quality of this water may not conform to inlet requirements of membrane filtration such as Reverse Osmosis. A typical effluent quality from a tertiary treatment based on the observations by this author is given in Table 6, just for reference.

Table 6: Quality of treated effluent

Parameter	Unit	Effluent after tertiary	Required at inlet of RO
pH		6–5 - 7.5	6.5-7.0
Suspended solids	mg/l	5-15	<1
BOD/TOC	mg/l	5-10	<2
Total Nitrogen	mg/l	1-5	<5
Total hardness	mg/l	100-200	<250
Turbidity	NTU	10-20	<2
Silt density Index (SDI)	-	10-20	<5
Calcium hardness	mg/l	75-150	<200
Silica	mg/l	15-20	<30
Oil & Grease	mg/l	0.3 -2	<1

Hence pre-treatment to membranes is required additionally for any good recovery and longevity of the membrane.

5 TECHNOLOGIES USED FOR DESALINATION OF TEXTILE EFFLUENT

Even though Reverse Osmosis (RO) remains as the most popular desalination technology, other technologies do exist and worth mentioning here. The list of such technologies and their pros & cons based on the information collected from the respective technology providers, are indicated here.

5.1 Electrodialysis

Electro Dialysis (ED) uses an electro dialysis cell of feed (dilute) compartment and concentrate (saline) compartments. The compartments are formed by an anion exchange membrane and cation exchange membrane placed between two electrodes.

It is a membrane process, ions are transported through semi permeable membrane, under the influence of an electric potential. The membranes used are cation- or anion-selective, which basically means that either positive ions or negative ions will flow through.

5.1.1 Advantages of ED

- It is a proven technology in desalination of water.
- It has higher flexibility in handling effluent of varying TDS.
- It could also be less expensive in some cases, especially if the TDS is very low.

5.1.2 Disadvantages of ED

- ED is less effective in high inlet TDS concentration.
- It can easily be fouled with silt, calcium salt and organics.
- Not suitable to give low permeate TDS if the inlet TDS is high.

5.2 Electro Dialysis Reversal (EDR)

Electro Dialysis Reversal (EDR), as name suggests, is similar in principle to electrodialysis. In EDR, an electrical current moves dissolved ions through an electrodialysis stack consisting of alternating layers of cationic and anionic ion exchange membranes. Periodically, the direction of ion flow is reversed by reversing the polarity of the applied electric current. The reversal help to reduce scaling and give higher recoveries.

While ED/EDR, as a technology, is essentially a replacement of RO, an unconventional application of EDR can be in the concentration of RO reject. This is because of its ability to give 50% recovery in each stage without undue increase in pressure. Hence this application for concentrating brine rejects tends to be more economical than a high pressure RO. However, barring a few trials, a commercial application of reject concentration is yet to be seen till now. The water wing of Industrial Technology & Research Institute (ITRI) based in Taiwan is conducting extensive pilot studies using EDR as a brine concentrator in operational effluent recycling systems in India.

5.2.1 Advantages of EDR

- It has better fouling resistance than ED
- It generally has longer membrane life than ED
- With EDR, high recovery of permeate is possible
- EDR can be appended with RO to obtain high recoveries.

5.2.2 Disadvantages of EDR

- More expensive than RO,
- Operation is complicated,
- Low salt reduction in stages, and
- Not suitable to give low permeate TDS.

5.3 Ion Exchange

Ion Exchange process is one of the earliest applications of a desalination technology. Ion Exchange uses resins to remove salts from water through selective adsorption. Ion exchange resin is a specialized polymeric material and when water with high TDS pass through it, dissolved ions in the stream are replaced by more desirable ions of a similar electrical charge.

Once the exchange reaches its exhaustion, it needs to be regenerated. Resin regeneration involves application of chemical regenerates to the resin, which can consist of a salt, acid, or caustic solution depending on the resin and application, as well as rinsing and backwashing cycles. Ion exchange resins are best used to treat streams with low to moderate TDS levels. High TDS results in frequent regeneration cycles, needing high consumption of regenerate chemicals, more downtime for regeneration, and more frequent replacement/disposal of the resins.

Replacement of resins may be needed after many cycles of sorption and regeneration.

5.3.1 Advantages of Ion Exchange

- It is a proven technology
- It can provide high quality of recovered water
- The system is simple and involve standardized operation
- It may be less sensitive to common fouling elements of RO
- It can be used for further desalinating permeate of high pressure RO.

5.3.2 Disadvantages of Ion Exchange

- It is not suitable for High TDS concentrations, say above 1500 mg/l.
- Operation not commercially proven in ZLD so far.
- Frequent regeneration of resins may be needed when applied for effluents. This in turn may produce more wastewater to handle.
- When used for higher TDS and contaminated water, frequent replacement of resins may be needed, resulting in additional cost and need for safe disposal of spent resin.

5.4 Membrane distillation

Membrane Distillation (MD) is an evaporation process in which the vapour alone is separated using a membrane. The system uses hydrophobic membrane as a barrier to keep the liquid separate.

The water vapours escape through the pores of membranes driven by vapour pressure created by a temperature difference (ΔP). Naturally, the vapour would be pure and would not contain salts.

The vapour is then condensed to recover water. The mother liquor is continuously concentrated till the desired conc. Is achieved.

5.4.1 Advantages of MD

- Very high concentration at reject side achievable.
- More economical than HP-RO and MEE

- Less sensitive to fouling
- Membrane life is better than HP-RO

5.4.2 Disadvantages of MD

- Not suitable for lower TDS concentrations,
- Much more expensive than RO,
- Operation is complicated,
- Still need a crystallization stage to separate salt

5.5 Forward Osmosis

Forward Osmosis (FO) is often regarded as the most promising technology in ZLD due to the fact that unlike RO, the FO does not need higher operational pressure when TDS of inlet water goes up.

Forward Osmosis incorporates an osmotic membrane process. Using a draw solution, a natural osmotic flow of water across a semi-permeable membrane. This allow water to flow from the saline liquid to a more concentrated draw solution. In this process the RO reject (feed) gets concentrated.

Depending on the draw solution TDS, the reject TDS concentration raised from 40-50 gpl to 150-200 gpl. Once the feed stream is sufficiently concentrated, the same can be sent to evaporator for salt separation and draw solution for regeneration.

The draw solution is regenerated using Low temperature heat transforming the diluted draw solution from a liquid into a vapor, leaving behind fresh water. The system does not envisage any feed water boiling and no high pressure pumping and hence it is one of the lowest in O & M cost.

5.5.1 Advantages of FO

- Very high concentration at reject side can be achieved.
- Lowest operating cost vis-à-vis HP-RO & MEE
- Less sensitive to fouling elements.

5.5.2 Disadvantages of FO

- It is not suitable for lower TDS concentrations,
- Type and kind of draw solutions are yet to be standardized.
- No commercial installation so far.
- The still may need a evaporation stage to separate the final part of salt

5.6 Mechanical Vapour Re-compression

Mechanical vapour recompression (MVR) is a technology mostly used as for concentration of RO reject and not much as a replacement of RO itself. MVR make use of water vapour produced even at low temperature and use it for further evaporation after compressing it. MVR uses a compressor to compress and thus increase pressure of vapour produced. Pressure increase of the vapour also generates an increase in the steam temperature.

This same steam can serve as the heating medium for the liquid from which the vapor was generated to begin with. The major component of the system is the heat exchangers, often constructed in stainless steel, in an evaporation vessel and the compressor.

A variant with polymeric heat exchanger was widely used with less pressure. Here instead of a conventional compressor and ID fan is used and the increase in vapour pressure (ΔP) and increase in vapour temperature (ΔT) is relatively lower than conventional MVR.

5.6.1 Advantages of MVR

- Proven technology
- Can be used a pre-concentrator for MEE
- Simple and standardized operation
- Less sensitive to fouling elements.

5.6.2 Disadvantages of MVR

- Less effective/expensive for higher TDS concentrations,
- Standard MVR with stainless steel heat exchangers are capital intensive.
- Still need concentration/ crystallization, often through a conventional MEE.

5.7 Comparison of desalination technologies

Desalination of wastewater is relatively new area with different kind of considerations (due to organics, high scaling potential and need to achieve reject management).

It is the most researched topic in water & wastewater treatment field. One part of research focus on development of different membranes of better fouling resistance and better flux rate. Other part is invention of new technologies such as FO. Many other Technologies still in the process of development.

All the technologies listed above have their own pros & cons. Factors such as TDS values, organic contaminants, presence of compounds with scaling potential etc. decide what kind of technology should be selected for the system.

Still, for wastewater RO remains as the most common technology and research are ongoing to make systems such as EDR more effective and as a possible replacement of RO.

6 PRE-TREATMENT TO EFFLUENT RECOVERY SYSTEMS

6.1 Making effluent fit for ZLD-RO: water quality requirements for membranes

RO Membranes were originally created for recovery of good quality water from saline, but otherwise clean water. The membranes are very sensitive to impurities including organics, oxidizing compounds, micro-organic contaminations, scaling compounds, silica and silt. The most common application of RO membrane is desalination of sea water. However, industrial effluent, though lower in TDS than sea water, has a number of impurities which are not compatible with RO membranes. Some of these are:

- Organics, especially long-chain aromatic compounds which are quite common in treated effluent of textile mills. Such organic compounds block a large number of pores in the membrane and reduce flux rates drastically.
- Suspended impurities. Even if the treated effluent conforms to norms of suspended solids, membranes cannot tolerate any suspended & colloidal solids and they need removal before feeding to membrane.
- Turbidity and silt: It may be proportional to suspended impurities to some extent. Most treated effluents are still turbid. The silt density index (SDI) needed at the inlet of most membranes are <5, whereas even good quality treated effluents has frequently shown SDI >50. It may be noted that other components like transparent exopolymer molecules too result in higher SDI values.
- Scaling compounds: water with hardness contains scaling compounds, mostly calcium salts of sulphates & carbonates create huge issues of scaling in membranes. It may be noted that calcium sulphate is slightly soluble (upto about 2 g/l) beyond which it will precipitate on the membrane surface. Almost all calcium carbonates (solubility only about 0.015 g/l) are insoluble and add to scaling.
- Oxidizing compounds: All oxidizing compounds like peroxides, hypo chlorites etc. can affects membranes. Since textile industry is one which uses such oxidants and many ETP too uses such compounds for oxidation of organics, any residual of oxidants can damage the membranes.
- Micro-organisms: bacteria or viruses present in the water can affect membranes adversely. Since most effluent treatment plants involves cultivation of micro-organisms in biological treatment, microbial contamination of treated effluent is high.
- Silica: presence of silica can be a major bottleneck, particularly for high recovery RO systems. The limit of silica in reject side of RO is max 150 mg/l. This means, if the recovery of RO is 75%, the silica concentration in treated effluent should not be more than, say, 35 mg/l. If the overall recovery is 90%, the final stage of membrane get the maximum impact and inlet silica should be less than 15 mg/l to protect this membrane. Most silica in the textile effluent may come from raw water used and sometimes from the raw materials.

- Multiple salts: RO operation will be smoother if the salts present in the inlet is uniform. Treated effluents often has multiple salts which affects the interactive chemistry in the system and often reduce the flux rates.

6.2 Major pre-treatment units for ZLD-RO systems

- Most effluent recovery systems use membranes for purification
- Most membranes are designed to treat saline, but otherwise pure water, as input
- Membranes are prone to fouling (plugging) if treated effluent high in
    - Fine suspended solids (silt)
    - Organic compounds (BOD/COD)
    - Microbial population (mostly bacteria)
    - High hardness
- Make treated effluent fit for membrane systems such as Reverse Osmosis is a major challenge.
- Advanced tertiary treatment systems are useful for this purpose.

The pre-treatment needed for RO varies with the components of the treated effluent and their intensity. Following are the common pre-treatment units used in RO systems for industrial effluent treatment:

- Pressure filters for removal of suspended solids: various categories of pressure filters with natural and synthetic media are used for RO pre-treatment. Dual media filters (DMF) and multi-grade filters (MGF) are the more common units than mere pressure sand filters (PSFs).
- Micro-screens: self-cleaning type micro-screens are another type which is used for pre-screening of fine solids. Such screens are capable of removing particles in micron levels.
- Ultrafilters: UF pre-filtration is the common pre-treatment for RO which will ensure removal of all suspended & colloidal particles.
- Nanofiltration: NF as a pre-treatment to RO is used in some specific projects where some polyvalent Ions & organics need to be removed.

6.3 Need for softening, Technologies, cost-benefit analysis of softening

As mentioned earlier, hardness, particular Calcium hardness can be major issue with membranes. Removal of hardness through softening therefore is a requirement.

There are different methods to reduce the hardness which include

- Ion Exchange
- Zeolite resin exchange
- Lime-soda softening

obviously, the Ion exchange which is essentially a desalination process itself cannot be a suitable pre-treatment for RO. The other two systems are extensively used for softening as pre-treatment for RO.

6.3.1 Zeolite softening

Zeolites are also known as permutits. Zeolite is hydrated sodium alumino silicate, capable of exchanging its sodium ions for hardness-producing ions in water and reverse the process during regeneration. Zeolites can be (a) natural (e.g. Natrolite) which are non-porous and (b) synthetic which are porous & prepared by heating china clay, feldspar and soda ash together.

For softening of water by zeolite process, hard water is percolated at a specified rate through a bed of zeolite, kept in a cylinder. The hardness causing ions, mostly calcium and magnesium are retained by the zeolite as CaZe and MgZe; while the outgoing water contains sodium salts. After its scheduled working hours, the zeolite is completely converted into calcium and magnesium zeolites and its efficiency to soften water reduces. The exhausted zeolite is reclaimed by treating the bed with 10% brine solution where the sodium zeolite is regenerated.

Generally, zeolite softening is done on effluents which does not have high hardness levels and also where space constraints are important deciding factor.

The advantages of zeolite softening include:

- The system is simple and effective.
- The softener can be constructed like a pressure filter filled with the resin as the media whose operation & maintenance is well known to ETP staff.
- It does not generate any sludge for handling & disposal.
- it removes almost all the hardness and water of about l0 ppm hardness is produced.
- The equipment used is compact, occupying a small space.
- It can handle varying levels of hardness.
- The softening process requires less time.
- Since majority of the textile factories in Bangladesh have softener for raw water treatment, operation & maintenance of it is well known to them.

Limitation of zeolite process include

- It is not suitable for water with high suspended solids & turbidity.
- It increases the overall TDS of the water.
- Acidic pH may be detrimental to the media.
- Presence of Iron and Manganese in the treated effluent reduces its efficiency.

To start the unit, first fill the vessel with water and load the resin from top or through vacuum eductor. As a rule of thumb resin bed depth is 2/3 of the vessel volume. The zeolite resin captures the hardness contributing ions and after some time depending the capacity of resin bed the system is exhausted and requires regeneration. Resin require periodic regeneration and backwashing to dispose of the accumulated solids and re-activate the resin media.

The regeneration cycle contains four steps. First backwash is done to remove the accumulated suspended solids in the resin bed, water flow is directed to the bottom of the tank, up through the resin bed, and out the top to the drain. This process expands the bed and flushes out the suspended solids and prepare the bed for brine draw.

When backwash is completed, an approximately 8 -12% brine solution is directed to the top of the resin bed. As the brine flows downward through the resin bed, the hardness ions attached to the resin are exchanged for sodium ion. When the brine draw is complete, fresh water continues to be directed slowly through the resin bed, completing the ion exchange process and pushing the brine from the resin bed to the drain. This slow rinse is completed, a fast rinse is directed to the top of the resin bed and through to the drain, flushing the remaining hardness and brine from the resin bed. After fast rinse step the brine tank is refilled again prepared to be ready for brine draw for next regeneration.

Needless to say, in most effluent softening it is not a very effective due to impurities like suspended solids and metallic salts.

6.3.2 Lime-soda softening

As the name suggests, it is a softening method involving lime and soda ash. In this method, the soluble calcium and magnesium salts in water are chemically converted into insoluble compounds, by adding calculated amounts of calcium hydroxide (lime) and sodium Carbonate (soda ash). Resultant products are insoluble calcium carbonate and magnesium hydroxide, which are precipitated and then removed by settling.

Lime soda softening can be done in ambient temperature or high temperature. In cold lime-soda process, lime and soda is dosed to the treated effluent. The sludge formed may be lighter and finer. Hence often common coagulants/flocculants such as poly aluminium chloride or polyelectrolytes etc. are added to improve sedimentation. When lime soda softening is done at high temperature it is called hot-lime soda softening where the temperature is maintained closer to boiling. This kind of softening is faster, sludge will be thicker and removes more hardness.

A variant of lime soda softening is pelletizer, which uses carbon dioxide instead of sodium carbonate. Depending on the availability of carbon dioxide or flue gas, the process may be more economical and may produce less sludge.

Advantages of Lime-Soda softening include:

- No increase in TDS values, in fact some reductions due to removal of compounds like sulphates could be expected.
- Can handle higher hardness in effluent.

- It is more economical than zeolite softening when higher effluent quantity with higher hardness need to be treated.
- Process control is easy and well standardized.

Limitations of Lime-Soda process include:

- The process may not be very effective when very high levels of hardness is to be handled or when the suspended solids are too high.
- The softening Increase pH of the treated water, which may need a neutralization before RO.
- Need consumables for routine operation which need sourcing, storage and handling of high quantity of chemicals.
- Need relatively more area.

6.3.3 Filtration - Cartridge filters

Cartridge filtration is used as a last pre-treatment step before RO. The filter cartridges are usually 1-10 and act as a final polishing step to remove larger particles that passed through media filtration. Particulate matter greater than 5–10 mm can foul the channels used to remove RO concentrate and hence filter cartridges are considered as necessary final step before RO treatment.

The cartridge filters are used for very fine filtration. They are not back washable and there for considered as consumable. It is however, possible to clean the cartridges by soaking in cleaning solution. The may need replacement once they are clogged irreversibly.

Cartridge filters are usually very small in construction and is generally used in-line of pumping lines. They have usually pore sizes in range of 0.2 - 20 microns. Needless to cartridges with smaller pore size give better quality filtered water, but get clogged faster and need shorter replacement period.

There are surface filters & depth filters in cartridge filters based on the material of construction. Surface filters mostly resemble a paper filter whereas depth filters usually appears like tightly wound fiber cylinder.

A general comparison of the two types of filters are as follows:

Table 7: Comparison of surface & depth cartridge filters

Surface filters	Depth Filters
Examples: Pleated cartridge filter, cellulose filter	Examples: String wound filter, Ceramic filter and Sintered filters
Surface filters are with smooth surface - prevent solids getting inside	Depth filters trap all suspended solids within the layers of the media.
Effective for solids larger than pore size.	Can remove smaller particles than pore size

Eventually, surface filter gets caked on outside with solids: to be cleaned or replaced	Solids get in the filter layer and get trapped there, gradually the pores get blocked and have to be cleaned or replaced.
Surface filters are comparatively cheaper and have a shorter shelf life.	Depth filter is relatively expensive but it has a longer shelf life.
Mechanical strength of the filter medium is less (except stainless steel filter)	Mechanical strength of filter medium is high

Surface filter cartridge

Depth filter cartridge

Figure 6: Type of cartridge filters

6.4 RO pre-treatment

The primary goal of any RO pre-treatment system is to lower the fouling propensity of the water in the RO membrane system. Wastewaters typically have a greater propensity for membrane fouling and require more extensive pre-treatment systems than saline groundwater.

Conventional pre-treatment typically consists of acid addition cartridge filtration and dosage of antiscalants.

Acid treatment reduces the pH of the feed water (typical pH range 5–7), which increases the solubility of calcium carbonate, the key potential precipitate in many feed waters. The most common acid used to lower feed water pH is sulfuric acid, But, hydrochloric acid (HCl) is used when sulfuric acid addition has the potential to cause sulfate precipitates.

Antiscalants are primarily used as pre-treatment to RO and are typically dosed after granular media filtration, either before or after cartridge filtration. The choice of a specific antiscalant depends on the composition of the feed water; many antiscalants are commercially available and are designed to target specific problematic precipitates. Optimization of antiscalant type and dose is as important as coagulant optimization in primary effluent treatment. It is reported that higher antiscalant doses do not necessarily decrease salt precipitation, and the presence of certain potential precipitates can change the effectiveness of a particular antiscalant[8].

The use of antiscalants is not recommended if the concentration of certain potential precipitates is too high. Supersaturation of a salt can be described by the saturation index (SI) of the salt. The saturation index is the ratio of the ion activity product (the product of the activities of each ion in the salt) to the solubility product for the salt (tabulated values found in Stumm and Morgan). The limit for calcium carbonate ($CaCO_3$) is often expressed as the LSI, or the Langlier Saturation Index, which is the logarithm of the SI (log10(IAP/Ksp,$CaCO_3$)). Antiscalants are typically dosed between the membrane pre-treatment and the RO unit.[9]

6.5 Fine filtrations prior to RO as pre-treatment

A new trend in pre-treatment has been a movement towards the use of larger pore size membranes (MF, UF, and NF) to pre-treat RO feed water. Installations and pilot-scale testing of MF and UF membranes have increased; however, pilot tests show successful implementation of NF pre-treatment to RO as well. Both MF and UF modules have backwash (cleaning) and near dead-end modes of operation that give these membranes more operational flexibility than NF modules.

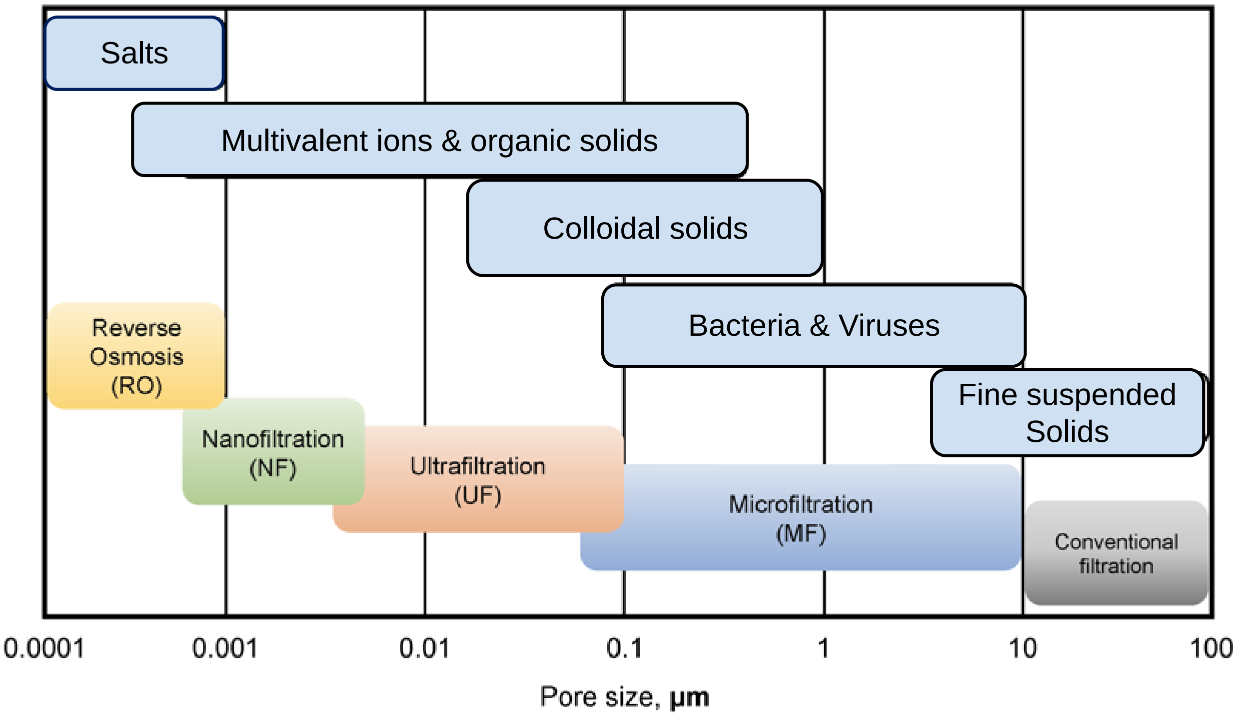

Figure 7: Comparative pore sizes of membranes

The micron filters in membranes are capable of removing bacteria and viruses. MF with pore sizes in between ultrafilter and conventional micro filtration are generally used in MBR systems. The commonly used MF membranes have pore size in the range of 0.25 -0.45 microns.

Ultrafilters are fine filters which can remove all suspended & colloidal solids. It reduces the turbidity & silt in water to very fine level. It is accordingly used as a pre-treatment to RO units in most effluent recovery units.

Nano-filters are used to remove organics & tighter NF can remove multi valent salts. RO membranes can remove salts too and allow only water to pass through. Most wastewater recycling systems and ZLD systems use RO membranes.

UF membranes seem to be, by far, the most common choice. UF membranes represent perhaps the best balance between contaminant removal and permeate production of the three membrane types; UF membranes have smaller pore sizes than MF membranes and higher flux than NF membranes. However, all three membranes have advantageous characteristics, and each treatment plant must choose pre-treatment based on specific contaminant removal issues. MF membranes are the appropriate choice for removal of larger particulate matter at higher permeate fluxes, while NF membranes are used to remove dissolved contaminants, as well as particulate and colloidal material. MF, UF, or NF provides several advantages as a pre-treatment to RO, in comparison to conventional multi-media filtration.

The membranes act as a defined barrier between the RO system and any suspended particles. Membrane pre-treatment can lower feed water SDI to less than 5 and can lower turbidity to less than 1 NTU.

Due to the superior removal of organic and particulate matter with membrane pre-treatment, the RO system can be operated at a higher permeate flux. Typical final permeate fluxes for a UF-RO system range from 15 to 24 L/m^2-h [10] while the permeate flux exiting the UF pre-treatment stage is within 60-150 l/m^2-h[11]. In addition, membrane pre-treatment reduces the general aging and destruction of RO membranes by feed water components; RO membrane replacement decreases, as well as the frequency of chemical (acid or base) cleaning. Membrane pre-treatment systems are, in general, decreasing in capital cost and are now becoming cost-competitive with conventional systems.

The key disadvantages of membrane pre-treatment lay in the inherent propensity of a membrane to separate foulants from product water and, in the process, become fouled itself. Both surface and pore fouling occur in MF, UF, and NF membranes. The risk of membrane fouling prevents general operation at high permeate flux (especially for feed waters with a high organic content), and fouling causes membrane damage and flux decline. NF membranes can also be subject to salt precipitation and membrane scaling, due to much smaller pore sizes. UF and MF membranes are typically replaced every 5–10 years.

6.6 Ultra-filtration as pre-treatment to RO: technology & conditions of usage.

The Reverse Osmosis membrane is protected normally by a coarser filter, often an ultrafilter. UF is a mechanical filter, but it can remove very fine particles, hence the name ultrafiltration. The UF can remove all suspended solids, microbial residue and some organics. Ultra-filter normally has a pore size of 0.01-0.08 microns. The UF membranes used as pre-treatment for RO can remove particles of 100-150 kilodaltons molecular weight.

Ultra-filter generally operates at lower pressure than RO or nano and usually need only about 3-5 bar pressure. Ultrafilter too is susceptible for fouling and is therefore often protected by conventional media filters and cartridge filters. The biggest advantage of ultrafilter is that unlike RO or nano, this can be backwashed. Whenever the transmembrane pressure increases beyond one bar, it is backwashed. It also needs clean in process (CIP) using specialty chemicals when deposits become high.

Operation of UF can be in dead end or cross flow mode. For dead-end filtration, the liquid flow direction is the same as the filtering direction. Particles larger than the pore size of the filter media in the raw water are trapped on the surface of the filter media, and the liquid and particles smaller than the pore size of the filter media pass through the filter media. In the process of dead-end filtration, the filter cake on the surface of the filter media will become thicker and thicker with time, and the pressure difference will become larger and larger. It is also necessary to use greater pressure for backwashing. Needless to say, this kind of operation can be suitable for effluents with very low TSS and less turbidity.

For cross-flow UF filtration, the liquid in the raw water and particles smaller than the pore size of the UF pass through the filter. Part of the particles larger than the pore size of the UF are trapped on the surface of the filter media, and part of the particles are washed away by the water which continuously scour the surface of the UF and get discharged as reject. Compared with dead-end filtration, the filter cake formed by cross-flow filtration is thinner, so the pressure difference and the pressure used for backwashing are smaller. Cross flow UF is more suitable for treated effluent which may have some suspended solids.

UF configuration can be tubular, spiral wound or hollow fibre. Hollow fibre is the most common. Hollow fibre filtration utilizes thousands of long, porous filaments ranging from 1-3.5mm wide, that are potted in place in a PVC shell. Each filament is very narrow in diameter and flexible. Hollow fibre can find uses in all types of filtration, ranging from microfiltration to reverse osmosis. Irreversible fouling and fibre breakage are the main problems concerning hollow fibre filtration. Because of the flexibility of the fibres, they are more likely to break when under high strain compared to other methods of UF filtration such as tubular or spiral wound elements. Hollow fibre membranes tend to have moderate capital costs, but high operating costs compared to other configurations.

The advantage of Hollow fibre membranes is that it can have a very high packing density because of the small strand diameter. Because of the flexibility of the strands, certain filter configurations are possible that cannot be achieved in other filtration configurations. They can also be back-flushed from the permeate side and air scoured, and can process feed streams with high total suspended solids.

The UF material can polyvinylidene fluoride (PVDF) or polyether sulfone (PES). Both material has got their specific advantages & disadvantages. While PES has got advantages like better throughput at lower pressure whereas the strength of PVDF material is higher than PVF and hence will not break so easily. Most of the new UF systems for treating textile wastewater is constructed in PVDF.

Efficiency of UF in removal of silt and turbidity vary with respect to type and characteristics of pre-treated water.

Results obtained by this author from a typical UF treating the filtered tertiary treated effluent in both dead end & cross flow mode with all three types of effluents (combined effluent, garment washing effluent and dye effluent), is given below, just for reference

Table 8: Performance of UF on Garment washing effluent

Operation Mode	Parameters	Influent to UF (outlet of ACF)			Outlet of UF			% redn average
		Value - range	Average value	Std. deviation	Value - range	Average value	Std. deviation	
Dead end	SDI	6.2 - 18.2	11.42	4.57	3.1-5.8	3.9	1.05	65.85
	Colour	68-212	110.4	73.26	42.2-88	55.6	11.4	49.64
	Turbidity	8.2-96.5	33.94	35.76	2.8-9.4	4.88	2.6	85.62
Cross flow	SDI	11.4 -22.5	15.3	4.54	5.5-7.8	6.22	0.92	59.35
	Colour	66.5-218	108.4	63.5	42.2-88	55.6	17.44	48.71
	Turbidity	8.2-96.5	32.2	36.6	2.8-9.6	5.12	2.7	84.10

Table 9: Performance of UF on Combined effluent

Operation Mode	Parameters	Influent to UF			Outlet of UF			% redn average
		Value - range	Average value	Std. deviation	Value - range	Average value	Std. deviation	
Dead end	SDI	8.1-19.8	10.45	3.85	3.2-5.2	3.8	1.05	63.64
	Colour	48 - 178	95.8	51.25	34.2-65.4	38.4	9.3	59.92
	Turbidity	10.5-88.4	41.4	31.4	2.8-9.4	4.88	2.6	88.21
Cross flow	SDI	10.8-20.2	14.8	5.1	5.8-6.2	6.1	0.88	58.78
	Colour	52.8-182	96.4	48.6	28.5-67	32.48	15.2	66.31
	Turbidity	5.8-82.4	38.5	32.3	2.6-9.4	5.7	2.6	85.19

Table 10: Performance of UF on Cotton dye effluent

Operation Mode	Param-eters	Influent to UF (outlet of ACF)			Outlet of UF			% redn average
		Value - range	Average value	Std. deviation	Value - range	Average value	Std. deviation	
Dead end	SDI	12.4-28.5	19.4	8.09	4.8-7.2	4.83	1.9	75.10
	Colour	142 - 285	95.8	51.25	58.4-102	76.8	17.34	19.83
	Turbidity	12.2-92	60.84	29.4	3.9-11.4	7.02	2.9	88.46
Cross flow	SDI	11.6-26.2	18.96	5.21	5.2-7.9	6.18	1.27	67.41
	Colour	136 - 220	165.2	33.69	72-172	124.8	37.05	24.46
	Turbidity	13.5-88	47.3	27.45	4.3-13.2	7.46	3.55	84.23

It may be seen that except for the colour, rest of the parameters are close to the required values at the inlet of RO. It is also clear that dead-end mode is more efficient compared to cross flow. But dead-end ode is more prone to clogging & the life span of membrane is shorter. Hence a choice need to be made based on the situation.

6.7 Nano filtration as pre-treatment to RO: technology & conditions of usage

The UF can be an effective pre-treatment to RO by removing the fine dust which can be a major cause fouling of RO membrane. However, the UF does not reject any dissolved solids or ions which can cause issues in RO because of its pore size being high. Even the UF with lowest pore size (so far 5000 Daltons were the lowest known molecular weight cut-off in UF applied in effluent treatment of textile effluent) does not remove any hardness causing ions.

To minimize scale formation potential in reverse osmosis (RO) membranes as a pre-treatment unit, nanofiltration membrane systems could be used to remove divalent ions/ polyvalent Ions from treated effluent.

The advantage of a NF before RO could be that some of scaling compounds could be removed so that RO can operate without much problem. Since NF needs relatively lower pressure, power cost be lower vis-à-vis RO.

Another application of NF before RO is to segregate sodium sulphate from mixed salt liquor which allow some sulphates and most of sodium chloride pass through. The reject of NF with higher concentration of sodium sulphate is processed to recover the Glauber salt through chilling and the mother liquor after chilling is evaporated. It has been reported to be practiced in some ZLD units.

There are few disadvantages to NF-RO combination systems. NF too can be fouled by all compounds which fouls the RO. However, unlike the UF, NF cannot be backwashed. The cleaning requirement and replacement of membranes are similar to RO. Further, since NF too generate significant quantity of reject, overall quantity of reject from a NF-RO combination would become higher compared to reject from an RO unit alone. Also, the NF stage increases the overall O & M requirement and membrane replacement volume.

7 REVERSE OSMOSIS FOR EFFLUENT RECOVERY

7.1 Reverse osmosis systems: definition, principle and technology

Reverse osmosis uses a membrane that is semi-permeable, allowing the fluid that is being purified to pass through it, while rejecting the contaminants that remain. Most reverse osmosis technology uses a process known as crossflow to allow the membrane to continually clean itself. As some of the fluid passes through the membrane the rest continues downstream, sweeping the rejected species away from the membrane.

The process of reverse osmosis requires a driving force to push the fluid through the membrane, and the most common force is pressure from a pump. The higher the pressure, the larger the driving force. As the concentration of the fluid being rejected increases, the driving force required to continue concentrating the fluid increases.

Reverse osmosis is capable of rejecting bacteria, salts, sugars, proteins, particles, dyes, and other constituents that have a molecular weight of greater than 150-250 Daltons. The separation of ions with reverse osmosis is aided by charged particles. This means that dissolved ions that carry a charge, such as salts, are more likely to be rejected by the membrane than those that are not charged, such as organics. The larger the charge and the larger the particle, the more likely it will be rejected.

7.2 Types of Reverse Osmosis membranes, comparison

RO systems generally consist of pre-treatment, high pressure pump, RO membranes. In spiral wound configurations RO membranes are stacked in pressure vessels (often FRP).

Usually there are six membranes in one pressure vessel. RO membrane made by modified polymerization process, leaves openings of molecular size. RO membrane comes in different configuration depends on how the membranes are arranged in a vessel.

The most common configuration is spiral wound. For wastewater applications, disc & tube is popular.

7.3 Types of membrane configurations:

There are four main types of membrane configurations, viz., plate & frame, tubular, spiral wound & hollow fibre. Plate-and-frame module is the simplest configuration, consisting of two end plates, the flat sheet membrane, and spacers. In tubular modules, the membrane is often on the inside of a tube, and the feed solution is pumped through the tube.

Most popular configuration for nanofiltration or reverse osmosis membranes is spiral wound. Here membrane is wrapped around perforated permeate collection tube. Hollow fibre modules are used for seawater desalination consist of bundles of hollow fibres in a pressure vessel.

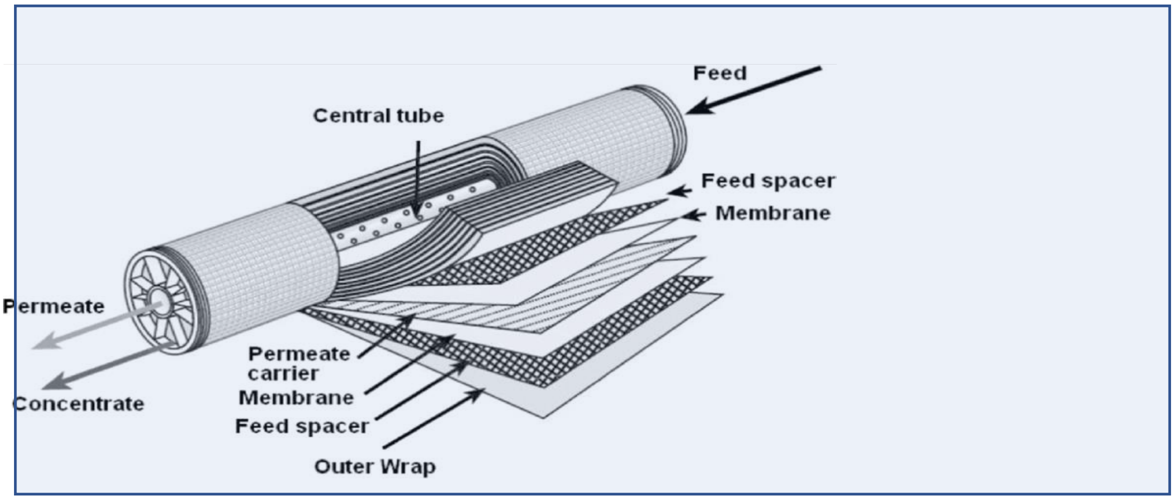

Figure 8: Spiral wound configuration of RO membrane

Figure 9: Disc & Tube configuration of RO membrane

7.3.1 Membrane used in Reverse Osmosis

Though many types of membranes are available in the market, spiral wound configuration is the most common one. Spiral-wound membrane elements (sepralators) were used mainly for basic water purification until the mid to late 1970s, when broader uses began to receive attention. New applications often required special consideration such as; sanitary construction, high temperature and high-pressure capability for desalination. In addition, aggressive chemicals either in the feed stream or in necessary cleaners had to be dealt with.

As the sophistication of the membrane industry grew, so did increased use of specialty polymers, improved adhesives, more engineering thermoplastics, and even stainless steel in sepralators and their ancillary parts. This has allowed the expanded scope of application, which continues to grow today.

7.3.2 **Design of spiral wound membrane**

Original designs used a plastic tape outer cover with a concentrate seal to direct flow through the feed channels. The permeate tube protruded from the material package on each end; requiring this thermoplastic part to bear the entire axial compressive load for the series of sepralators (up to six) placed in one housing. An FRP outer cover was then developed for both handling protection and improved hydraulic load-bearing.

A "close-coupled" design followed where the sheet materials are trimmed flush with the permeate tube end. This maximizes the available space in the housing and efficiently transfers the load between sepralators. Most commercial sepralators today employ this design.

7.3.3 Membrane materials

The membrane is usually the compatibility limiting component of a sepralator. Thus the advantages of the spiral-wound design make it the first configuration to consider for all four membrane classes (RO, NF, UF, MF). Membrane choice is often governed by compatibility considerations rather than separation performance and flux-related characteristics.

The evolution of membrane materials for RO sepralators began with the cellulose acetates (which are still workhorses). Both homogeneous and thin-film composite polyamide membranes followed to provide wider pH range, improved separation and biological degradation resistance. Since these are more expensive and less tolerant of oxidizing agents than the cellulosics, they have nearly replaced cellulose acetate for RO. Sulfonated polysulfone RO membrane is more resistant to oxidation, but must be operated on completely softened, brackish water to maintain its salt rejection capacity, which is not as high as the polyamides to begin with.

7.3.4 Accessories to Membrane systems: Membrane supports, adhesives & feed channel spacers

Membrane backing materials (substrates) are usually required for support and therefore are a factor in sepralator performance (although often overlooked). Available in woven, non-woven or spun-bonded form, the polymers are typically polyester or polypropylene. The fabric manufacturers have now identified membrane supports as an attractive market, and alternate materials and improved mechanical properties are being developed at an unprecedented rate to overcome the chemical limits of polyester and temperature/strength/ adhesion limits of polypropylene. Wovens provide a uniform surface for coating but are expensive. Non-wovens and spun-bondeds are much less expensive but lack of uniformity can cause quality and manufacturing yield problems. Price, uniformity, and of course operating capabilities are three factors the membrane and sepralator manufacturer must evaluate for every substrate.

A permeate carrier fabric (PC) is also an essential support material for spirals. Traditionally a tricot weave, PCs are chemically treated to attain compressive strength. Treatment was initially melamine, but the advent of epoxy sizing in the early 80s has improved heat and chemical resistance. High pressure operation, especially at elevated temperatures, was improved by changing weave patterns and thread density of the PCs, as well as by a few novel approaches (both patented and proprietary) to the use of common fabrics and films.2 Monofilament weaves, although sometimes limited to low pressure operation, are useful in certain applications.

Adhesives are frequently a problem and often are the next weak link after the membrane. Adhesives must be somewhat flexible when set, and have certain manufacturing related handling characteristics. These requirements have limited the available choices.

Improvements are considered proprietary. Typical adhesives have a long-term upper temperature limit below that of some of the membranes. Solvent compatibility may also make the adhesive the weak link. While substantial progress has been made, adhesives remain an area of focus for sepralator improvement.

Early feed spacers act as turbulence promoters and were limited to co-axially extruded, diamond-mesh polypropylene. These fabrics were only available about 0.030 inch thick (0.8 mm) & with 8-11 strands per inch. This design has changed little over the years and still predominates in water purification & most process applications, due to the general success of the design. However the size and configurations available in mesh net spacers have expanded in recent years.

The results of the Levy and Earle study is just the most recent confirmation of the long established fact that the presence of a mesh spacer over a cross flow membrane surface maintains higher flux. On a 1% bovine serum solution, the membrane flux in a cross flow cell was 39% higher with a diamond-mesh spacer than with no spacer at similar "wall shear rates."3

Varying the thickness of the spacer is a simple way to extend the range of applications for the sepralator. Thinner mesh spacer can be used in ultrapure water treatment and other low fouling applications to increase membrane area. Thicker mesh spacers (up to 2 mm) reduce effective membrane area but may also reduce fouling and channel plugging.

Reverse Osmosis is the finest of all membranes. It is manufactured by polymerization process, modified to create molecular level pores in it. It has pore size so small that even the salt molecules are filtered out and only water is allowed to pass through. RO operates under very high pressure. Pressure depends on inlet salt concentration. Unlike MF or UF, RO units are not backwashed and cleaned only using chemicals.

7.3.5 Membrane cleaning chemicals

Keeping membrane clean is an important aspect to ensure good performance and longevity of membrane. To obtain this, RO inlet is kept at slightly acidic side to reduce scaling potential. Periodically, membrane cleaning by cleaning-in-process (CIP) is done. Special CIP chemicals with acid/alkali cleaning is used for this process. Over a period of time, RO recovery rate (flux rate) comes down due to scaling. At the stage when cleaning does not improve recovery, membranes are replaced (2-4 years).

A combination of acidic and/or basic (alkaline) chemicals is used to clean RO membranes. Common acidic solutions include hydrochloric acid, phosphoric acid, sodium hydrosulfate and sulfamic acid while alkaline chemicals include sodium lauryl sulfate, sodium hydroxide, sodium ethylenediamine tetra acetic acid and proprietary cleaners. Most cleaning solutions are made from stock chemical solutions to a final concentration of 0.03–2.0% (wt.).

7.3.6 Membrane flow configurations

Membranes can be used in either dead-end or crossflow filtration. RO membranes are typically operated in crossflow mode and are most commonly available as spiral wound modules, where the membrane sheets are wound around an inner tube that collects the permeate.

Most membranes allow filtration through pore flow, where the fluid is forced through the membrane by a positive hydrostatic pressure. The fluid flow depends upon the membrane porosity, the fraction of membrane volume that is void space and can contain liquid, and tortuosity, the distance a molecule must travel through the membrane divided by the thickness of the membrane. Fluid flux through membranes also occurs due to diffusion.

7.3.7 Membrane pore sizes

RO membranes do not have distinct pores that traverse the membrane and lie at one extreme of commercially available membranes. The polymer material of RO membranes forms a layered, web-like structure, and water must follow a tortuous pathway through the membrane to reach the permeate side. RO membranes can reject the smallest contaminants, monovalent ions, while other membranes, including nanofiltration (NF), ultrafiltration (UF), and micro- filtration (MF), are designed to remove materials of increasing size. Membranes are also categorized by the molecular weight cut off (MWCO) of the membrane, or the molecular weight where the membrane will retain 90% of the solute in solution. The general MWCO ranges for UF and NF are 2000–500,000 Da and 250–2000 Da. For MF and UF membranes, the diffusion term is negligible compared to the convection term. Solvent transport through NF membranes occurs through a combination of convective flow and diffusion.

Transport through RO membranes, however, is controlled by diffusion, and no open channels exist for pore flow; the RO transport mechanism has been termed solution-diffusion [(12)]. In the solution-diffusion model, water transport across an RO membrane occurs in three separate steps: absorption onto the membrane surface, diffusion through the thickness of the membrane, and desorption from the permeate surface of the membrane.

Once a water molecule has absorbed onto the membrane surface, the water concentration gradient (of the water-membrane system) across the membrane causes the water molecules to diffuse down the concentration gradient to the permeate side of the membrane. The water molecule then desorbs from the membrane and becomes part of the bulk permeate.

An RO membrane is operated by achieving a hydrostatic pressure greater than the osmotic pressure of the solution. The positive difference in pressure creates a chemical potential difference (concentration gradient) across the membrane that drives the liquid through the membrane against the natural direction of osmosis (the movement of water molecules from an area of high concentration to an area of low concentration), while the salts are retained and concentrated on the influent surface of the membrane. Some salt passage through the membrane does occur; salt passage for the same membrane increases with salt concentration and temperature[(13)].

Operating an RO module at a higher permeate flux often results in flux decline and operating an RO module at higher recovery without an increase in flux causes an increase in salt passage. [(13)] During RO operation, concentration polarization occurs at the surface of the membrane where dissolved ions accumulate in a thin layer of the feed water; concentration polarization is the ratio of the salt concentration at the membrane surface and the salt concentration in the bulk solution. At any recovery, concentration polarization causes greater salt permeation through the membrane than what would be expected based on bulk solution salinity.

When a membrane module is operated at higher recovery, the concentrate or reject stream becomes more concentrated, thus increasing the concentration at the membrane surface. As the salinity increases at the membrane surface, the local osmotic pressure increases as well. Consequently, the overall pressure difference between the hydrostatic pressure and the osmotic pressure decreases, decreasing permeate flow, and the increase in salinity at the membrane surface increases salt transport through the membrane. In addition, phenomena such as salt precipitation and fouling can increase due to the higher local salinity.

Salt flux is a function of salt concentration, and salt transport occurs from a region of high salt concentration to a region of low salt concentration. To overcome the osmotic pressure, feed pressures in seawater applications range from 6000 to 8000 kPa, whereas those in brackish water are 600–3000 kPa. Recovery is an important indicator of RO performance.

7.4 Membrane fouling mechanisms

Two fouling mechanisms are generally observed for membrane processes: surface fouling and fouling in pores. However, RO membranes do not have distinguishable pores and are considered to be essentially non-porous. Thus, the main fouling mechanism for RO membranes is surface fouling. Surface fouling can occur from a variety of contaminants, including suspended particulate matter (inorganic or organic), dissolved organic matter, dissolved solids, and biogenic material. In addition, fouling can develop unevenly through a membrane module or element and can occur between the membrane sheets of a module, where spacers are located to create space for the concentrate stream. Overall, sea water RO plants, particularly those treating water from an open water intake, are primarily fouled by organic and particulate material, while brackish water RO plants are fouled by dissolved inorganic salts and precipitation. However, both types of RO can experience both general groups of contaminants. In addition, the types of problematic foulants are site-specific, particularly for brackish water RO, and can depend on pre-treatment processes.

The capacity of a water to foul RO membranes is often described using the silt density index, or SDI. The SDI of a water is determined from the fouling rate of a 0.45 mm filter at a pressure of 207 kPa (30 psi) and is described in the ASTM standard method D4189 (ASTM, 2007). Kremen and Tanner (1998) showed the relationship between SDI and water fouling propensity by relating the SDI to a total flow resistance. The total flow resistance (Rt) is the combination of two resistances, the resistance of the filter (RP) and the resistance of the foulant (on the filter) (RF). The theoretical relationship between SDI and Rt, displays an exponential relationship between increasing SDI and increasing foulant resistance (or increasing foulant accumulation on the membrane)[(14)]. This relationship indicates far greater fouling resistance between SDI values of 4 and 5 than between SDI values of 1 and 4. Therefore, ideally, a pre-treatment scheme that can lower the SDI to below 2 (membranes) will provide a water with a lower fouling propensity than a pre-treatment scheme that provides an SDI of 3–5 (media filtration) (14).

An index similar to the SDI, the modified fouling index (MFI), has been developed to better correlate membrane fouling, flux decline, and particle concentration. The original MFI method used a 0.45 mm microfiltration membrane in dead-end filtration and provided a linear correlation between the index and the particle concentration(15). However, the MFI did not always accurately predict the fouling observed in membrane systems, due to the number of small particles that pass through the 0.45 mm membrane. More recently, a modified MFI, the MFI-UF, has been developed; the MFI-UF uses ultrafiltration membranes to retain a larger portion of the small particles that can pass through microfiltration membranes but will foul an RO membrane. The MFI-UF has subsequently been used to analyze pre-treatment performance and RO membrane fouling potential during plant operation(16)

Turbidity, a measure of the light scatter by particles in solution, is also often reported as a measure of pre-treatment efficiency. Measured in NTU (nephelometric turbidity units), turbidity is recommended to be less than 2 NTU for successful RO treatment. Raw water can have turbidities between 0.1 and several hundred NTU;

Both conventional and membrane pre-treatment lower the SDI of feed water, but each pre-treatment choice may have negative and positive aspects, technologically and financially. An SDI of 3 or less is preferred for RO influent(17). Both SDI and turbidity have limitations in predicting the quality and fouling ability of a RO feed water. The SDI test uses a dead-end filtration cell, whereas most commercial RO membrane modules operate in crossflow mode. In addition, the membrane (0.45 mm) used for SDI does not retain contaminants such as biological polymers; biofouling, often a critical concern for RO operation, cannot be predicted by SDI(17). In addition, SDI values do not correlate linearly with colloidal or suspended matter, two important foulant groups. Research has shown varying fouling problems that do not necessarily correlate to the SDI value of the feed water and therefore, SDI can be used as one indicator of the fouling potential but should not be relied upon as the sole indicator for fouling. No direct relationship between SDI and turbidity is possible, although low SDI values often correspond to low turbidity.

The critical fouling problem in brackish water RO systems is salt precipitation and membrane scaling. The higher relative concentrations of calcium, carbonate, and sulphate, combined with the higher recoveries possible for brackish water, cause calcium sulphate and carbonate precipitates to be typical concerns in brackish water RO. An important factor in the membrane fouling potential of dissolved inorganics is concentration polarization. While calcium carbonate is often the primary precipitate of concern, many other salts can be problematic in brackish water RO. Calcium sulphate precipitation and membrane scaling have been extensively studied; barium sulphate, strontium sulphate, and silicates, have low solubilities and can become limiting factors in brackish water RO recovery(18). However, barium and strontium precipitates tend to be less important because the cations are present in low concentrations, as compared to calcium.

The process of membrane scaling occurs in several stages. The first stage of homogeneous precipitation occurs when ions of opposite charge associate and begin to cluster together in large groups (>1000 atoms). In the second stage, the ion clusters begin to form nuclei, characterized by more orderly association and aligning of ions. The third, and final, stage is the growth of salt crystals on the formed nuclei (seed crystals). While the first two stages are reversible, the third stage is irreversible and will continue to occur until the ion concentrations decrease to reach the solubility limit. Heterogeneous precipitation may also occur, where nuclei or ion clusters precipitate associate with suspended or colloidal particles in solution [(19)]. In addition, metals such as magnesium, barium, and strontium often coprecipitate when salts such as calcium carbonate precipitate.

Chemicals called antiscalants are used in RO systems to prevent precipitation. Antiscalants prevent precipitation by disrupting one or more aspects of the crystallization stages. In particular, antiscalants are able to be used at relatively low concentrations (<10 mg/L), where the ion concentrations are stoichiometrically much higher. Antiscalants are effective in increasing the ion concentration threshold required for clustering, as well as disrupting the nuclei ordering and crystal structure. Some antiscalants also will adsorb onto crystal surfaces and repel other ions in solution or fully chelate with dissolved ions. Of all of the possible actions between antiscalants and ions, only the chelation mechanism requires equimolar amounts of ion and antiscalant.

Antiscalants were originally developed in the 1800s for use in boilers and cooling water. Today, the chemicals have been adapted for use in RO systems. Antiscalants are organophosphonate-, polyphosphate- or polymer-type compounds that are added to the feed water before the feed enters the RO modules. Antiscalants do not completely prevent precipitation at high ion concentrations, and as the salt concentration increases, precipitation will eventually occur.

Antiscalants themselves can become foulants if used at excessive concentrations. Typical antiscalant concentrations in the RO feed do not exceed 35 mg/l and are often less than 10 mg/l [(19)]. Some antiscalants have additional limitations: polyacrylic acid antiscalants will foul membranes in the presence of high iron concentrations, and hexametaphosphate (SHMP) will eventually hydrolyze in the presence of air, producing inorganic phosphate, possibly leading to calcium phosphate precipitation. High concentrations of antiscalants in feed tanks or dosing systems can promote precipitation and biological growth, and the placement of the antiscalant dosing system is critical to avoid unwanted reactions with other chemical addition.

In addition, chemicals used in tertiary treatment for coagulation can carry through the system and cause RO membrane fouling. Other water components, such as silica, can cause membrane fouling in association with added pre-treatment chemicals; aluminium silicates will precipitate during RO operation.

To determine the composition of the foulant cake deposited on the membrane surface Tran et al. conducted a study of a spiral wound RO membrane after it had been used for one year in a desalination plant (surface brackish water: 900 mg/L TDS), using advanced analytical and microscopic techniques. The results showed that foulants initially deposited on the membrane surface as a thin, amorphous layer (<1 mm thick) containing particulate matter. Layered on top was another amorphous layer (w3 mm thick) containing mostly extracellular polymeric material from organisms and some aluminium silicate. A third and final layer formed in areas where the first two layers were thicker (w10 mm total) and consisted solely of aluminium silicate crystals; in this case, the second amorphous layer contained no aluminium silicate. Further analysis showed high concentrations of calcium, chloride, aluminium, and phosphorus, indicating sparingly soluble salt precipitation ($CaCO_3$), hindered diffusion or entrapment of dissolved ions, and the presence of pre-treatment chemicals (aluminium coagulant and phosphonate antiscalants), respectively. The amorphous matrices contained high levels of carbon, oxygen, phosphorus, and aluminium, indicating organic and biologic material and silicate crystals[20].

7.5 Reverse osmosis system design

Typical operating ranges for key RO parameters have been studied extensively. Due to lower feed water TDS concentration, most parameter values for BWRO are less constrained than seawater RO. In addition, the RO flux can be highly dependent on membrane fouling, and the maximum flux of a specific commercial membrane is limited by the specifications of the manufacturer. The normal operating range of pH values remains the same for both types of RO membranes due to precipitation control and membrane materials.

Feed water characteristics play a large part in the RO system design. For a one-pass RO unit, with a salt rejection of 99.7% and a recovery of 35%, the TDS concentration in the permeate would range from 300 to 400 mg/l. If the product water target concentration for TDS is much below 200 mg/l, at least two passes are necessary to achieve the target value. In addition, individual components of a feed water can affect RO system design.

The basic system design for Brackish water RO is critically different from seawater RO; in brackish water RO, the feed to a second stage is the concentrate from the first stage, whereas in seawater RO, the feed to a second pass is the permeate from the first pass. This key design difference results from the lower TDS concentrations found in brackish water and allows BWRO systems to achieve much higher system recoveries. Brackish water RO systems often consist of two stages, and each stage has a recovery of 50–60%, achieving an overall system recovery of 70–85%. Some RO systems also use NF membranes for salt removal. NF membranes can be used in series following the RO system to treat the RO concentrate and increase system recovery; the RO and NF permeates are blended together as product water. Apart from the number of stages, another important decision in brackish water plant design is the method of concentrate disposal. The ideal solution would be to further increase BWRO recovery, but membrane scaling limits RO systems.

Some research has focused on combination of existing technologies to increase overall system recovery. Almulla et al. (2002) investigated different strategies to increase overall recovery from 70–75% to 90–95%, including HP-RO membrane treatment of normal RO concentrate, UF treatment of multi-media filtration backwash, and crystallizer-UF treatment of RO concentrate. The HPRO membranes were operated at a feed pressure of 2700 kPa and a recovery of 40%, increasing the overall recovery from 73% to 83%. During this RO concentrate treatment, precipitation of calcium carbonate, magnesium sulfate, and silica dioxide limited the recovery. Crystallization could remove significant portions of the silica (83%), calcium (92%), and magnesium (92%), the overall system recovery due to crystallizer-UF concentrate treatment was estimated at 95%(21).

Both the relative capital cost and the energy cost (per unit of plant production capacity) of a RO plant decrease as plant size increases(21). The energy required by a RO system is primarily used to power pumps; the larger the plant, the greater the required power for larger pumping systems.

Data from operational RO systems in textile effluents shown that the power costs can account for up to 40-50% of the total plant operating and maintenance costs. The second largest cost is typically fixed costs (approximately 37%), including capital investment amortization and insurance. Other costs include maintenance and spare parts (7%), membrane replacement (5%), labor (4%), and consumable chemicals (3%). Capital costs remain slightly higher than multi-media filtration capital costs, membrane pre-treatment can substantially lower RO operation and maintenance costs, particularly the cost of RO membrane replacement. However, membrane pre-treatment still tends to be more expensive than conventional pre-treatment due to the higher cost of membrane replacement relative to the operating and maintenance costs of media filtration.

Factors resulting from lower feed salinity, including the lower energy requirements and less frequent membrane replacement, help decrease the permeate water cost. The pre-treatment costs can represent a significant portion of the capital cost, particularly if membrane pre-treatment is chosen.

Initially, the membrane manufacturers never considered wastewater recovery as a serious business at all and all their focus was solely on seawater desalination. Now many manufacturers are giving attention to RO membranes is in wastewater treatment where water recovery is needed and where the limits for COD is not achieved due to presence of trace organic contaminant, the removal of which is very difficult. Using RO membranes in wastewater treatment presents unique process challenges; calcium salt precipitation can occur, and wastewaters tend to have much higher organic carbon content. Membrane fouling and pre-treatment design will be primary concerns as RO systems are developed for wastewater treatment. The development of energy recovery devices and hybrid desalination/power plants has allowed significant advances in energy recovery. In addition, new RO membrane module design, including larger diameter spiral wound modules and high-flux membranes, has provided cost and energy efficiency improvements to the typical RO system design. Further research and technology development in energy recovery and system design will allow additional gains in energy recovery and cost reduction.

It was reported that a key limitation to commercial polyamide RO membranes and treatment system design is membrane degradation through contact with chlorine, one of the common disinfectants used in wastewater treatment. Recent research in novel membrane materials and polymer chemistry has resulted in the development of sulfonated polysulfone composite membranes that are highly resistant to chlorine attack(22). Commercial development of chlorine-resistant membranes would eliminate the need for de-chlorination of the RO feed and re-chlorination after the membrane system, reducing the overall cost of RO.

It is expected that the need for RO membranes for wastewater applications will continue to increase in the future, and the primary limitations to cost and technical feasibility of concentrate disposal will be addressed better. Optimization of anti-scalant dosing, chemical addition, and pH control is necessary to improve the cost of concentrate treatment. Full-scale use of concentrate treatment is just beginning and will be necessary to allow economic use of inland brackish water resources.

The demand for better water quality standards will cause further optimization and development in RO membrane technology. As membrane costs decrease, the use of membrane pre-treatment will become a more viable alternative to conventional pre-treatment. Particularly for surface water sources, membrane pre-treatment is a constant barrier to particulate and colloidal RO membrane fouling and can greatly improve RO feed water quality. Research on SDI values and membrane fouling has shown that SDI is not always an appropriate indicator of RO fouling. An improved method for prediction of fouling potential is needed.

Membrane technology has improved, allowing significant increases in product production and cost savings. While the basic operating principles remain the same for all RO applications, individualized applications have developed, based on feed water quality. In particular, the two key types of feed water, seawater and brackish water, have distinguishing features that demand specific parameter adjustment and system design. Brackish water RO membrane systems typically consist of two RO stages in series; key issues include salt precipitation and concentrate management. Further improvements in membrane technology, energy use, and concentrate treatment will allow a wider application of RO to inland and rural communities.

7.6 Major control parameters of RO systems: SDI, LSI, membrane pressure, flux rates

7.6.1 Silt Density Index (SDI)

Silt is composed by suspended particulates of all types that accumulate on the membrane surface. Sources of silt are organic colloids, traces of chemical sludge and fine particular matter.

Silt Density Index testing is a widely accepted method for estimating the rate at which colloidal and particle fouling will occur in reverse osmosis or Nanofiltration membranes. SDI is a measurement of the fouling potential of suspended solids. It is not measuring the quantity of particular matter, since the fouling potential vary with size & shape of the particles.

An SDI value of less than 5 is required for low fouling of membranes. The SDI test is used to predict and then prevent the particulate fouling on the membrane surface. The test is defined in ASTM Standard D4189, the American Standard for Testing Material.

It measures the time required to filter a fixed volume of water through a standard 0.45µm pore size microfiltration membrane with a constant given pressure of 30 psi (2,07 bar). The difference between the initial time and the time of a second measurement after normally 15 minutes (after silt-built up) represents the SDI value.

SDI is often confused with Turbidity. Turbidity is a measurement of the opacity of the water and is not necessarily proportional to the amount of suspended solids. SDI and Turbidity are not the same and there is no direct correlation between them. In practical terms however, the membranes show very little fouling when the feed water has a turbidity of < 1 NTU.

7.6.2 Langelier Saturation Index

The Langelier Saturation Index (LSI) is a measure of water balance developed by Dr. Wilfred Langelier to know if/when water becomes corrosive or scale-forming. In short, the LSI tells us how saturated our water is with calcium carbonate.

Perfect saturation is 0.00 LSI and the acceptable range is 0.30 to + 0.30 LSI. Perfectly balanced water is zero (0.00) LSI.

If the LSI is lower than -0.31, water will dissolve calcium from the most available sources first. If the LSI is -0.31 or below, water is aggressive because it is under-saturated with calcium carbonate. Above +0.31, the water has too much dissolved $CaCO_3$, so it begins to precipitate $CaCO_3$ out. The result could be carbonate scale, plaster dust, or other forms of $CaCO_3$.

Calculation of LSI is complex and there are many programs available on the net to calculate LSI online. To calculate the LSI we need to know the wastewater value of pH and pHs, which is the pH at saturation in calcium carbonate. LSI = pH - pHs

7.6.3 Trans-membrane pressure (TMP)

Transmembrane pressure is defined as the difference in pressure between two sides of a membrane. It is a useful measurement as it indicates how much force is needed to push water (or any liquid to be filtered through an RO or NF membrane. Each membrane has an optimum TMP based on its material composition. In dead-end configuration of membranes, it is a clear value with inlet pressure minus the permeate pressure. However, it is little complex in the crossflow filtration which involves recirculation of the feed. Here TMP is subject to both concentration polarization and membrane fouling.

To estimate TMP, first measure the feed pressure. Then measure the pressure of the reject. This is the reject pressure. Finally, measure the pressure on the opposite side of the membrane, i.e. the permeate. Thereafter add feed pressure and reject pressure. Then divide this sum by two and subtract the permeate pressure. The result is the Transmembrane pressure.

7.6.4 Membrane Flux

The membrane flux is defined as the daily or hourly water flow through a membrane's surface area i.e. litres per day/square meter of membrane surface or litres per square meter per hour ($l/m^2/h$). Most membrane manufacturers refer the flux values of their products as lmh.

The flux rate depends on the membrane type and the operating conditions including the feed pressure, temperature etc.

7.7 Prevention of membrane fouling

Fouling of membranes is the major issue when the same is used for wastewater recovery. It occurs when the pores of the membrane gets blocked by solids. Prevention & minimisation of fouling can be done either by (a) precautions in design and/or (b) correct operation and cleaning practices.

Fouling of membranes are minimised through better membrane coatings & higher feed spacers. Newer membrane materials, e.g. poly vinylidene difluoride (PVDF) instead of polyether sulphone (PES), mostly for UF membranes. While PES give better membrane flux, PVDF is sturdier and hence more suitable for input with contaminants.

The RO vessels are arranged in arrays with flow of raw water and part of rejects are balanced. 2 +1 array is the simplest of this arrangement.

Clean-in-process (CIP) is done whenever membrane flux rates decrease and transmembrane pressure increases.

7.7.1 Factors affecting recovery from RO

- Percentage of water recovery
  - The feed pressure and fouling potential increases exponentially with increase in recovery. Hence the recovery drops at higher percentage of recovery.
  - Getting 70% recovery compared to 60% is several times more difficult
- Feed water quality
  - If the input water is high in silt and organics, the fouling potential increases and reduce recovery.
  - If the total dissolved solids in the feed water is high it reduces the membrane flux rates and reduce recovery.
- Quality of the membranes
  - Much research is progressing on the membrane material and configuration.
  - Low fouling brackish water membranes give good recovery.
  - Higher pressure membranes can higher recovery with higher salinity.
- Pre-treatment to RO

- If the input water is turbidity, silica & silt density index is kept low, recovery will be high.
- Good pre-treatment (commonly involves a UF pre-filtration) would get good & consistent recovery from RO.

7.8 Selection of membrane material for textile wastewater treatment

Since there is a huge variation in quality of treated wastewater, it is not easy to conclude which membrane material is suitable for textile wastewater. A typical comparative study done by this author using membranes of different material is presented here just for reference. In actual scenario, it is always required to take the actual effluent quality into account and if possible conduct a pilot study using the model suggested by the supplier.

Table 11: Comparison of different membranes

MoC	Polysulfone co-polymer (Membrane 1)	TFC polyamide (Membrane2)	Polyamide Urea composite (Membrane3)	Polyamide thin film composite (Membrane4)	Aromatic polyamide composite (Membrane5)	Polyamide thin film composite (Membrane6)
pH range	2 - 10	4 – 11	2 - 11	2 – 11	2 – 11	3 – 10
Operational flux l/m^2/h	19-26	18 - 28	20 - 28	19 - 31	19 – 29	20 - 22
Feed SDI needed,	<5	<4	<5	<5	<4	<5
Max. feed turbidity	2	1	2	2	1	1

Performance of the membranes against various SDI levels at the inlet was as follows:

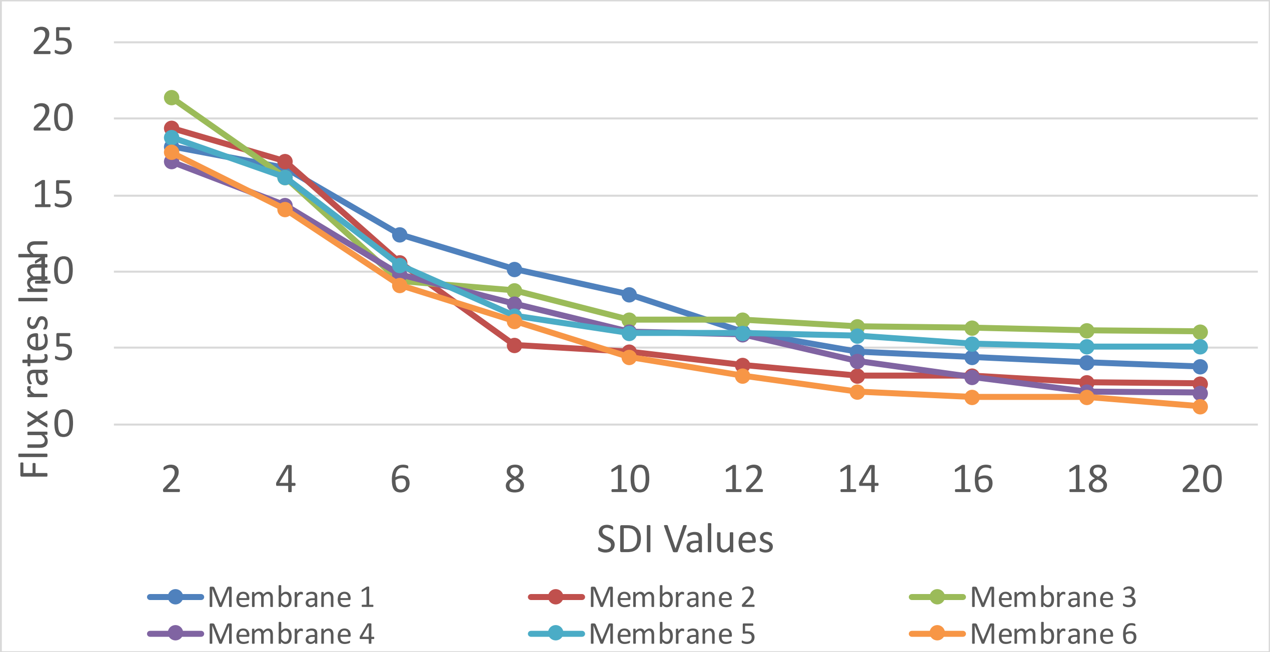

Figure 10: Performance of the membranes against SDI values

The increase in pressure in these membranes at varying levels of LSI levels is given in the chart below:

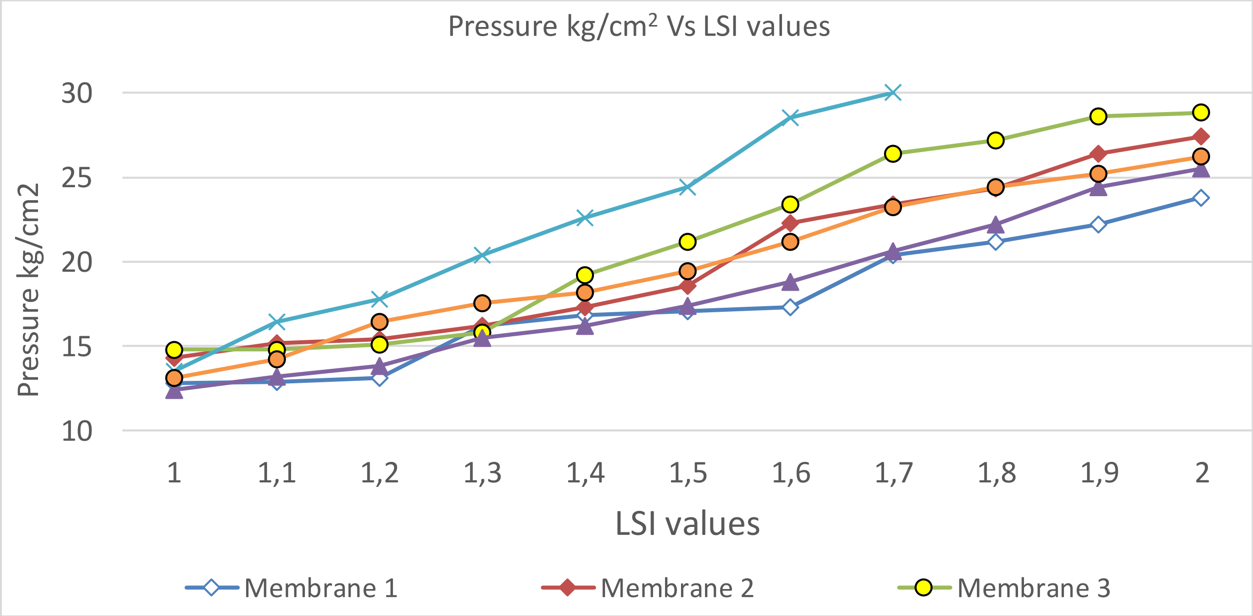

Figure 11: Pressure increase membranes against LSI values

The variations in system recovery against different levels of COD at the inlet can be seen in the following chart:

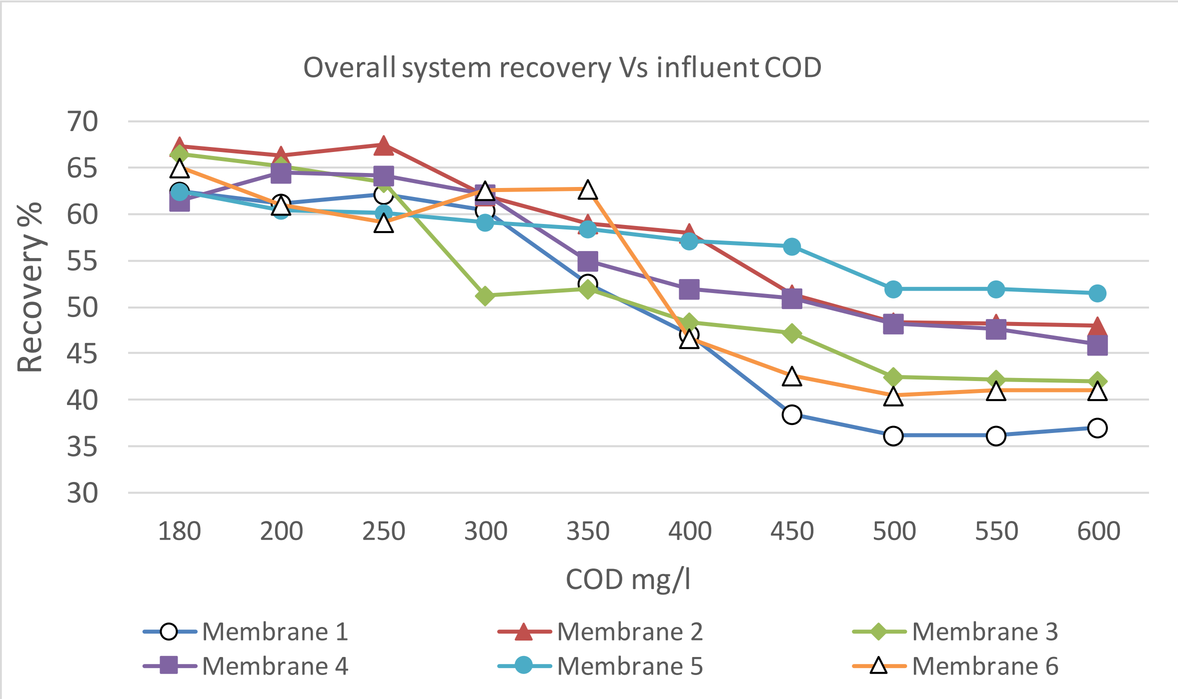

Figure 12: RO system recovery variations against COD

The variations in recovery at different TDS levels at inlet of RO systems can be seen in the following chart:

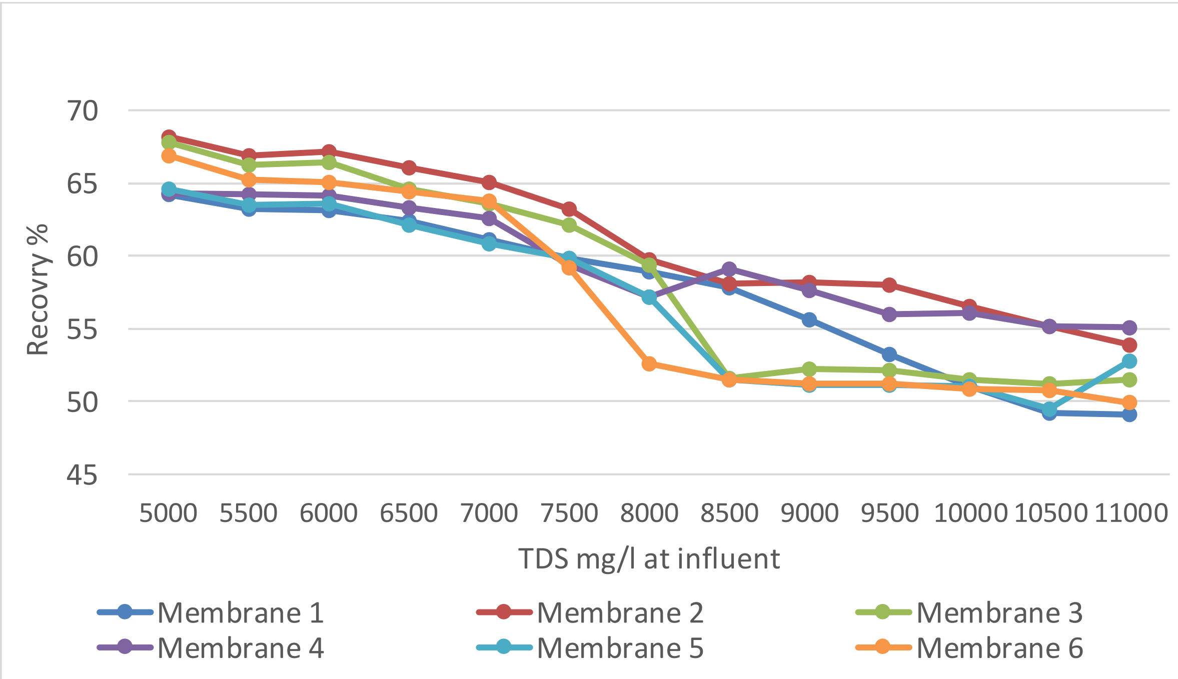

Figure 13: RO system variations against TDS

As already mentioned, the above values are applicable only for the influent tried for the study and given just for reference to show how different membranes should be tested for comparison.

7.9 Challenges for effluent recovery & solutions

7.9.1 Foulants in treated effluent

The smooth operation of membranes get affected by fouling by silt, organics, hardness and solvents in the treated effluent. In spite of good pre-treatment, the organics and silt tends to be beyond the desirable limit of RO membrane.

Fortunately, many new membranes exhibit good anti-fouling properties and research are in full swing to develop fouling resistant membranes. Better coating of membrane surface to minimise fouling is one of the key research projects in this area.

Simultaneously, the membrane configurations with better resistance to fouling too are in the development and systems such as disc & tube, tubular, vibratory and high efficiency RO system (HERO) are gaining popularity. To compete with such systems, conventional RO manufacturers are also coming up with better models. For example, many spiral wound RO manufacturers have now introduced membranes with higher feed spacer to handle higher silt load. Earlier the best feed spacer in spiral wound membrane available was 28 mil (0.7 mm) and today 34 mil space is very common and 42 mil space membranes are available as special design. Bigger spacer reduces the cleaning frequency and improve consistency of permeate flow.

It is hoped that in the near future, membranes will be specifically produced for effluent recycling and performances could be much better.

7.9.2 Management of saline reject

To manage saline reject from the RO system which is 8-10 times more saline than the treated effluent is a major challenge in effluent recovery. If the salt is evaporated, the resultant salt would be mixed salt with contaminants including organics & heavy metals. As such this evaporated material has no beneficial use.

To minimise the quantity of evaporated salt generation, salt recovery measures (either in liquid stage through nano or crystallised through chilling after some concentration) are tried by the industry.

Even with some brine recovery & re-use there will be some evaporated salt. At present, research work is ongoing to recover valuable material from this mass through technologies such as fractional crystallisation, differential centrifugation etc.

7.9.3 Low efficiency of pre-treatment units

Even though there are many choices for pre-treatment, a technically consistent and financially viable system are yet to be standardised. Some of the pre-treatment options such as Ozone may be even costlier than RO treatment itself.
Proper pre-treatment systems to achieve desired input at RO system consistently providing <5 Silt Density Index, < 50 mg/l COD, <200 mg/l hardness and <20 mg/l silica is still a question mark.

It is hoped that the ongoing research works may result in better and more efficient pre-treatment systems.

7.9.4 Quality of recovered water

Though it is generally accepted that recovered water from RO is very good in quality, it should be understood that quality of recovered water is not the same at all recovery rates. When recovery rates goes up, permeate quality too deteriorates. Usage of permeate from high pressure RO units are an issue. It is quite clear that the recovered water at all times should be equal or better in quality vis-à-vis the water being used, i.e., less than 150 mg/l TDS and less than 10 mg/l hardness and preferably no organics.

7.9.5 Availability of area for effluent recovery system

As discussed later in this document, availability of space as most of the textile units in clusters has little free area for any future construction. This issue may be resolved through intelligent planning.

7.9.6 Technical Challenges specific to textile effluent include the following:

Technical Challenges specific to textile effluent include the following:

- Printing effluent usually gives trouble to membranes and need special care in design.
- Presence of sizing agents (PVA or CMC and others) make serious issues with membranes.
- Binders used in process can clog membranes. Presence of pumice stones if any in the effluent makes problems in membrane operation.
- Many enzymes used in washing operations can make chelating reactions with membrane materials.
- Lastly, an indigo presence in the effluent decreases the membrane flux and reduces the output.

Fortunately, the special membrane configurations available today are capable of managing these issues. However, the industry should be vigilant to ensure that the membrane they receive is equipped for these challenges and not a general one.

7.10 Re-use potential of recovered water from RO systems

The permeate from the RO systems is very good in quality with TDS in the range of 50-200 mg/l. The permeate from first stage of RO as well as the RO system operating with low recovery or treating inlet with low TDS would provide quite lower TDS It would have low hardness, mostly less than 50 mg/l.

The permeate usually have relatively high concentrations of carbon dioxide and therefore is highly corrosive. In order to use the water for production purpose, it would be good to drive out the carbon dioxide from the permeate. Therefore in many cases of re-use, a degasification stage is added to the system. In most factories the permeate is pumped to the common water tank for supplying water to the factory. Some factories construct the water tank for permeate as a separate tank.

7.11 Monitoring of RO systems

Normally, the RO systems are operated as either fully or partially automatic. Most RO systems are operated through SCADA. The major monitoring parameters for RO operation are the following:

7.11.1 Feed pressure & differential pressure

Increase of TDS at the inlet of RO tends to increase the Osmotic pressure and therefore the pressure required to do reverse osmosis. If we keep the recovery rate constant, the pressure may go on increasing and the fouling of membrane too would be increasing.

The differential pressure (dP) is the pressure lost due to friction as water passes through the system. This is called the pressure drop or the hydraulic differential pressure (ΔP). As long as the flows and temperature are constant, the ΔP should not change unless something physically blocks the passage of flow, i.e., fouling. Therefore, it is important to monitor the ΔP across each stage of the system.

7.11.2 Flux rate

The flux rate, i.e., the flow through membrane in litres per square meter per hour ($l/m^2/h$) gives the performance of membrane. It need to be monitored continuously. Fouling can reduce the permeate flow rate. Hence, the same may be monitored continuously. However, just measuring the permeate flow rate is insufficient because it varies with the feedwater temperature, feed pressure, permeate pressure and feedwater conductivity/TDS.

Nevertheless, for steady inlet flow, the variations in flux rates indicate operational issues. Hence measurement of flux rates provides daily comparisons of RO performance.

7.11.3 Silt density index

The SDI can be on-site measurement of the suspended particles and colloidal particles in the feedwater. It is used to monitor the performance of the pre-treatment equipment. SDI measurements may be taken with pre- and post-multimedia filters, carbon filters, and post-cartridge filters. Pre-treatment should be controlled efficiently using the designed flow rates and differential pressure limits for backwash of the equipment prior to the RO and replacement of the cartridge filters to give an SDI less than 5 before the membranes.

7.11.4 Percent rejection

Percent rejection is the monitoring of the permeate TDS and comparing it with inlet TDS. Since RO systems are used to remove dissolved salts, measuring salt (ion) rejection is a direct way to monitor the performance. Salt rejection is the percentage of the feedwater TDS that has been removed in the permeate water. Percent rejection refers to the percentage of TDS (conductivity) rejected by the RO. The simplest way to monitor the salt rejection is to measure feedwater and permeate water conductivity. When the RO membranes are in trouble, percent rejection usually decreases, i.e., the permeate conductivity begins to increase. It can be calculated using the following formula:

Percent rejection = (feed conductivity - permeate conductivity) ÷ feed conductivity x 100

The permeate conductivity should be measured for each pressure vessel continuously and percent rejection should be calculated on weekly (at least on a monthly) basis. This will help determine if a high-salt passage problem is universal (indicating membrane damage), isolated to a certain stage (possible fouling) or isolated to an individual pressure vessel (indicating other problems such as issues with O-rings). Measuring the conductivity from each stage is called profiling. Measuring inside the vessels via the permeate tube by inserting a plastic tubing or stainless steel tube/rod is called probing. Probing of individual pressure vessels can be carried out to isolate a salt rejection problem of an individual membrane element. A drop in percent rejection may be a sign of a leaking O-ring, fouling, scaling, improper pH, too high a recovery rate, too low a feed pressure or a change in feedwater composition.

8 MANAGEMENT OF SALINE REJECT

Management of RO rejects (about 8-15% of inlet volume) is crucial in deciding managerial & financial viability of ZLD. This is done in multiple ways, either by re-using part of reject or by concentrating reject to the maximum extent. Evaporation to dryness continues to be the common option for management of saline reject.

8.1 Options for saline reject management

There are technical and managerial options to deal with the saline reject from RO. Since it contains the pollutants in the treated in a concentrated form, the disposal of RO reject is a major issue. The managerial solutions include dilution with municipal sewage, disposal into sea, disposal to abandoned mines and disposal through deep-well injection. Technical options include re-use of saline liquor in production process with/or without concentration, evaporation of reject and recovery of salts through crystallization, evaporation of into dryness and disposal of evaporated salts.

8.1.1 Salt recovery

In some cases, reject is purified through a nano filter & brine is re-used. Rejects of nano filter needs to be evaporated. In many cotton processing units, it would be feasible to recover sodium sulphate using adiabatic chiller and re-use the same in dyeing. The rest of saline liquor - multiple salts are evaporated and disposed.

8.1.2 Precipitation of salt

Another option to traditional concentrate disposal is the treatment of the concentrate for specific salt recovery. Using the specific makeup of the concentrate, individual salts can be removed in series using pH changes and salt precipitation. In case of textile effluent with Glauber salt as the predominant salt, precipitation of sulphate is technically feasible, but not much attractive due to cost of treatment, sludge disposal and TDS exchange potential.

8.1.3 Mixing with municipal sewage

Where feasible, concentrate disposal to a combined sewer is often the method of choice. A combined sewer transports concentrate and other wastewaters to a local municipal wastewater treatment plant, where the mix of both waters is treated; some of the salt from the concentrate flow becomes part of the sludge, while the rest remains dissolved and becomes a part of the plant effluent. Local regulations, the size of the desalination plant, and availability of a nearby wastewater treatment plant often dictate the feasibility of this disposal option. However, in Dhaka where the textile effluent quantity is high and the municipal sewage treatment is not very organised, this option is not practically viable at present.

8.1.4 Deep well injection

Deep well injection, where the concentrate is injected several hundred to several thousand meters into the ground below the freshwater aquifers, is another concentrate disposal option. Complications include need for appropriate site selection, need for concentrate conditioning with chemicals, corrosion and leakage from the well and resultant groundwater contamination and unknown well lifetime, as well as blockage of passage due to salts which are less soluble (e.g. calcium salts). Further, there is not adequate information for sufficiently long period to know if the injected salt will eventually leach into the fresh water aquifers above. In any case, such an option is not viable for any wastewater in Bangladesh and it holds only academic interest.

8.1.5 Disposal through marine outfall

Since the principal contaminant in RO reject is only the total dissolved solids, discharge of the same into the sea or estuary is a viable and cost-effective solution. The discharge line need to be extended into the sea for such distance where enough diffusion dilution is ensured. Special distribution arrangements are provided at the exit point.

However, such an option is not available for Dhaka and this can be considered only in locations such as Chittagong.

8.1.6 Thermal evaporation of reject

When the management of saline reject is done through thermal evaporation of the reject, the water recovery system tend to be zero liquid discharge system. The ultimate achievement in concentrate disposal and RO recovery is to operate a system with zero liquid discharge, where the recovery would approach 100%. In ZLD, most of the water in the concentrate is recovered as product by completely separating the salt from the water. ZLD systems include thermal evaporators, crystallizers, brine concentrators, centrifuges or spray dryer.

8.2 Importance of proper reject management

Reject management is the costliest step in effluent recovery systems. Hence, concentration of rejects to minimise the quantity of saline liquor to handle is essential. Reject concentration can be done by MVR, WHE, MD and Forward Osmosis. Concentration of RO rejects usually is done using Ultra high-pressure RO (HP-RO) which can concentrate the liquor upto 8%.

All membrane manufacturers now introduced HP-RO, spiral wound membrane introduced by Hydranautics is the new one. Disc & Tube configuration can handle fouling at third stage more effectively.

Very small ZLD units tried using solar evaporation ponds (with enhancement through sprays etc.), but were not very successful till now.

Most popular unit is multiple effect evaporator (MEE). Three, Five or Seven Stages MEEs are commonly in use. Mechanical evaporation included Mechanical vapour Recompression (MVR) systems, multi-effect distillation and Multiple effect Evaporators (MEE). In MEEs, the liquid is evaporated thermally in calendrias, assisted with thermal re-compressors and salt is usually separated using centrifuges. Salt with organics may need Agitated Thin Film Dryer (ATFD) for salt segregation.

8.3 Quantity and quality of saline reject

The quantity and quality of saline reject depends on the inlet pollutants including TDS and the designed recovery of RO system.

If the inlet TDS is 4000 mg/l and the RO has a recovery of 70%, one MLD of inlet water will generate 300 m^3/d of reject with a TDS of around 13000 mg/l and similar would be the increase in other pollutants including COD, hardness etc. If the recovery is 90%, the concentrations of pollutants in reject would be ten-fold.

8.4 Re-use of saline reject through Nano filtration

The basic concept of recovery & re-use of brine through nano filtration is to pre-treat saline reject of RO with filtrations & sometimes chemical oxidation and then pass it through a Nano membrane. This allows only salt to pass through & remove organics, colour, other impurities.

The RO reject 4 to 6% salt concentration is the feed. The product will be about 6-7% brine. Permeate will be clear salt solution and reject have all colour and multivalent ions etc. The permeate is re-used in dyeing after adjustments.

Based on molecular size of organics in exhaust dye bath, a nano-filter with 400-500 Daltons (about 0.0008 microns) pore size can give a decent recovery.

Nano filtration allows only mono/divalent ions and water to pass through, retains hydrolysed dyes and multivalent salts. Hence, theoretically it is possible to recover all salts through the membrane, in practice recovery is affected by a variety of factors.

Pore size of the nano membranes is crucial. Too large a pore size (say >1000 Daltons) ensure good recovery, above 70% of salt liquor, but allows passage of some smaller organic molecules too. Passage of organics makes recovered salt solution coloured and potentially unsafe for re-use

On the other hand, too narrow pore sizes (say <300 Daltons) ensure recovery of clear salt liquor, safe for re-use. But then recovery rate could be very low, say less than 35% of input.

Also, the mass balance of the entire system is somewhat complicated by the presence of reacted salts, i.e., salts produced due to inter-reaction of acid and alkali used in the textile processing.

8.5 Concentration of saline reject: MVR and Membrane distillation

Since the handling of reject is very costly, it makes all the sense to reduce the quantity of the reject to handle. Normally the concentration of reject can be done through high pressure RO, mechanical vapour re-compression, forward osmosis, membrane distillation etc.

8.6 Evaporation to dryness: options, technology and applicability

For evaporation of reject to dryness, technologies such as multi stage flash distillation, multiple effect evaporation etc. The process of converting a liquid to a gas under the influence of heat is called evaporation. The process of obtaining gas or vapour from liquids through boiling and condensing to liquid is called distillation.

8.6.1 Multi-stage flash Distillation

A Multiple Stage Distillation unit has different stages, which have heat exchangers and condensate collectors in each stage.

These stages operates different pressures corresponding to the boiling points of water. During normal operation, feed water at the cold inlet temperature flows through the heat exchangers in the stages and warms up. When it reaches the brine heater it already would have reached the maximum temperature. Heater heats it up further.

The heated brine is then returned to the stages . In each stage, as the brine enters, its temperature is above the boiling point at the pressure of the stage. Here, some fraction of the brine water flashes to steam thereby reducing the temperature until it loses its heat but increasing the temperature of feed water in the heat exchanger.

The steam cools and condenses at the heat exchanger tubes. In this way, about 80- 85% of the water flowing through the system, depending on the range of temperatures used. With increasing temperature there are growing difficulties of scale formation and corrosion. 110-120 °C appears to be a maximum, although scale avoidance may require temperatures below 70 °C.

The feed water carries away the latent heat of the condensed steam, maintaining the low temperature of the stage. The pressure in the chamber remains constant as equal amounts of steam is formed when new warm brine enters the stage and steam is removed as it condenses on the tubes of the heat exchanger. The equilibrium is stable, because if at some point more vapor forms, the pressure increases and that reduces evaporation and increases condensation.

In the final stage the brine and the condensate have a temperature near the inlet temperature. Then the brine and condensate are pumped out from the low pressure in the stage to the ambient pressure. The brine and condensate still carry a small amount of heat that is lost from the system when they are discharged. The heat that was added in the heater makes up for this loss.

The heat added in the brine heater usually comes in the form of hot steam from an industrial process co-located with the desalination plant. The steam is allowed to condense against tubes carrying the brine (similar to the stages).

The energy that makes possible the evaporation is all present in the brine as it leaves the heater. The reason for letting the evaporation happen in multiple stages rather than a single stage at the lowest pressure and temperature, is that in a single stage, the feed water would only warm to an intermediate temperature between the inlet temperature and the heater, while much of the steam would not condense and the stage would not maintain the lowest pressure and temperature. Such plants can operate at 23-27 kWh/m^3 (appr. 90 MJ/m^3) of distilled water.

Because the colder salt water entering the process counter-flows with the saline wastewater/distilled water, relatively little heat energy leaves in the outflow, most of the heat is picked up by the colder saline water flowing toward the heater and the energy is recycled.

8.7 Solar assisted evaporation for small units

Another mode of evaporation is to evaporate the reject using solar energy. In this method, the saline reject is held in a shallow tank or pan and allow the same to naturally evaporate to dryness. The loading rate is based on the evaporation rate prevailing in the installation site. Needless to say, this arrangement may work with low quantity of saline reject and only in areas which have low rainfall and more time of sunshine.

While calculating the area for evaporation pan, lowest evaporation rate in the area, excluding the days of actual rains, need to be considered. At an average monthly evaporation rate of 4 mm (0.04 m), an area of 100 m^2 corresponds to 100 x 0.04 = 0.4 m^3 or 400 litres per day of evaporation.

For instance, if the designed evaporation rate prevailing in the area is 3 mm per day, for evaporating 10 m^3 of water (10,000 litres per day), the area requirement of the pan would be 3300 m^2. This is a huge area and if the rainfall in the region is high, the entry of rainwater during rainy months could be much higher than the quantity evaporated.

In order to increase the natural evaporation rate, different techniques have been tried by the industries which included spray evaporation, pre-heat the inlet water before spray evaporation and flat plate collector for solar heating. Another modification is solar tunnels where the evaporation pans are covered with transparent plastic roofs (to prevent entry of rain water) and evaporation is enhanced by sprays and/or fibre pads. The general observation was that such modifications do increase the evaporation rate in sunshine days by 2-3 times but the additional mechanical arrangements increase the capital and operating costs.

Another concern related to evaporation pans equipped with mist-spray is the carry-over of concentrated brine through wind and contamination of ground and corrosion of structures in the surrounding area.

Other variants of spray evaporations in closed vessels too were tried, most of which resembled cooling towers than evaporators. At the moment, not many such working units have been reported.

The bottom line is that most such natural evaporation units have not succeeded in producing evaporated salts corresponding to the TDS load in the saline reject. In few units where significant quantity of evaporated matter was collected it resembled dust/sludge than crystallized salt.

It is easy to note that such an option is not easy for Bangladesh, except for very small ETPs with lot of land area.

8.8 Multiple effect evaporator: technology, process & application

The multiple effect evaporator uses steam for evaporation of saline reject. In order to maximize the heat from steam, the spent steam from one 'effect' is used in another stage, sometimes after compressing the vapour. Water is boiled in a sequence of vessels named 'Calendria', each held at a lower pressure than the previous. The Calendria vessel is filled with fixed number of tubes through which the water to be evaporated is passed through.

Because the boiling temperature of water decreases as pressure decreases, the vapor boiled off in one Calendria can be used to heat the next stage (held at a lower pressure) and steam is admitted usually in one stage. There are different type of MEEs based on flow pattern as given below.

8.8.1 Steam admitted in the direction of flow (forward feed)

Here both steam and the feed is admitted in the first Calendria and the spent steam is used in subsequent stages. Since the feed is started with higher pressure, pumping between different stages can be avoided. However, this is less practical with feed at low temperature and has less steam economy.

8.8.2 Saline flow is reverse direction to steam (backward feed)

Here the steam is admitted in one end Calendria (usually first) and the feed is admitted in the other end (usually the last) Calendria and water moves in the opposite direction of steam flow. This configuration can give better steam economy. But since the feed is often required to pass from lower pressure to higher pressure, pumping is required to transfer the feed from one Calendria to another.

8.8.3 Parallel flow of feed

Here the feed is admitted in each of the Calendria and the fresh steam is admitted in the first Calendria. It is, however, suitable for rejects with very high concentration and thus is not popular in textile effluent RO reject handling.

8.8.4 Feed is admitted in the intermittent stage (mixed feed)

Here the feed is admitted in the Calendria in the middle part of the MEE. Say if the MEE is Six effect, the feed may be admitted in the Fourth effect. The fresh steam is admitted in the first stage and spent steam is used in subsequent stages. This way, pumping of water can be avoided in the last two stages. But this may not have the same steam economy of the backward flow MEEs.

Each effect in the MEE increases the concentration of salinity and the last effect is designed to achieve the concentration equivalent to the crystallization concentration of the salt. After the last effect, the saline liquor at desired concentration (35-45%) is admitted into a crystallizer. The crystallized salt is separated using a centrifuge or dried as a powder in Agitated Thin Film Dryer or spray drier.

There are different types of Calendria in evaporation. These types can be used for the entire evaporator or the MEE can be a combination of different types. Common types are the following:

8.8.5 Falling Film Evaporators

They are long tube evaporators where the water to be evaporated is allowed to fall as a thin film through the side of the Calendria most suitable for low temperature applications and for high thermal efficiency. They can be used for non-fouling and relatively non-viscous products.

8.8.6 Forced Circulation Evaporators

They are short tube evaporators with very high velocity in tubes. They are preferred mostly for fouling and viscous products. The forced circulation evaporator comprises a heat exchanger, a separator and a circulation pump. The product is sent to the exchanger where it is heated and then sent to the separator. After evaporation, the liquid portion is pumped again to be resent to the exchanger.

The Forced Circulation Evaporator is often used in combination with the Falling Film Evaporator as high concentrator or as crystallization evaporator for saline solutions.

8.8.7 Scrapped Surface Evaporator

These types of MEE have continuous scraping action and high turbulence inside the Calendria which ensure impressive heat transfer coefficient when concentrating high solids material. Advanced design allows such MEEs to handle high viscosity and high fouling materials that exceed the limitations of other evaporation solutions.

Scrapped surface Evaporator is used for evaporating the heat sensitive material under high vacuum using thin/scraped film technology. Thin film yields high heat transfer coefficients, making the process highly effective. Usually such systems are used in mostly in evaporation of food products and these systems are not so popular in textile RO reject evaporation.

8.8.8 Rising Film Evaporator

They are not so common system in the textile RO reject evaporation. These thermally efficient and are for low temperature and foaming application. They are flexible enough to convert to forced circulation types.

8.9 Enhancement arrangements for improvement of evaporation

8.9.1 Condensate and product Flashing

By flash pulling the outgoing streams like product and condensate, maximum heat recovery within the system is ensured and that accounts for substantial steam reductions.

8.9.2 Thermo vapour Re-compressor (TVR)

The TVR is used for compressing the vapour before it is admitted to the next stage, they ensure reuse of evaporated vapours and thereby account for a good reduction in steam requirement, almost equivalent to one additional effect. Almost all MEEs installed in the reject concentration of textile effluent uses TVR in its design.

8.10 Salt separation: centrifugation, ATFD, chilling of sulphates

8.10.1 Pusher centrifuge

Pusher centrifuge is a continuous filtering type centrifuge used for solid-liquid separation in the chemical and mineral industries. Pushers have been used for more than 60 years for dewatering relatively large, free-draining crystals. The pusher centrifuge has a unique design that minimizes moisture, impurity and crystal breakage in discharged cake.

Pusher centrifuges are used for continuous solid-liquid separation. They enable the products to be dewatering with high efficiency. Quality of final product can be increased by using various washing modes.

Centrifugal devices, often used to achieve quick and efficient solid-liquid separation, work on two basic principles: sedimentation and filtration. Sedimentation or settling involves allowing the heavy phase to fall through the light phase and collect on an imperforate surface and typically involves fine solids with long settling times. Examples are decanters, disk nozzle centrifuge, etc. On the other hand, filtration depends on the particle size being large enough to build a cake on a filter cloth or a screen. The cake must also be porous enough to allow mother liquor to flow through it. Examples are pusher, peeler, vibrating screen centrifuge, etc.

Various types of centrifuges are manufactured, and each type of centrifuge has certain advantages over a specific range of process variables. The pusher centrifuge feed has 25-65 wt.% solids concentration of large free draining crystals (typically 80% retained on 150 microns). For most applications, these particles are crystalline in nature, but non-crystalline materials too have been successfully dewatered on the pusher centrifuge. These particles must be distinct and free draining.

The pusher centrifuge separates solids from liquid by means of a centrifugal force, which rotates about the horizontal axis. A hydraulic system supplies power to the centrifugal piston and leaves the discharge area by separating moisture from the wet materials. The operation of the hydraulic mechanism allows the separation of liquid and solids through the reciprocation of an operating valve and directs it to the solid discharge chamber.

8.10.2 Agitated Thin Film Dryer (ATFD)

Most new RO reject systems now use ATFD for production of salt. ATFD is used for separation of solids from evaporated slurry where it does not get crystallized easily and thus not effectively removed by centrifuge. Usually, such scenarios occur when the organic content in the saline slurry is high and when it has presence of oily content.

The ATFD commonly consists of a cylindrical, vertical body with heating jacket and a mixer with multiple blades on the shaft extending the entire length of the dryer. The rotating blades spread the wet feed product in a thin film over the heated wall. The turbulence increases as the product passes through the clearance before entering calming zone situated behind the blades as the heat will transfer from jacket to main shell under the smooth agitation. The water content in the brine will further evaporate and the slurry is converted into a dry powder.

The vapors produced rise upward, opposite direction of the brine feed and gets cleared in entrainment separator before leaving through vapor nozzle. This vapour will be condensed in condenser and recovered as condensate.

The feed enters evaporator at top, tangential to shell and gets distributed along the shell by the distributor. The rotor blades spread the feed evenly on the heated surface into a thin film and further agitate the film. Scaling on heat transfer surface is avoided due to the agitation of film. The type of rotors can be varied depending on the type of salt.

Unlike the centrifuge, the solids separation process does not depend on efficiency of crystallization and not affected by high organics in the brine. The major disadvantage of ATFD is that it consumes live steam and therefore tends to be costlier than a centrifuge.

8.11 Reject Evaporation with salt recovery

It may be possible to crystallize sodium sulphate from MEE evaporated liquor and recover salt. Multiple effect evaporator stage 1 will have 4 or 6 Calendria with tapping of concentrate from 6th stage, cooling condenser, adiabatic chiller, concentrate pumping back.

The temperature at which the Glauber salt crystallizes out depends on the concentration of sodium sulphate in the reject. The higher the concentration, lower will be the need for chilling and thus lower energy. The salt recovered from the adiabatic chiller may have residuals of organics and some sodium chloride with it. This salt may also have some colour depending on the efficiency of ETP and pre-treatment system of the RO.

The residual liquor after chilling is sent to evaporator Stage 2. Multiple effect evaporator stage 2 shall treat the residual saline liquor with 2 Calendria and ATFD for mixed salt crystallization.

The system would need all common associated units such as Boiler, cooling towers, MCC, SCADA and power backup.

Though some units are already operational, sufficient data explaining mass balance is yet to be available and hence this system is not discussed in detail.

9 ZERO LIQUID DISCHARGE

9.1 Concept of Zero Liquid Discharge, Genesis of ZLD

Concept of zero liquid discharge have been brought by regulators in some country as a single solution for water scarcity and problems due to discharge of treated effluent with high salinity.

The ZLD is achieved in stages:

It is done first by making the effluent fit for treatment in a RO membrane. This is achieved through conventional effluent treatment, say physico-chemical and biological treatment. Thereafter a series of pre-treatment removes hardness, silt, turbidity and organics to a level where fouling of membranes does not occur. The pre-treatment usually involves softening (if hardness is high), pre-filtrations in MGF/ACF/Micron filters.

There are micro-screens which can take care of occasional overflow of solids from the ETP. Some cases, advanced oxidation methods are employed to control organics. Organics can also be removed using adsorption systems (organic scavengers).

Usually, inlet to RO is protected with an Ultra-filtration membrane to reduce the silt & turbidity in the treated effluent. In most ZLD systems, RO system is in multiple stages to optimise the recovery and minimise the reject to handle. While first stages use brackish water membranes later stages use sea water membranes.

As mentioned in the previous chapter, RO membranes of different combinations (e.g. Disc & tube following spiral wound) are often considered for better recovery.

The reject from the RO stage is either re-processed for brine recovery or evaporated to dryness.

9.2 Experience of ZLD in various countries

The first countries to use desalination on a large scale for municipal drinking water production were in the Middle East. Seawater distillation plants were first developed in the 1950s, and in the 1960s, the first industrial desalination plant opened in Kuwait.

Membranes then began to enter the desalination market, and the first successful RO plants used brackish water as the feed in the late 1960s. In the following decade, membrane material improvements increased product permeability, and RO membranes were then applied to seawater desalination.

Over the past 40 years, improvements in RO membrane technology elevated RO to be the primary choice for desalination. Earlier high cost of membranes made other options more attractive. However, the twenty first century saw an exponential growth in world desalination capacity, resulting in mass production of membranes which played a crucial role in reducing the cost of membrane. This made the effluent recovery much cheaper.

For example, in 2005, Israel opened the world's largest sea water RO desalination plant, with a production capacity of 330,000 m^3/day, or 100 million m^3/y(23). The United Arab Emirates (UAE) opened its Fujairah desalination plant in 2005; the plant combines MSF and RO technology to produce 454,000 m^3/ day of fresh water(24). Both these increased the demand of membranes, reduced its cost and helped development of lower fouling membranes. Today, RO technology is the principal choice when need for removal of salts is considered.

9.2.1 USA

The concept of Zero Liquid Discharge in industries has been originated in early 80's in USA. The major consideration was to prevent public ire against location of industries in residential area.

Industries opted for ZLD was mostly mildly polluting industries with little or no increase of TDS in effluent. The second category opted for ZLD for recovering lost products in the effluent e,g. wastepaper mills.

The birth of ZLD dates back to when increased salinity of the Colorado River led to mandate of ZLD for nearby power plants. Today, the power plants remain the major domain of ZLD implementation in the USA. Here feedwaters, such as flue gas desulfurization (FGD) effluent and cooling tower blowdown are treated and recycled.

By 2008, among the 82 ZLD plants listed in a survey, more than 60 plants were associated with the power industry. The rest were distributed across areas such as electronics, fertilizer, mining, and chemical industries. ZLD has been mandated for inland desalination plant rejects too in USA. However, this stipulation made the overall process costlier and resulted in fewer inland desalination plants except where dilution with municipal sewage is viable.

This quickly followed by industries who recognised that effluent recovered from one industry could be used in other industries For instance, use of pickling liquor in textile effluent treatment, could avoid effluent discharge in one, save chemical in other. It was reported that >15 wastewater crystallizers in operation in North America by end of 2010. From about 80 ZLD projects in 80's, the number has grown to about 560 in 90's and to over >2000 in the 21st century.

9.2.2 China

In China too, first priority of ZLD was non-saline effluent streams which successfully re-used after treatment and polishing with disinfection etc. Of late, the non-complying industries show preference to ZLD systems, mainly due to the easiness of obtaining approvals.

After implementing a series of water reducing measures, power plants use ZLD as the final stage. The ZLD drive is steered by coal industry after the successful implementation of the 55 MLD plant installed at Shenhua Ningxia Coal Industry.

Though there are no reliable reports on the number of ZLD plants in China, it is considered that the country had >1000 ZLD units in China by 2018.

Chinese ZLD market took a turn due to the recent boom in coal-to-chemicals industry. The industry, utilizing coal instead of oil or natural gas to produce petrochemicals consume a lot of freshwater. But they are often located in water-stressed areas like Inner Mongolia. Hence ZLD is made mandatory.

Several ZLD facilities are already installed and being installed at the Chinese coal-to-chemicals plants. It is reported that the plants deal with low to medium TDS and has treatment capacity at 110–2300 m^3/hour.

The growing influence of public concern may force industries to adopt ZLD as a necessary solution to gaining public acceptance.

World's first and largest forward osmosis based ZLD plant is being implemented in the Zhejiang Province. The FO - ZLD is implemented at Changxing coal-fired power plant for flue gas desulphurization plant effluent (650 m^3/d).

The Membrane Brine Concentrator (MBC) system and pre-concentrating reverse osmosis (RO) supplied by Oasys Water, USA. The system has elaborated softening FGD effluent. Three trains of MBC raise dissolved solids from 60,000 mg/l to 220,000 mg/l. A crystalliser and pusher centrifuge separate the salt from 22% brine. The draw solution used is ammonium bicarbonate and regenerated using the spent heat from the factory.

9.2.3 India

The ZLD projects in India are generally concentrated in certain states like Tamil Nadu, Gujarat, Orissa, Maharashtra, and Andhra Pradesh. India's ZLD drive is steered by the acute water scarcity and complaints of pollution about cluster of Industries. Tamilnadu, the southern State of India was the forerunner in implementation of ZLD.

Apart from non-saline effluent plants main polluting industry joined bandwagon of ZLD in India were textile and tannery industry by end of 90's.

By end of twentieth century, all tanneries& textile factories in Tamil Nadu had the distinction of being connected to a full-fledged ETP, either individual or common. This was the aftermath of closure of over 400 tanneries in the State by the Hon. Supreme Court of India in 1994. This was quickly followed by brisk implementation of ETPs by other industries.
The industries in Tamil Nadu adopted ZLD during the period 2000-2010.

Stringent implementation of water discharge laws and social responsibility of corporate world reasons behind the ZLD drive. The closure of 700 textile factories in Tirupur by Madras High Court in 2011 triggered a massive adoption of ZLD in the country.

As on date industries such as textiles, distilleries and breweries, and power and petrochemicals, electroplating and pharmaceutical plants in India are required to achieve ZLD. Under the Clean Ganga project, NGT and CPCB have mandated ZLD for high-polluting industries (red category)

As on date all textile plants generating more than 25 m^3 of wastewater effluent per day to install ZLD facilities. Tamil Nadu & Gujarat has a greater number of ZLD projects. In Tirupur alone, 12 CETPs catering to almost 500 dyeing units and about 50 individual ETPs had implemented ZLD during 2008-2015.

9.3 Pros & cons of ZLD concept

Advantages of ZLD concept and the common disadvantages are listed below. Since ZLD is not the focus of this report, a detailed discussion on the same is not attempted.

9.3.1 Advantages of ZLD

- It will provide full legal security for the industry.
- It is the ultimate proof of environmental compliance.
- There will be water security for the industry.
- The industry will have better image with buyers/public/ NGOs/EPA.
- ZLD will ensure protection of environment, particularly the Rivers in Dhaka.
- Water recovery ensure zero loss of production.
- ZLD ensure consistency in product quality too.

9.3.2 Disadvantages of ZLD

- Ensuring ‘zero’ is very difficult.
- It is the costliest treatment in installation (about 3 times of conventional ETP).
- Prohibitively costly in operation, MEE is the costliest, could affect the competitiveness of the industry.
- Disposal of evaporated mixed salt is always a challenge.
- Lack of adequate technical support.
- Need for trained staff for operation.
- Consumes lot of space, which is an issue for industry in Bangladesh.

10 MANAGEMENT OF RESIDUALS FROM EFFLUENT RECOVERY PLANT

10.1 Characteristics of salt

The salt evaporated generally less than 15% moisture content. The average generation of salt can be taken as 0.8-1.2 kg salt/m3 of effluent from garment washing and 2-3 kg salt/m^3 from combined dye effluent plant.

The salt shall be brownish/grey in colour, resembling mostly powder silt and is not crystallized. Salt from a typical ZLD unit treating combined effluent can be a mixture of Na_2SO_4: 65-70% and NaCl: 5-10%. It may also contain 2-3% $CaCO_3$, 1-2% Ca Cl, 0.5-1% Nitrates, 2-6% mixed mineral salts and 2-3% organics. Needless to say, for units using sodium chloride in dyeing, this salt will be more in the form of mixed salt.

Salt from typical ZLD unit treating garment washing effluent mixture of 75-80% Na_2SO_4, 5-6% NaCl, 0.5-4% mixed salts,1-2% organics. Here too salt configuration will vary with respect to the process.

10.2 Disposal of mixed salt

As such these salts have no re-use value and need proper disposal. A safe disposal of the mixed salt is still an issue. Options such as secured landfilling is not much suitable due to its leaching potential.

Trials to purify this salt and segregate it into sodium chloride and sodium sulphate is underway with no commercial success so far.

Segregation of these two salts, i.e., sodium chloride and sodium sulphate, is difficult since their crystallisation points are close to each other. However, their solubilities in water at different temperature varies.

Technologies including fractional crystallisation and differential speed centrifugation has been tried and trials are still in progress.

For salt with higher sodium chloride, it may be possible to purify it using brine washing technology leaving other salts & impurities in wash reject and it may be possible to recover Glauber salt from this wash liquor through chilling.

As of now, a fool-proof solution for utilisation of the salt is yet to be developed, though there are many research and trials in progress. It is hoped that by the time the textile ETPs in Bangladesh adopt effluent recovery systems and migrate into zero liquid discharge status, a viable re-use option of salt would be developed.

10.3 Re-usability of recovered water

10.3.1 RO permeate

The permeate from RO unit forms bulk of the recovered water. This water is generally very good, quality varies with respect to TDS of inlet of RO membrane unit.

The first two stages of RO (providing about 65-70% of the recovered water) would treat low TDS water. Normally, the recovered water from this stage will have less than 150 mg/l TDS and less than 5 mg/l hardness.

The next stage(s) of RO, if implemented, would produce about 20-25% of the total permeate. This permeate will be of relatively higher TDS (say, 250-350 mg/l).

Units with ZLD will aim for maximum recovery and minimum quantity of saline reject. Hence usually such units may include high pressure RO to increase the recovery and to reduce the reject quantity for evaporation to less than 5-8%. This unit will produce permeate which will form the final 5% of recovery in the membrane section. But this water will have higher TDS, often 800-1000 mg/l TDS.

Hence in regard to the permeate we can use the first set, about 70% of water, in any processes in the factory.

The rest may either to be used in areas which can use lower quality water or this water should be given further treatment (say, a polishing RO) to make it fit for universal application.

10.3.2 Evaporator condensate

In unit with ZLD, the second set of recovered water comes from the condensate from the thermal evaporation system.

The condensate from evaporator would normally be very good for the first three stages of multiple effect evaporator with TDS less than 50 mg/l. It is possible that condensate may contain free ammonia if the nitrogen in effluent is high. This condition may need special treatment like ammonia stripping or ammonia recovery through hydrophobic membranes.

This condensate can be mixed with RO permeate for re-use or alternatively this can be directly used as boiler feed water. Use of condensate as feed water to boiler has advantage of heat recovery since its temperature will be >60 degree Celsius.

The condensate from final stages of evaporator may contain entrains of feed and may be coloured. Normally, this water could be sent back to ETP.

11 COST IMPLICATIONS OF WATER RECOVERY OPTIONS

11.1 Factors influencing cost of effluent recovery plant Installation

As mentioned elsewhere, installation cost of Effluent Recovery systems are much more than basic ETP cost. On an average it can be 2-4 times of ETP installation cost. Factors which influence the capital cost of Effluent Recovery include:

- Capacity of the complete effluent Recovery units including ETP.
- Scheme of effluent treatment plant.
- Material of construction in ETP and Effluent recovery units.
- Type of pre-treatment of RO needed, say softening.
- Type of membrane used in the desalination.
- Number of stages of RO and type of membrane used.
- Recovery from RO and measures to increase recovery (e.g. third stage RO).
- Absence or presence of pre-concentrators (e.g. MVR, MD and UHP-RO,FO etc.).
- Presence or absence of salt recovery.
- No. of effects in evaporator.
- Type of crystallizer & solids separator (centrifuge Vs ATFD).
- Level of automation of the entire Effluent recovery system.

11.1.1 Impact of capacity of Effluent recovery on cost

Capacity of the ETP and Effluent recovery units play a major role in Capex. Higher the capacity, lower will be the cost per cubic meter. For instance, if the Capex is US $2000 per m^3 for a 100 m^3/d Effluent recovery plant, Capex for a 5 MLD plant could be US $1500 per m^3.

The capex of the system owes a lot to the ETP scheme. More elaborate treatment (say, combined ETP or MBR) cost higher.

Advanced tertiary treatment (ozone, VSA etc.) improve life & performance of membrane. However, the ETP Cost increases by 20-30%

11.1.2 Impact of MoC on cost

The material of construction is another crucial aspect of cost. Higher the grade of material, higher will be Capex, but life & maintenance cost lower.

The construction ETP mechanisms can be is stainless steel 304/316. Many constructs in mild steel, cheaper but very low life. If clarifier bridge, aeration tank handrails, support structure etc. is costly to construct in SS, concrete (RCC) structure can be used. Cost increase may be about 20-25% of ETP cost.

RO skid, ducting etc. can be in SS 304. The piping can be in SS 316. Permeate pipe need to be in SS 904/905. This is because the permeate, with low hardness, could be corrosive in nature.

Evaporator Calendria can be either in duplex steel or Titanium. Cost increase from SS 316 L/316 Ti to duplex/Titanium can be about 30-35% of MEE cost.

11.1.3 Impact of effluent quality on Effluent recovery cost

If the hardness of the effluent is high, softening may be needed. This increases the desalination cost by about 35%. In case of lime-soda softening, additional sludge (30%) needs dewatering.

Similarly, if the organics in treated effluent is high, special systems such as ozonation etc. would be needed and this will add cost to the entire system. Often the cost of such pre-treatment units may be 40-80% compared to the RO system cost.

Type of membrane play a role in the costs. UF or RO costs vary a lot depends on membrane material and configuration. PVDF cost more compared to PES, increasing the cost of ultra-filter by about 25%. Disc and Tube membrane system is about 90% costlier than spiral wound but since some of the pre-treatment systems can be avoided by opting for disc & tube configuration, the effective cost increase of the entire RO system would be about 25%.

Level of automation of the entire Effluent recovery system plays a role. More automation means more cost, but less labor and manual errors. A fully automated system may cost about 10% more compared to semi-auto systems.

11.1.4 Impact of desalination system configuration on Effluent recovery cost

The number of stages of RO determines its Capex. If the RO system is in 3 or more stages, the cost may also go up. Generally, the increase would be in the range of 30-45% of RO cost with every stage addition.

Similarly, if there is any pre-concentrators like MVR or MD is present, the cost may still go up. But in such a case, the MEE sizing & its cost may go down. But overall cost may still be high (about 20-25% increase in RO-MEE cost). The main advantage of pre-concentrator is the Opex.

11.1.5 Impact of salt management system on Effluent recovery cost

If there is a salt recovery through nano from concentrated RO reject, the nano membrane system may cost extra, but MEE will be smaller. Over apex of salt handling system will go up by 10%.

If there is Glauber salt recovery in MEE, the cost may go by about 30-40%. Opex also may go up, but less salt for disposal.

No. of effects in evaporator is the principal cost factor in MEE. A seven effect MEE cost 120% more compared to a 3 effect MEE. Forced circulation in MEE is costlier than falling film. For every stage of falling film made into forced circulation, cost increases by 15-20%.

Type of salt separation system plays a role in Capex. Simplest system is crystallizer & solids separation through centrifuge. If organics is high, centrifuge may be replaced by Agitated Thin Film Dryer (ATFD). Costs 15% more in MEE. If ATFD too does not work due to binders & wax, spray dryer may be needed. Costs 30% more than MEE with centrifuge.

Salt collection system is done generally manually. If conveyor & loading system is installed, it may increase cost of MEE by 15%. If salt purification system is installed, it may greatly reduce qty of salt for disposal. The capex in salt management would go up by 20-35%.

11.2 Factors influencing Effluent recovery operation cost

As mentioned already, effluent recovery options, in particular Effluent recovery, are the costliest options of effluent treatment. In general, the following are the factors influencing recovery cost:

- Power consumption in ETP and Effluent recovery.
- Chemicals needed for ETP & Effluent recovery sections.
- Consumables such as cartridges, membranes, diffusers etc.
- Manpower & labor needed for operating ETP, Effluent recovery and salt management.
- Fuel costs (mostly for standby generator and MEE)
- Monitoring (on-line, offline, statutory)
- Sludge and salt management.
- Depreciation/amortisation costs.
- Miscellaneous including R & D.

11.2.1 Cost of power in Effluent recovery O & M cost

ETP is a power intensive unit. For textile ETP, power consumption can be 0.6 -1.6 kWh/m^3 based on ETP type. Assuming power tariff @BDT7 per kWh, a one MLD ETP may cost BDT 4200-11200 per day.

The effluent recovery consumes about 1.8 to 4.5 kWh /m^3 based on effluent quality and the degree of recovery. This power consumption is owing to high pressure pumps in RO, compressors, feed/recirculation pumps in MEE etc. This means a cost of BDT 12600-31500 per day for 1 MLD Effluent recovery system. When one add cost of emergency power back up it may still go up.

11.2.2 Cost of Chemicals & consumables in Effluent recovery O & M cost

Primary or combined ETPs use ferrous sulphate, lime, polyelectrolyte, PAC, nutrients for aeration tanks. They also need lubricants/paints for the maintenance of the ETP units. The all-biological treatment plants use Hcl for neutralization, nutrients and colour removal agents, If lime-soda softening is done, soda ash & lime is required. Depending on the hardness, this may add BDT 5-60 per m3 of effluent treated.

RO section uses anti-scalants, anti-oxidants, CIP chemicals. MEE also need cleaning chemicals. As a rule, the chemical cost per m^3 of textile effluent varies from BDT 7 -16 per m^3. The consumables in RO section are cartridges and membranes. These may cost about BDT 2-8 per m^3. Then there are general spares which may cost about BDT 0.5-1 per m^3.

11.2.3 Cost of Chemicals & consumables in Effluent recovery O & M cost

Cost of fuel is generally applicable to the standby power generators for ETP-Effluent recovery systems and fuel for boiler in MEE. Standby generators can be powered by different fuels like gas, diesel is more common. Naturally, operation of DG is very irregular and cost estimation is difficult.

Boiler fuel can be gas or alternatives such as wood chips, brickets, RDF, coal, coke, oil etc. While wood is the cheapest & most popular in Tamilnadu, India some ZLDs there use coal and coke too. In case of Bangladesh, gas could be the fuel of choice. If gas is not available, units in Bangladesh too may need to depend on wood. Approximately 45 -65 kg of firewood is needed to evaporate one m^3 of saline reject.

11.2.4 Cost of Fuel in Effluent recovery O & M cost

Disposal of dewatered sludge is a costly affair (BDT 4000-12000/ton) based on the charges levied by the service provider like Geocycle. Many factories installed measures such as sludge maturation to reduce the thermal sludge drying, digestion of sludge to reduce volume, co-processing for sludge.

Disposal of evaporated salt is even more difficult & costly. If the salt re-use is not adopted, disposal of salt may be a major issue. Most Effluent recovery-ETPs in India just stored huge quantity. Solid waste receivers indicated a cost of money equivalent to BDT 6000-8000 per ton. Marine disposal also may cost similar. Research to find out recovery and/or proper disposal of the salt is ongoing. Efforts to use it as raw material in some factories (like alkali chemicals) is in progress.

Break-up of operational cost of ETP & ZLD is shown in the graphs below.

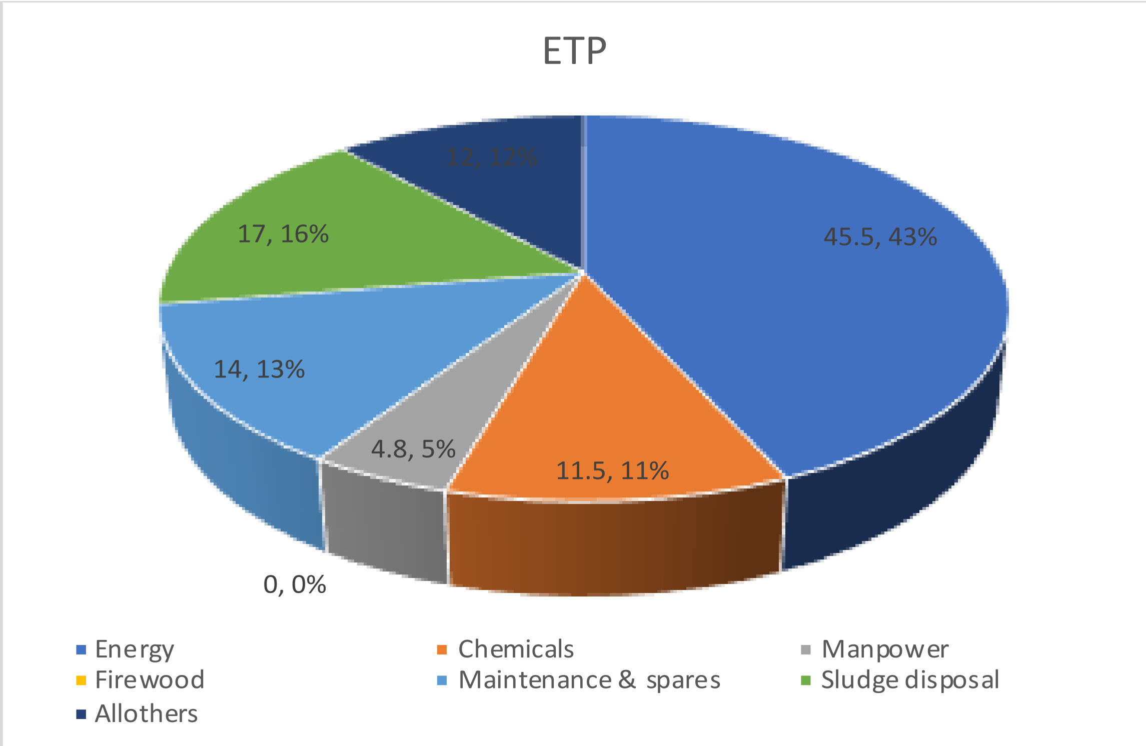

Figure 14: Cost components in ETP

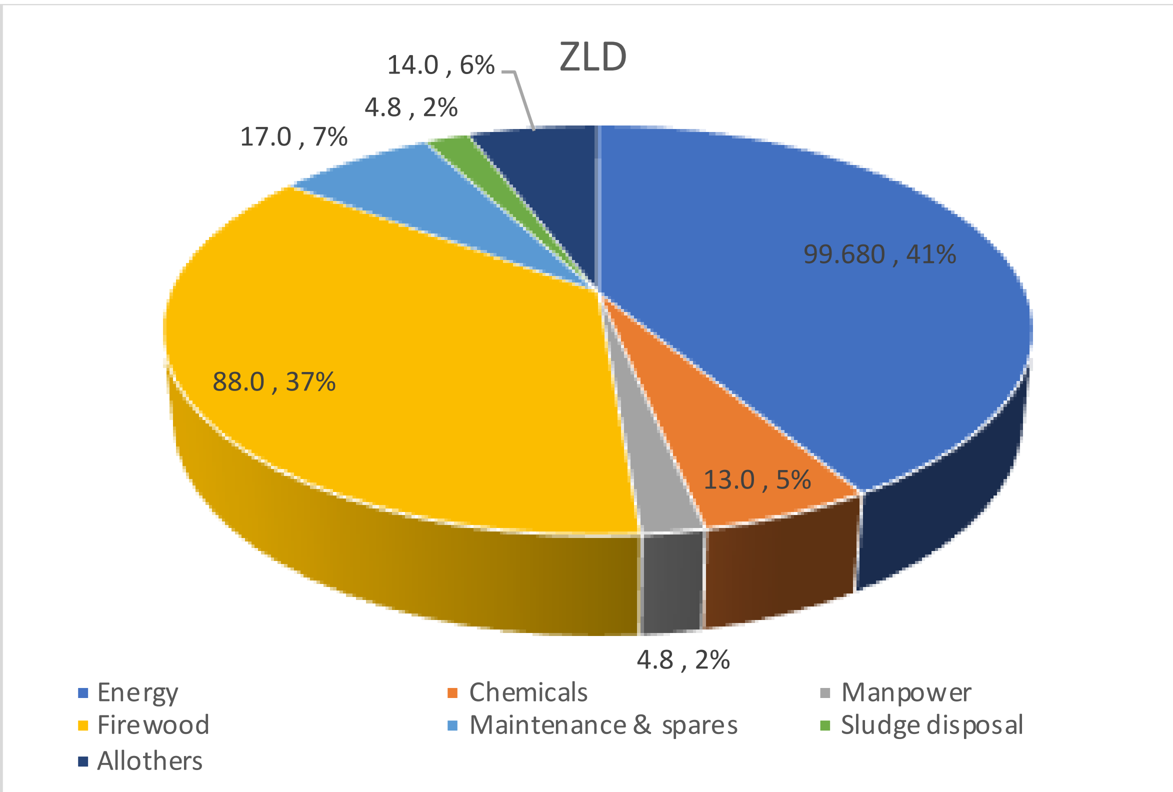

Figure 15: Cost components in ZLD

11.3 Overall cost of Effluent recovery O & M

A typical Effluent recovery plant without evaporation may cost BDT 30-80 per m^3, based on quality of effluent and/or recovery rate of effluent. If the recovery system incorporate evaporation of RO reject, the cost may go up and may range at BDT 120-280 per m^3. This figure is the additional cost besides the basic effluent treatment cost, which is considered obligatory even if no re-use is considered.

In the case of complete effluent recovery plant with reject evaporation, the percentage of electrical energy was found costing the maximum at 35-45%, Second highest was fuel for evaporator at 25%. Maintenance & spares accounted for about 9% of total cost. All the other expenditure together was about one-fourth of the cost.

Clearly, electrical power and fuel should be given priority for cost optimization.

11.4 Optimization of O & M cost of effluent recovery plant

Since waste management is a non-productive socio-legal obligation, all efforts should be made to reduce the cost of effluent treatment. The same should be applicable to effluent recovery systems too.

11.4.1 Optimization of power cost in Effluent recovery plant

Power consumption can be optimized through following measures:

- VFD controlled motors for pumps & blowers.
- Energy efficient motors for equipment (e.g. turbo-blower).
- Dissolved oxygen controlled aeration system.
- Automatic power factor controllers.
- Energy recovery systems such as PX for high pressure pumps.
- Optimization of MEE stages with optimum recirculation.

Managing lesser TDS in effluent reduces power consumption too.

To reduce the power consumption many Effluent recovery-CETPs in India started installing solar power projects with subsidy from Government of India. It may be worthwhile to try similar initiatives in Bangladesh too.

11.4.2 Optimization of Chemical cost in Effluent recovery-ETP

Chemical cost in effluent recovery can be optimized through following measures:

- Use optimum dosage of chemicals, do jar tests for fixing dosages.
- Automatic dosing of chemicals (flow based dosing of coagulants, pH based dosing of acid/lime saves chemicals and money.
- Ensuring good quality tertiary effluent minimize consumption of cartridges.
- Minimising frequency of RO cleaning (CIP & Maintenance). CIP is a costly affair. If proper operation of ETP, Tertiary and UF ensured, cleaning of RO will be minimal.

- Clean inlet increases the life of membranes from 1.5 -2.5 years to 3-4 years and save membrane replacement costs.
- Proper & correct lubricants and good epoxy painting is essential. Proper store management for spares needed.

11.4.3 Optimization of fuel cost in Effluent recovery-ETP

Selection of the cheapest fuel for generator, optimization of operation, synchronization of DGs etc. will ensure lower cost of fuel. Always select locally available fuel for boiler. For instance, most Effluent recovery units in Tamilnadu, India mostly uses wood chips as the fuel. In case of Bangladesh, it can be compressed natural gas.

Always use fluidized boiler which will ensure optimum utilisation of fuel and less wastage of the same.

Since the Effluent recovery plant is an energy guzzler, alternatives like CHP (combined heat & power) plants would be of advantage as it can provide both steam as well as power. This may be viable where sufficient biomass can be found nearby at affordable rate. In large Effluent recovery systems, units such as heat cascading boiler where multiple boilers are installed and are allowed to work in sync to provide heat can also be considered.

It may be possible to obtain better output from boiler by

- Ensuring clean tubes
- Proper insulation of entire steam conveyance lines
- Condensate recovery
- Waste heat utilization
- Cooling tower optimization

If possible, it will be beneficial to consider solar energy for steam/hot water generation. The heat reflectors to be used must be efficient. While production of steam with required pressure may be difficult, it is advantageous to generate hot water, which can be used as input to boiler, thus saving heat required to heat it up to the boiling point. In such a case only latent heat may need to be provided.

11.4.4 Optimization of cost of disposal of residual material in Effluent recovery-ETP

Since the residual materials are sludge & evaporated salt, any reduction of quantity of these will result in reduction of cost.

Sludge quantity could be reduced by opting for less sludge generating coagulants & flocculating. When disposal of sludge is considered, many polyelectrolytes may emerge to be more economical than conventional chemicals.

Less TSS in effluent may reduce the sludge quantity. Similarly less TDS in effluent will result in lower quantity of evaporated salt for disposal. Hence cleaner technologies may be considered, keeping these points too in mind.

Any beneficial usage of sludge & salt will reduce the quantity of sludge/salt and ensure lower cost.

11.5 Cost-benefit analysis of effluent recovery

A general evaluation of economics of effluent recovery in textile industry is very difficult since neither the cost of water used at the moment nor the likely cost of recovered water can be determined accurately. It is, therefore, very important that cost-benefit analysis of effluent recovery should be evaluated by individual factory managements based on their own baseline data and situation analysis.

To give a general idea about the economics of effluent recovery, following has been assumed and used for a computation.

11.5.1 Cost of water at present

The basic cost for units using ground water is the pumping cost and the extent of softening needed before the same can be used in the factory. Ground water pumping costs depends on the depth of groundwater table and the cost of electricity. Generally, this may range from BDT 1.5 -3.5 per m^3 of water. If all the water needs to be softened, depending on the hardness the total will cost about BDT 10 -16 m^3 . If the water needs desalination due to high TDS, cost of water could be BDT 19-32 m^3 of water.

11.5.2 Savings due to recovery of effluent

We can expect that the recovered water from effluent recovery plant would of high quality and may not need further softening or desalination. A typical Effluent recovery plant with about 50-60% recovery may cost BDT 30-40 per m^3. If the recovery is above 70%, the cost may become BDT 50-80 per m^3. If the system incorporates evaporation of RO reject, the cost may range from BDT 120 to 280 per m^3.

11.5.3 Cost-benefit analysis

A general cost-benefit analysis for a typical factory with median values for all cost as above may be as follows:

Table 12: Cost comparison of water recovery

Water Type	Basic price BDT/m^3	Cost difference from desalinated water (BDT/m^3)	% Increase
Ground water with softening	14	0	0
Groundwater with desalination	26	0	0
Recovered water from effluent at 55%	35	9	35%
Recovered water from effluent at 80%	65	39	110%
Recovered water from a full ZLD	220	194	300%

Note: the above values are without considering basic effluent treatment and assume that non ZLD options will discharge the saline effluent.

11.6 Financial Viability

It is quite clear that for most of the industry in Dhaka which uses groundwater, the value of recovered water, even after considering cost saving due to avoiding softening/desalination, is not going to justify the effluent recovery, even if discharge of reject from RO is permitted.

If the DoE insist on proper management of saline reject from RO, the cost implication will be even more and make the option even more unattractive.

At the moment, DoE may consider directing few large units to Implement effluent recovery system. However, if the stipulation of effluent recovery across the Country is not uniform, it may lead to a situation of non-uniform application of norms and may affect competitiveness due to additional cost of invest & operating cost causing an imbalance in terms of production costs and profitability. This may result in closure of some industries or migration of them to other countries where there is no such norms.

There is no incentive today for implementation of effluent recovery other than better image, better security through avoiding complaints on pollution issues from public and action by courts.

11.7 Financial incentives

Countries like India has offered some financial support for installation of ZLD systems. However, such support is limited to only CETPs and not to any individual factories. Similarly, there is no financial support for operation and maintenance of ZLD plants. Even with subsidies it may not be worthwhile for opting for ZLD in Bangladesh at present considering other issues like large area requirement and disposal of residual salt etc.

Issues with competitiveness due higher operating expenses due to Effluent recovery needs to be addressed. To offset this regional/ national trade imbalance due to additional costs, the viability gap needs to be funded.

Effluent recovery may add to the overall expenditure of the factory which can be as high as 3 to 10%. This increases the cost of the dyed fabric. However the buyer may prefer to buy the product from a country where it is cheaper due to no need for any effluent recovery Policy. This would then result in closure of such manufacturing industries and loss of manufacturing jobs and shifting of such polluting industries to other lower economies. Earlier, one of the reasons for migration of industry from Europe to Asian countries. When industries in Tirupur adopted ZLD, some of the business had migrated to Bangladesh which. A similar shift may happen from Asia to Africa if we do not address the pollution issue and the costs associated with it.

This therefore requires a policy intervention to protect the industry where the additional cost is managed through supported incentives or higher market price through ecolabels and better grade of certification from international agencies like ZDHC.

11.8 Carbon footprint of effluent recovery system

At the moment, all the operational effluent recovery systems are basically ZLD systems and making a projection of carbon footprint for a design for effluent recovery alone could be difficult due to the extent of variables involved. The carbon footprint noted in an operational ZLD plant is given here, just for reference.

Table 13: Carbon footprint of an ZLD plant

Item	Unit	ETP	ZLD	Total ETP/ZLD
Flow	m^3/year	4,15,859		
Consumption of electrical energy	kWh/year	13,49,980	26,68,830	40,18,810
Consumption of Diesel	L/year	47,711	74,029	1,21,740
Consumption of firewood	kg/year		38,06,396	38,06,396
TOC removed during biological treatment	kg/year	3,09,122	0	3,09,122
CO_2 emissions from consumption of electrical energy	kg/year	12,14,982	24,01,947	36,16,929
CO_2 emissions from Diesel	kg/y	1,37,885	2,13,944	3,51,829
CO_2 emissions from biological treatment	kg/year	11,34,478		11,34,478
CO_2 emissions from firewood for MEE boiler	kg/year	0	69,20,720	69,20,720
Total CO_{2e} emissions, year	kg/y	24,87,345	95,36,611	1,20,23,955
Total CO_{2e} emissions, year	tonnes/year	2,487	9,537	12,024
Total CO_{2e} emissions	%	20.69	79.31	100

It could be seen that the carbon footprint may increase four fold if a full ZLD system is installed and operated.

12 BOTTLENECKS IN IMPLEMENTATION OF EFFLUENT RECOVERY IN BANGLADESH

12.1 Legal Challenges

The first and foremost challenge in implementation of an effluent recovery system is meeting the legal requirements prevailing in Bangladesh.

While the ZLD option is actively encouraged by the DoE, all stakeholders are aware of the difficulties in adopting ZLD at least in the immediate future. The difficulties include (a) lack of space for constructing ZLD, (b) huge cost implications in installation and operation, (c) lack of adequate technical expertise in design/installation/operation/maintenance/ monitoring and (d) issues related to disposal of residual wastes such as evaporated salt.

Hence it is quite clear that the immediate solution could be to attempt partial effluent recovery (say, 50-70%) of the treated effluent. The biggest challenge to this option is meeting the discharge standard for the remaining treated effluent. In particular, the TDS and COD of the remaining water may not meet the discharge standards stipulated by DoE.

12.2 Technical challenges

As mentioned repeatedly in this manual, making effluent fit for a recovery system is a real challenge. The units like RO system are basically designed for clean saline water without many organics or silt. Though there are over hundred units already operating in the textile sector, there is no reliable data and technological model which can be replicated through appropriate scaling.

The first issue is that unlike other wastewater treatment systems/units, there are no standardised design criteria. Different suppliers/technology providers claim performances based on some projections and try to get quick business. Most of such plants may fare reasonably good in the beginning and fail eventually. This is because any damage to the membrane is slow and the quality of permeate would be good till then.

The industries which implemented effluent recycling technologies are generally quite secretive about the performance of their system and try to conceal the weak points in the system. Having implemented the project after spending a fortune, no companies are willing to come out with the handicaps of the system. Often the model implemented is touted as the best example and the supplier get multiple orders based on the positive feedback from the client and/or good visual appeal and the same mistake in original design is repeated in scores of other projects. By the time the draw backs become evident and issues in performance recognised, much money would have been wasted. Eventually based on bad experience by a large section of the industry, it is concluded that the recycling technology itself is a failure.

Due to this reason, there are no demonstrated, published and peer verified good examples of textile effluent recycling technologies as a model, even after two decades after the first recycling plant was constructed.

The first issue is that there are no standardised technology options available for textile effluent recycling. Due to this, the suppliers tend to offer their own technologies as the best option, each one claiming superiority over other.

12.3 Enforcement challenges

At present DoE has standards only for discharge of wastewater. There exists no policy or rules for reuse and recycle of treated wastewater directly or indirectly even though the department always requested the industry to come up with a road map to achieve ZLD in stages.

Most of the enforcement by DoE is presently based on the following rules:

- National Water Policy 1999/2001, which describe standards of effluent disposal into common watercourses. Industrial polluters are required under law to pay for clean-up of waterbody polluted by them.
- Environmental Conservation Act 1995, which laid out importance of Environmental Clearance Certificates (ECC) for setting up a textile industry.
- Bangladesh Textile Policy, section 4.14 of which delineates steps for setting up effluent treatment plants (ETPs) in dying, finishing and wet processing factories.
- Environmental Conservation Rules (ECR) 199 which categorised Fabric dyeing and chemical treatment industries falling under red category (highly polluting industries) and under these rules they are required to prepare and submit environmental management plan (EMP) to prescribe measures for reducing environmental impacts and risks associated with the industry.

None of the above policies specify rules/regulations for legal enforcement of water recovery from effluent or ZLD. In the absence of any such legal compulsions, the industries opt for effluent recovery only when (a) there is acute water scarcity (b) pressure from buyers/brands and (c) when options for discharge of treated effluent are difficult

Other drivers in this direction include (a) Specific requirements and standards by Brands / Buyers, (b) Compliance protocol adopted by Individual industry (c) Brand initiatives such as ZDHC. At the moment, though these drivers encourage the industry to adopt water conservation and effluent recycling, they too do not provide any legal framework to ensure efficacy of the effluent recycling system.

Similarly, there are no monitoring parameters and applicable standards for effluent recovery. As a result of this, the enforcement agency or monitoring agency engaged by the brands/buyers finds it quite difficult to monitor the functioning of the ETP managements claiming effluent recovery too as a part of their treatment.

12.4 Motivation Challenges

12.4.1 Lack of awareness among the industry

The industry considers effluent treatment mainly as a legal requirement to satisfy the DoE and pre-requisite by the buyer. They do not regard effluent management as their social or moral responsibility and never consider effluent treatment as a part of their production. In short, most of the industry consider ETP installation and its operation as an un-avoidable nuisance.

12.4.2 Apparent cheapness of water

Among the raw materials consumed by the industry, water is given the lowest importance. Further the cost of ground water today is so low that cost of water does not figure in their cost-benefit projections.

At the moment, there is no appreciable amount of cess paid by any industry for the water they consume. Industries tend to consider groundwater as their personal asset (a.k.a the land) and do not realise that groundwater is a common natural resource which should not be squandered by one industry even though they have access to a confined aquifer with sizeable water.

12.5 Operation & monitoring challenges

Unlike ETPs which are sturdier in nature, any wastewater recycling system would be very sensitive and it is quite possible that the membranes may irreversibly get damaged by even one day's wrong operation. The control and data aquisition systems too need careful maintenance.

At the moment, Bangladesh do not even have adequate managers and skilled operators even for normal ETPs and there is hardly any one management with hands-on experience in effluent recovery systems. Even if the entire operation is made automatic, an effluent recovery system need highly skilled personnel to operate the sensitive and complex units of the recovery plant. As a result, it is very much possible after installation of a recovery system at very high cost, the system may not be maintained properly, making these systems redundant after some time.

Even with SCADA and other data acquisition systems, on-site/off site monitoring are required and the DoE has limited capability to effectively monitor the recovery systems, particularly the number of installations goes up.

12.6 Challenges in monitoring by DoE

DoE is expected to monitor the performance of any effluent management system, be it effluent treatment & disposal or effluent treatment & recovery. While the monitoring of normal ETP is a routine affair by DoE staff and well understood protocols are place, there is no such guidelines for monitoring of effluent recovery systems.

In general, the following can be considered as challenges in enforcement.

- Lack of a legal framework for effluent recycle
- Absence of any quality standard for effluent recycle monitoring
- Lack of monitoring infrastructure, both in terms of equipment & manpower.

12.6.1 Legal framework

At the moment, any directions from DoE to the textile industry in Bangladesh to adopt effluent recovery is advisory in nature. Absence of a legal framework makes it difficult to enforce the water recovery options across the industry sector.

A proper legal framework needs to be created and adopted by Government to enforce & control directions to implement effluent recovery measures. The actions in this regard should start with development of a 'effluent recycle policy' by the Government and then development of a guideline for the specific industry, in this case the textile industry. Then a road map to achieve the target should be finalised.

As such there is no clear understanding of the operating parameters and monitoring of effluent recovery systems within the DoE. Unless such an awareness is created it may be difficult for the DoE engineers to verify the performance of effluent recycling systems and to check if these systems achieve the desired goals.

It is therefore recommended that a detailed training program making the DoE engineers fully aware of the technical & managerial requirements of effluent recovery systems and to sensitise them about the need and expected outcomes of effluent recovery.

12.7 Economic challenges

It goes without saying that water recovery from effluent is no way cheap and may cost many times of the water cost currently born by the industry. If the effluent recovery step increases the cost substantially, the resultant increase in cost should be passed on to the ultimate buyer.

At the moment, much of the textile business remains in Bangladesh also due to the economically attractive prices of the product. If the product costs high, buyer may shift his base from Bangladesh to other affordable countries and the country may eventually lose the business. Such a scenario could be catastrophical to the textile industry in Bangladesh and detrimental to the economy and employment currently provided by the industry.

Hence any implementation of effluent recovery systems need active understanding and support of the buyer/brands and the additional cost burden should be shared by all stakeholders.

12.8 Logistic challenges

Bangladesh in general and Dhaka in particular has a huge shortage of land for industrial establishments. Most of the factories in Dhaka occupy more than 90% of the land area and there is practically no space to construct any more effluent treatment facilities. In fact, lack of space for additional ETPs have forced many factories to halt their plans for expansions. Many factories installed ETP in multiple levels and the system had become quite complicated to control.

Though the effluent recovery systems can be designed in such a way that it does not consume too much area, still a minimum area is needed and many factories do not have such space.

13 CURRENT SCENARIO OF IMPLEMENTATION OF EFFLEUNT RECOVERY IN BANGLADESH

13.1 Status of effluent recycling in Bangladesh

It is not known if any textile factory in Bangladesh has achieved successful implementation of water recovery. A study report made for DoE in 2017 indicate that till that time only one industry, which was a washing plant, had adopted RO system and about 10 industries had submitted their plans to DoE to achieve even ZLD status soon. The unit which has installed RO system is stated to be achieving 63% recovery. There was no information about the management of rejects from this unit even [(25)].

Interestingly, the common terminology used for any ETP with recovery in such reports is ZLD, even though there is a discharge of effluent. Many reports in the public domain freely uses the term 'zero discharge' for such units. Obviously, the definition and concept of ZLD or ZD has not been understood and taken into its true meaning.

13.2 Present Situation

At present many industries shows urge to implement water recovery measures or even zero liquid discharge. Most of them are driven by the desire to be the first to implement Zero Liquid discharge in the country, rather than based on a conviction that such recovery measures are necessary for their survival and technically & financially viable.

Their plans are also based on ultra-positive projections on O & M cost of effluent recovery by the suppliers of RO system which are seldom realistic.

In all probability, once the plants are installed, it may fail and/or the cost of operation would be proven to be way above the projection and these factories may stop operating the effluent recovery plant which may remain as a show piece.

Eventually, the same factory owners who took initiative to install the effluent recovery plant may come out (though not in open forum) with the feedback that the ***technology is a failure***.

13.3 Status of offers received by industry

Based on the interaction with many factories in Bangladesh, it has been revealed that many ETP managements have obtained offers from suppliers from India, China and European countries like Italy, Germany, UK etc.

The offers are of two types. The first group is from suppliers, mostly from India, who have already supplied effluent recycling plants/ZLD systems for currently functional ZLD plants in Tamil Nadu & Gujarat in India. Most of these proposals have elaborate recycling schemes, including combination of pre-treatment, multi-stage RO units and multiple effect evaporators for reject handling. Normally, such offers would have been very costly, but the suppliers tend to keep the prices down by downgrading the quality of materials, say mild steel construction of skids instead of stainless steel, lower quality stain less steel etc. Very clearly, such units would not have longevity and would eventually fail.

The second group of offers are from reputed manufacturers of effluent treatment projects, mostly from Europe. Many such companies, especially Italian firms, have already implemented effluent treatment systems for textile Industry in Bangladesh and consider themselves as eligible for making such offers. Unfortunately, most such companies have no practical experience with effluent recycling or ZLD. Most of their schemes are too simple to function effectively, with name sake pre-treatment and barest minimum design criteria for RO etc.

The situation become even more difficult due to the fact that there are not many consultants in Dhaka who are technically qualified and experienced to evaluate offers and provide supervision during implementation of effluent recycling projects. It is another matter the factory managements are not so keen to utilise the service of qualified consultants and make their decisions based on feed-back from other industry groups or their own impression of the supplier.

At the moment, the indications are that these factories may go through the same cycle which their compatriots in Tirupur, India had gone earlier.

A typical such cycle may be in the following lines:

<u>Stage 1:</u>

- Industries install some recycling system with much fanfare, which eventually fail,
- They may stop operating such systems due to technical difficulties and/or realising the cost of treatment involved.
- Many may conclude that the recycling system is unviable and tries to focus back on basic effluent treatment.

<u>Stage 2:</u>

- Industries which implemented recycling systems understand that it is not easy to revert to earlier situation due to the image they created for buyers, pressure from DoE and the fact that recycling units will get damaged if left idle.

- Meanwhile, the dwindling water availability make them realise that effluent recovery may be a necessity, beyond stipulations of DoE or pressure from buyers.
- Based on experience from failures encountered and the observations/lessons learnt from such units, the factories try to implement modifications in the installed unit or opt for a better designed recovery system.
- The industry realise the techno-commercial challenges in effluent recovery and mentally condition themselves to that reality.
- Try to re-commission the modified/upgraded/replaced recovery system.

Stage 3:

- Units with effluent recycle operate the upgraded recycling system with better efficiency and eventually the same becomes a part of the production process.
- The cost of recycling is taken as part of production cost. For an interim period, this will result in reduced margins.
- Based on the compliance as a new marketing tool, try to gain some benefits in business to reduce the loss in profits.
- As time progresses such firms will realise the less evident benefits like production security, un-hindered expansion plans etc.
- Based on the few (apparently successful) units operating with effluent recovery, DoE (and buyers/brands) will insist on other units to follow suit.

In this cycle, companies with strong marketing ties and loyal customers may gain and factories operating like a job-work will suffer and may lose business to competitors (within or outside the country) with no compulsion to do effluent recovery.

13.4 Scenario for immediate future

The simple fact is that the industry in Bangladesh is not yet fully ready for adoption of any serious effluent recovery measures. Many are just contemplating the same without recognising the technical/managerial/economic challenges of the same.

It will be much more sensible to start with part recovery of effluent and migrate to ZLD in steps which may need support of DoE.

The risks associated with hasty installation of an effluent recovery system without proper planning could be:

(a) Effluent recovery is a serious matter. Unlike treatment & discharge of effluent, a recovery system performance has significant impact on the quality control in production. If the water recovered is not of sufficient quality, the impacts could be huge.

(b) Once an effluent recycling system is installed at significant cost and with a lot of publicity, it may not be easy for an industry to simply stop the process and revert to treatment & disposal.

(c) Even as a first step, the factory may implement an effluent recovery plant to get 50-70% water recovery, only to realise that the disposal of residual (reject) liquor from the system is a major handicap. The TDS of this liquor may be >10,000 mg/l and it is not legally allowed to discharge this liquor.

(d) The partial recycling of effluent can only be the beginning and eventually the factory may be required to adopt ZLD. Even before implementing the part recovery, it should be ensured that the factory has enough land area & resources to go for this ultimate step.

(e) Even partial recovery options need installation of sophisticated technologies such as Reverse Osmosis. As mentioned elsewhere, even one day's careless operation in ETP may result in permanent damage of membranes. The factory needs to ensure that they have qualified & experienced manpower to manage the entire system.

14 NEED FOR AN EFFLUENT RECOVERY SYSTEM IN BANGLADESH

One may wonder, if the effluent recovery is a difficult proposition, why should we even consider it? Unfortunately, the situation with groundwater compels the industry to look at effluent recovery seriously.

The need for effluent recovery system in the textile industry of Bangladesh should be considered at different levels. They are briefly discussed here.

14.1 Need for effluent recovery at Government level

14.1.1 It gives proof of compliance

There is often a biased projection that industries in developing countries do not maintain environmental standards and the claims made are not credible. The fact is that while the system still need improvement, the progress achieved in the past few years is truly remarkable.

An effluent recovery system, by definition, pre-supposes the presence of a very well operated ETP. If a factory actually recovers their treated effluent, either fully or partly, it gives ample proof that the ETP is well maintained and operated.

14.1.2 Protection of water resources

The groundwater table in and around Dhaka is falling down alarmingly. The indiscriminate extraction in effect means that the precious ground water is actually pumped out to the river which eventually drains off to the sea. A total extraction of 5000 MLD (50,00,000 m^3/d) is equivalent to a million pumps continuously pumping out the groundwater to the sea! It is easy to see the country cannot afford such a huge wastage for long.

At the same time, the river water too is getting contaminated, effectively losing the precious water resource providing livelihood to many.

Effluent recovery will solve these issues to the extent it is recovered. Even if the TDS in the remaining water after recovery would be high, the salt load to the river may still be lower and it should be noted that discharge load of other pollutants including organics, suspended solids etc. will certainly come down.

14.1.3 Protection of employment and economical balance

It is fact that at the moment the entire economy of Bangladesh depends on this industry. The employment provided by this industry too is huge. If by any reason, be it due to the

shortage of water or through actions of brands/government, this industry reduces or slow down its growth the impact will be disastrous.
The effluent recovery, to the extent it is practiced, will ensure security of this industry and protect employment and economy.

14.1.4 Reduction of salt import and saving foreign exchange

It is assumed that as on date bulk of the Glauber salt used by the factory is imported from outside expending the valuable foreign exchange. If salt recovery is practiced as a part of the effluent recovery, the factory can reduce purchase of salt and the country can save equivalent amount of foreign exchange.

14.2 Need for effluent recovery at factory level

14.2.1 Water Security

It is one of the most important requirements for the factories now. A proper baseline analysis will make the picture clear and the risk due to over-exploitation of water will be fully known.

If the groundwater level falls down by 5-10 m every year, it is very clear that the factory may not survive beyond few years. The risk to the investment already made, market & business secured till now and the profits is indeed huge.

Even 50% reduction in water extraction will make the longevity of the factory by many fold.

14.2.2 Compliance with buyers/ customers/ brand requirements

Buyers/brands and organizations such as ZDHC has come out with stringent guidelines in line with their customer expectations. The growing ZLD implementation in countries such as India has led to amendment of the ZDHC guidelines with recognition of ZLD and the pressure for effluent recovery is going to increase substantially.

Therefore it makes sense to plan now itself for effluent recovery measures in stages so that the financial burden and sustainability of the recovery plant can be ensured by spreading out the implementation strategy.

By responding to the demands of brands pro-actively, the industry can prevent migration of business to other countries.

14.2.3 Improving competitiveness and boosting image

By opting for effluent recovery, the industry can get a huge boost in their image with the buyers/brands and the general public.

The pro-activeness in this regard can be marketed as the ethical business strategy of the factory and it may pay-off handsomely.

14.2.4 Better legal security

By opting for effluent recovery, the factory may get a better legal security. The industry should keep in mind that DoE is planning to make on-line monitoring a part of their upcoming norms and they may not be able to get away with any malpractices for long.

14.2.5 Better quality control in production

Strange as it may sound, the recovered water from effluent recovery projects are generally better than ground water and this may result in better quality control in production.

Also, the recovered water may not go through any seasonal quality variations and this may ensure consistency in product quality.

14.3 Need for effluent recovery at Buyer/Brands level

14.3.1 Ensuring availability of products from Bangladesh

From the fore-going it should be clear that the water security of the industry in Bangladesh is likely to get affected in the immediate future if the present practice of water extraction continues and no water recovery measures are instituted.

The supplies from Bangladesh serve as a reliable source for quality product at affordable price for the Brands. If the survival of the industry is affected, eventually it affects the brands/ buyer too. Hence it makes enough reason for the brands to support a water saving measure by the industry.

14.3.2 Better liaison/image with the ultimate buyer

The brand/buyer can capitalise on the fact that that the supplier from Bangladesh practice an effluent recovery system. It could be a major image booster for them with the ultimate buyer.

15 STRATEGIES TO IMPLEMENT EFFLUENT RECOVERY IN BANGALDESH

15.1 Strategies needed by Government

15.1.1 Incentives

It may not be easy to provide any Government incentive to an industry, which is essentially a private business and earns profit. If the industry is required to pay any taxes based on capacity of the factory, reduction incentives could be considered based on the degree of effluent recovery.

Further, if the industry establishes common effluent recovery systems, some subsidy options, similar to the ones adopted by India, could be considered. Soft loans from financial establishments may also be considered.

15.1.2 Instituting & rationalizing Water cess

Enforcing a water cess would encourage the industry to seriously consider and adopt effluent recovery measures. This will make the industry to consider groundwater as a public asset and not as their property.

However, the water cess commonly levied by most countries is not high enough to seriously consider alternatives. For instance, if the water cess is BDT 1-2 per m^3 as commonly adopted, no industry may consider effluent recycle which may cost much higher than the cess they may save. Hence it is necessary to fix the rate of Cess accordingly. However, fixing of a high rate for water cess may invite serious protests from industry. Hence sufficient interaction/discussion & brainstorming with stakeholders is necessary to fix the rates.

Also, there should be a provision to reduce the cess proportional to the quantity of effluent recycled by the industry. The rate of incentives need to be arrived at based on detailed deliberations within the government.

Just for reference, it may be considered that the incentive for effluent recycle can be double that of Cess. This means, at 25% of effluent recovery an industry can prevent paying any cess.

For instance, if the CESS is fixed at BDT 5 per m^3, the reduction for verified effluent recycle can be BDT 10 per m^3. This means if the water consumption is 1000 m^3/d, the CESS to be paid would be BDT 5000 per day. If the quantity of effluent recycled as verified through the flow meter readings is 100 m^3/d, the Cess to be paid would be BDT 3000 per day. If the factory recovers 250 m^3/d or more of effluent and provide proof for the same, they may be exempted from paying Cess.

15.2 Strategies needed by DoE

15.2.1 Existing standards

Basically there are three products possible from a Effluent recovery facility. These are treated effluent, sludge, recovered water and salt/brine if recovered. The effluent discharge standards are already in place and ETP sludge is considered as a hazardous waste in Bangladesh and standards defined. The standards for the rest need to be finalised.

15.2.2 Fixing Definition and standards for effluent recovery

At the moment, the term ‘effluent recovery’ is just a concept and there is no clear cut boundaries about ‘how, when and how much’ the effluent recovery should aim to. Based on wider interaction and deliberations with experts & stakeholders, DoE may fix up proper definition to the effluent recovery philosophy and fix grades of recovery and time based targets.

Even though the technology for effluent recycle may be out of DoE’s purview, since DoE is responsible for environment protection and prevention of malpractices, basic quality control criteria may be defined and published by DoE or by other organisations like GIZ with DoE’s support.

The standards for recovered water may be based on existing standards for use of fresh water for various purposes including production process, boiler, cooling, washing etc. The relevant ISO codes for quality of water for industrial purposes shall be applicable.

The purity of the recovered salt or brine can be as per industry’s own need and as long as it is not disposed off outside there is no discharge specific standard required.

It will also be useful to have a general **guideline for effluent recovery** prepared in this regard by an organisation like GIZ with experience in this field.

15.2.3 Fixing level of recovery targets

While everybody agrees that Zero Liquid Discharge should be the ultimate target for the industry for ensuring compliance and water security of the industry, there is ample realisation that the industry is not yet ready for the same and that much effort is needed to make the ZLD financially, technically and managerially viable.

Hence the practical approach should be to fix targets to achieve this goal in stages. A realistic time period needs to be arrived at based on consultations with experts, institutions and industry.

15.2.4 Finalising standards for effluent recovery

The big challenge in effluent recovery is how to dispose off the saline reject from the RO plant, if partial recovery is attempted. The options available are as follows:

(a) Dispose of the saline reject where it may not create any environmental degradation, ideally a marine coastal area. Areas such as Dhaka is far away from marine coastal areas and therefore options such as marine discharge may not be feasible.
(b) Mix the reject with municipal sewage at a ratio where it does not result in mixed water TDS not exceeding the limits. Unfortunately, the textile effluent quantity in Dhaka region is too high to get a good dilution by available municipal sewage.
(c) Concentration of salt liquor and re-use in the process. It is a viable proposal but the required technical skill and production pattern improvements are not available at present and it may take time adopt this.
(d) Mix the saline reject with rest of treated effluent and discharge the same. However, as mentioned the TDS in the water in terms of concentration (mg/l) will shoot up, even though the total quantity of salt load (kg/day) may remain the same.

Among the above, the last option appears to be the immediately viable option. As mentioned already, even when everyone agrees that there should be reduction in water consumption, **the biggest challenge** faced by the industries in reducing water consumption and/or practice partial effluent recovery measures is the difficulty in meeting the discharge standards stipulated by DoE, in particular the **TDS** and **COD**.

It is true that at the moment DoE has taken a lenient stand by not taking any action against many ETPs exceeding TDS limit, the fact that they do not meet the standards keep many worrying.

The limit stipulated for TDS for textile industries as per ECR 1997 is 2100 mg/l. Even now, many of the industries exceed this value. Those industries which are meeting this standard achieves that only because their water consumption is too high. Units which attempted water conservation found out that their treated effluent is not achieving this standard and many units, mostly large and socially responsible units, quickly back tracked to high water consumption, to maintain their compliance with the standards.

It goes without saying that any attempt to partially recover effluent will exponentially increase the TDS in the remaining effluent for discharge.

It is abundantly clear that unless some policy intervention is made in this regard, the drive to reduce water consumption will not achieve any purpose.

It may be possible that DoE may consider delisting TDS as one of the standards for textile effluent for some time to promote this effluent recovery. However, it may not be a good movement as it might promote indiscriminate discharge of salt into the river which is already polluted by the discharge from textile factories. Any interventions made should be ensuring that the river is not getting polluted any further.

One recommendation here is that DoE may come up with an acceptable standard for the interim period, like the one detailed in the next chapter.

15.3 Fixing a monitoring mechanism for effluent recovery

Generally, monitoring of effluent treatment & discharge may be done easily by collecting samples of treated effluent and ensuring that they are within the limit specified by DoE. Here the flow meters are only meant to be verifying that all effluents are treated and may not necessarily be real time.

Case of effluent recovery systems are different and they need special monitoring mechanisms. The monitoring of such systems may be done by DoE, Stakeholder Institutions and by buyers/brands.

15.3.1 Monitoring of ZLD systems

General monitoring of ZLD should be relatively easy since the industry is not expected to discharge any effluent and any one can easily find out if the industry discharges any water.

From DoE side, frequent visits, coupled with online data acquisition systems could ensure compliance. There should be flow meters at raw effluent, RO permeate and evaporator condensate. If there is any saline water recovery part, flow meters should be there in those lines too. Comparing the raw effluent flows with net recovered water can show if there is any difference and any illegal discharges are likely. The water balance may need to factor different losses such as evaporation and additional inputs from chemical preparations, boiler feed water etc.

Another way of verifying ZLD status is by measuring the quantity of salt generated and compare it with the TDS inlet to the ETP. Here TDS meters are combined with flow meters to give inlet TDS load and the salt generation should be proportional to this value, except for permissible losses. If there is any saline water recovery line, a TDS load measurement unit may be needed in this line too.

At a later stage, measurement of raw water consumption and ensuring that the top-up requirement does not exceed 10% of the effluent quantity too would be a tool for effective monitoring of ZLD.

ZLD systems in India need to install PTZ (Pan-Tilt-Zoom) cameras in ETP area, particularly one of them focussing the erstwhile treated effluent discharge line to ensure that there is no bypass. The effectiveness of such monitoring need further study and evaluation.

15.3.2 Monitoring of partial effluent recovery systems

Monitoring of partial, non ZLD, effluent recovery systems are quite different from effluent treatment/discharge systems and the monitoring systems needed may not be as complex as ZLD units.

For monitoring the partial effluent recovery system, an online monitoring arrangement may become necessary. In order to verify how much effluent has been recovered the following arrangement may be helpful:

- There should be three flow meters in the ETP with online data acquisition and monitoring system. One flow meter may be in the raw effluent line, second one may be in the recovered water line and the third one could be in the treated effluent.
- If a saline water recovery is practiced, a flow meter is needed in that location too.
- The combined flow of recovered water (including saline water recovered, if any) and the treated effluent discharged should be equal to the raw effluent flow rate. Any difference indicates by passing of effluent.
- If possible, systems could be installed to measure the raw water input. The difference in treated effluent with the raw water quantity should be equal to the recovered water quantity.

In addition to the above monitoring, DoE engineers may visit the ETP periodically and verify the extent of recovery and re-use.

15.4 Preparation of effluent recovery policy

Preparation of an effluent recovery policy should be a collaborative effort between DoE, brands/buyers and the industry.

Many international organisations including ZDHC has specified goals for reduction of water consumption in the factory. With the support of technical organisations having expertise and experience in this field like GIZ, salient features of an effluent recovery policy can be delineated. Based on this data, a suitable effluent recovery policy may be drafted by DoE.

15.5 Strategies needed by industry

15.5.1 Reduction of water consumption & generation of effluent

It is quite clear that the effluent recovery option will be much costlier, compared to the in-house water conservation measures. Hence the industry should take a re-look at cleaner technologies. Water conservation and waste minimization should precede effluent recovery, as this will reduce both the water to be treated and the pollution load. It is noted that many industries who adopted effluent recovery system or ZLD took active steps to implement water conservation measures seriously.

Instead of taking that route where such efforts were done ***after*** the installation of effluent recovery and only after feeling the punch of extra cost, it will be much more sensible to try such measures ***before*** the design of effluent recovery is made and money invested in effluent recovery.

Since there is a lot of material already available on cleaner technologies with impact on reduction of water consumption and pollution load and such measures actively pursued by brands/buyers and organisations such ZDHC, a discussion on such options are not attempted here.

15.5.2 Management of energy costs and increase in carbon footprint

Effluent recovery is an energy intensive operation, mainly due to the high pressure pumps in membrane feeding. In case of ZLD, requirements of thermal evaporators etc. increase the energy consumption and the carbon foot print many folds. The industry may try to minimise the increase by adopting energy efficient systems and renewable energy options such as roof top solar power plants.

15.5.3 Instituting a cost sharing mechanism across the product chain

It should be understood by every stakeholder that effluent recovery is a costly affair. A mechanism to share the cost across all parties involved including the industry, brands and end user need to be evolved. For instance, if there is an increase of BDT 5 on a piece of jeans, the increase should be equally shared by all and impact on an individual stakeholder may not be much.

The brands should understand that having effluent recovery & water security at their supplier level ensure the survival of their supplies for a long time and they could claim better image in front of the end-user; hence it justifies sharing the cost burden.

The industry should also be willing to absorb the cost impact on their profits. If they try to pass on the entire cost increase to the product price, the buyer may opt for some other supplier who can offer cheaper rate. Making an eco-label could be considered by the brands/organisations such as ZDHC to justify the increase in cost.

15.5.4 Familiarizing themselves on pros & cons of effluent recovery

In India, where the effluent recovery is being done with reasonable success, the industry has reached the current after a lot of trial & error, burning their fingers many times before identifying the suitable combination for them. If the industry in Bangladesh starts from scratch they may also go through the same path and makes the same mistakes done by their counterparts in India.

It makes ample wisdom to make a study tour and observe the existing systems and to learn from their experience before venturing into this sector. The lessons learnt by the industry in India may be used for finalizing the scheme for effluent recovery in Dhaka.

15.5.5 Equipping industry for operation of effluent recovery system

The effluent recovery system needs much more expertise and skill than conventional effluent treatment. At the moment manpower resource for even managing the basic ETP is scare and manpower for managing an effluent recovery system is non-existent.

At the same time, the effluent recovery systems are much more sensitive and need careful management. Even with automatic operation, the performance of the system depends a lot on input management. As already mentioned, even one person’s negligence can result in irreversible damage to membrane.

All the membranes used in effluent recovery are imported from other countries and at the moment there are not many who stock membranes in Dhaka. On the other hand, keeping membranes in stock in factory for a long time is not a viable option since membranes have a limited life-time, even if the same is put to use. If a set of membrane get damaged, the only option is to wait till the same is imported and fixed. Hence, besides the wastage of money, replacement of membranes result in avoidable down-times.

Improper operation will also result in frequent chemical cleaning and replacement of consumables such as cartridge filters, resulting in huge wastage of money.

From the foregoing it should be clear that before venturing into the effluent recovery, industries should take effort in creating a pool of skilled and trained manpower. Brands, institutions may provide support in such a venture.

16 WAY FORWARD AND STEPS TO IMPLEMENT EFFLUENT RECOVERY

16.1 Planning effluent recovery in stages

While ultimate aim of the effluent recycle initiative could be zero liquid discharge, a practical approach would be to plan in stages, ensuring sustainability at each stage. Such a plan may be finalised after wider consultation with experts & stakeholders. A typical stage-wise implementation program is explained here, just for reference.

16.1.1 Stage 1: partial recovery of effluent, which may not DoE standards

This may be attempted straightaway by the section of industry which has got good working ETP and the resources to proceed to the next step. It can also be considered by those industries which are likely to have water scarcity due to ever falling groundwater table.

In this stage, 50-65% effluent can be recovered and the rest may be permitted to be discharged as treated effluent. If the existing ETP has MBR as the part of ETP, the treated effluent can be directly taken to an RO, with or without an oxidation stage depending on the colour and organics in the treated effluent.

For normal ETP, a tertiary treatment in the form of filtration and an activated carbon/ advanced oxidation may be considered. The tertiary treated effluent may then be taken to a UF-RO system. The ultra-filtration may have a pore size to provide 100-150 kilo Daltons molecular weight cut off. The reject from UF may be sent back to the raw effluent stage or provided with dedicated advanced oxidation treatment before discharge. The filtered water from UF may be taken to an RO, may be of brackish water RO membrane with low fouling capability. If the RO has a second stage, it can be a sea water membrane, based on the TDS value.

The reject from RO, constituting 35-50% of the total effluent may be discharged as surplus treated effluent. Depending on the TDS of treated effluent and the rate of recovery, the final effluent to be discharged may or may not conform to the norms of DoE, particularly in terms of TDS and sometimes, the COD.

Alternate to the above, depending on the quality of treated effluent may be to admit only part of the effluent to RO and mix the reject from RO with the rest of the effluent for discharge. For instance, if 70% of the effluent is treated in an RO plant for 75% of recovery, the reject from RO stage would be 18% (25% of 70%) and overall quantity recovered will be 52% and reject quantity will be 48% (30% + 18%).

It may be possible that COD of this water to be discharged too would be higher than the tolerance limit, even if overall COD load may be lower. Still, unlike TDS, it should be possible to adopt advanced treatment systems to reduce the COD lower.

16.1.2 Stage 2: partial recovery of effluent, with salt recovery

At this stage, the effluent recovery system may be tweaked and modified for providing 80-85% recovery and the brine is recovered for re-use. For obtaining this result, the RO may be installed in 2-3 stages. The reject from RO, if needed, may be further processed in High pressure RO to get maximum TDS and treated for salt recovery, either through a nano filtration or other suitable process (including concentration & crystallisation). The permeate from HP-RO may be blended with raw effluent. The small quantity of reject from the system with mixed salts and unrecovered salt may be discharged as effluent. The TDS in this stream will be much higher than the limit, but the quantity of salt (salt load in terms of kg/day) will be much less than initial scenario. The COD of the effluent too may be higher than the limit if its concentration is considered, but the overall COD load may be much lower.

If such a system is planned for a new ETP, the ETP itself can be constructed as modules for high TDS streams & low TDS steams and recovery system integrated with the same.

16.1.3 Stage 3: Zero Liquid Discharge with or without salt recovery

This may be the ultimate stage of effluent recovery. Here the multi-stage membrane systems, may be in combination with reject concentrators, concentrate the reject to the maximum extent. Thereafter, the salt may be recovered at the liquid stage through nano or recovered through crystallisation after initial evaporation.

The mixed salt liquor after salt recovery may be evaporated to dryness for ultimate disposal. If the salt is not recoverable (say, in case of sodium chloride rich exhaust dye bath), the entire reject may need evaporation. Ultimate fate of this evaporated matter is not clear at the moment and it is hoped that a viable solution may be found out by then. The recovered water comprising of the RO permeate and evaporator condensate is reused in the process. Except for the top-up to compensate for the water loss in production, no fresh water is used in the factory.

The ZLD technology is still evolving and if the third stage is required after some time, say, 10 years more economical & efficient systems may come into practice by then. A more efficient reject concentrator like forward osmosis may change the economics of the entire ZLD operation.

16.2 Resolving legal challenges related to effluent standards till ZLD is achieved

It is quite clear that unless the issue related to non-conformity of discharge standards is resolved, efforts on effluent recycle cannot start stage-wise enabling the industry to discharge the rest of the effluent after recovery. In such a situation the only option would be to do no effluent recovery or to go for ZLD.

Detailed deliberations are required with experts and stakeholders to make an acceptable, yet environmentally sound solutions for this aspect.

A typical intermittent solution till the industry migrates into ZLD may be that the DoE may consider accepting the salt load as the discharge standard in case of ETPs with effluent recovery instead of the concentration. In such a case, it is required to install a flow meter coupled with a TDS meter to measure instantaneous and cumulative values of TDS load with real time data acquisition to any server including that of DoE.

The permission may then follow original provision of environmental clearance from DoE.

The limit of 2100 mg/l (or 2.2 kg per 1000 litres) means the maximum allowed salt load as per original clearance from the factory is 2200 kg or 2.2 tons per MLD. As long as the total load of salt does not exceed this value, it may be considered as meeting the standard.

For example, take the case of an ETP with capacity 1000 m^3/d and the TDS in the effluent as 2000 mg/l before any recovery. This ETP meets the limit of TDS and the total TDS load is 2000 kg/d. If this factory recovers 60% of the water with a TDS of 100 mg/l and discharge remaining 40% as reject, the TDS in RO reject will go upto 4850 mg/l.

However, even though this concentration of TDS is far above the tolerance limit, the TDS load in the current discharge of 400 m^3/d would be 1940 kg per day (4850 mg/l x 400 m^3/d) which is actually ***lower*** than the previous value.

If the industry adopt salt recovery along with higher recovery through 3-4 stage of RO, the TDS concentration may go up very high, but salt load will be much lower.

For example, if the ETP with 1000 m^3/d capacity recovers 90% of the water with a TDS of 200 mg/l, the remaining 100 m^3/d may have a TDS value of 18200 mg/l which is very high if TDS concentration is considered. However, the total salt load will only be 1820 kg/d, which is much less than the previous value.

Now, if the ETP recovers 50% of the salt, the TDS concentration will come down to 9100 mg/l (still much higher than the limit) and salt load will come down to only 910 kg/day which will be a major improvement in the situation.

It should also be possible to link the TDS load to the production capacity based on standard water consumption figures. This may be done based on review and deliberations by DoE with experts and stakeholders. For example, if the water consumption is taken as 100 litres per kg of processing, a factory processing 10 tons/day may be allowed to discharge upto a maximum of 2200 kg of TDS in their effluent.

16.3 Development of water conservation & effluent recovery policy

The Government may fix the target for reduction of water consumption by industry and encourage effluent recycling. In the present scenario, it should not be difficult for any factory to reduce 25-30% of water consumption just by water conservation in the factory. A factory adopting strict water conservation targets and some effluent recovery could easily reduce the water consumption by 50-60%.

After review with stakeholders and based on proper modelling by technical experts, model targets with time frame may be finalised.

A fictional target is given here just for reference. Actual target may be fixed on wider consultation.

- By 2025, it may be targeted that 10% of industry (mainly the large units & exporters) adopt intensive water conservation and partial effluent measures and achieve 60%. reduction in water. Another 25% of the industry (mainly major units) may reduce the water consumption by 40% and remaining may achieve 25% reduction.
- By 2028, it may be targeted that 50% of the industry reduces the water consumption by 60% and remaining reduces water by 40%.
- By 2030, fifty to hundred large factories in Dhaka may opt for Zero Liquid discharge and others may achieve 50%.

Based on the target, the Government may consider framing a water conservation & effluent recovery policy.

16.4 Creating awareness

16.4.1 Sensitizing the industry

In order to get sufficient commitment from the industry, there is a need to sensitise the industry that:

- Pollution is the by-product of their own production and control of the same is their own responsibility, irrespective of the economic/employment benefits provided by the industry.
- Preservation of water bodies (be it ground water or surface water) is in the best interests of the industry itself. A classical argument in this direction could be that despite having copious amount of water flow in Turag, the industry is not finding it useful to them since they themselves have degraded its quality.
- A better policy in the long run to sustain the export oriented business is to demonstrate themselves to be socially responsible.

Once the industry realizes the importance of this issue, better initiatives from them could be expected.

16.5 Development of a master plan for water management

The industry associations like BTMA, BKMEA and BGMEA may take initiate to make a master plan for water management for next 10 years. Support from Brands, ZDHC and organisations like GIZ could also be sought for this purpose.

The master plan may present the current status of water and likely demands in ten years' time. It can then propose the additional measures to be taken by their members for meeting this demand.

16.6 Creation of support services for effluent recycle

If a system of effluent recycle need to succeed, support services for implementing the same need to be created by the industry. Here also, the association can play a major role.

16.6.1 Technical support services

Local engineering support is essential for a successful scheme. Even if the basic design of effluent recovery systems can be sourced from suppliers/consultants outside the country, local expertise in engineering, supervision during installation and trial run/commissioning of the system need to be created.

Laboratories which can conduct reliable tests for effluent and water parameters are important and some more additional institutions may be needed in Dhaka.

16.6.2 Service centres and spares

After sales support is indispensable for a sophisticated system like effluent recovery plants. Major suppliers may be encouraged to open service centres in Dhaka to address after sales service and to stock necessary spares.

General repair workshops and service set ups too may be identified and their contact details kept for emergency references.

16.6.3 Manpower resource training

At the moment skilled and trained manpower required for managing an effluent recycling system is not available. In order to ensure trouble free and smooth functioning of the system to be installed at a high cost, sufficient manpower need to be ensured.

It is therefore recommended that intensive training programs may be organized by institutions and service providers to the staff already engaged in/to be recruited for ETP. The service providers already trained by GIZ under the Train-the-trainers program organized by the FABRIC project may take the lead for such programs. The wealth of training materials made available to them by GIZ should make the task easier.

16.7 Managing land requirements of water recovery options

ZLD systems consume much land, in many cases 50-80% of the area occupied by the ETPs. However, basic effluent recycling units may not take that much space (may be 20-30% extra). Still, availability of land is a major issue in Dhaka.

At the same time, an effluent recycling plant is a unit which the factory management would like to show case in front of buyers and visitors and a visually appealing & compact system would be required. It will be useful if the possible layouts of the system may be presented by consultants as isometric drawings and the option with best appearance may be selected by the factory management.

Intelligent space planning may be an integral part of design layouts. To save area, following options may be considered:

- It may be possible to construct the recovery systems in different levels. For instance, the pre-treatment units, RO system and the control & utility rooms may be constructed in different levels.
- It may be possible to construct intermittent tanks in one level and RO building may be constructed on top of the same after placing concrete cover with sufficient strength to install RO skids.
- Pre-fabricated skids with all pumps, pipelines/valves, and monitoring systems built alongside the UF/RO pressure vessels may be much more compact and better looking.
- It may be possible to plan the entire effluent recovery system on roof tops of buildings such as blower room, dewatering building and admin/lab building etc. if their roofs have sufficient strength.

A proper 3D sketch (isometric) could be of great help to make such planning.

16.8 Other water management options: surface water treatment & use.

A viable option to manage the complete water scarcity issue could be to use the river water after treatment.

As mentioned earlier, even though the industry states that they do not want to use the river water due to its bad quality and rather use the effluent recovery, it is mostly based on their impressions and not on any proven data. At the moment, it appears that no one has a clear idea about the quality of the river water through the various seasons and the suitability of this water as an input for the industry's water treatment plant.

An option could be to pump this water, treat it in purification plant, possibly incorporating an RO system itself with moderate recovery and send back the reject to the river.

The perceived benefits in considering this option may include:

- It can obviate the need to extract ground water and may ensure water security.
- The water source can more or less be perennial.
- Since the TDS of the water is likely to be low, the purification cost may be lower and the option to send back the reject may avoid the need for elaborate reject management.
- With source from and discharge to being the same river, water cycle can be ensured.

The perceived disadvantages in this option include:

- It does not provide any solution to the pollution problem to the river and may make it little worse.
- The option would be available only to the industry located near the river.

- The quality deterioration in the river is entirely due to some section of industry not treating their effluent properly. Hence in a way it can be stated that the industry doing this treatment may be treating someone else's waste.
- There could be seasonal variations in the river water quality and it could affect the plans of the industry.

With intelligent planning, it may be possible to combine the issue of water and the disposal of effluent in a single plant and operate it as a Common Effluent & Water Treatment Plant.

In the absence of baseline data, it may not be proper to make any concrete recommendations in this direction and hence this option is not discussed in detail in this document.

It is, however, recommended that a proper baseline study and feasibility evaluation may be done by an expert agency with support from DoE and organisations like GIZ.

16.9 Action plan by the industry

The industry need to act at the earliest on the water security issue to protect their investment & business.

They should really asses the need and regulate the use of quality water. It makes no sense to use single quality water for all purpose. Good quality water may be used on priority for processes needing high quality water and not for other areas or for domestic purposes.

It may be possible to take one spent water as input for another. For example Cooling tower blow downs can be used for toilet flushing. It also pays to regulate water treatment where necessary. Softening of water helps in dyeing, but it may not offer any benefit in many other areas.

Steps to be taken by the industry may be as follows:

16.9.1 Step 1: Decision on Implementation of general water conservation measures

- Most of the simple water conservation measures does not need any investment.
- With measures needing minimal investment, major savings could be obtained.
- Implement those on priority irrespective of good water availability.

16.9.2 Step 2: Check water security

- Critically analyze and review water requirement for next 5 years.
- Develop strategies if availability of water is low:

    - ✓ Intelligent management of water based on quality requirements of process
    - ✓ Implement simpler water recycling measures
    - ✓ Simpler wastewater recycling effluents

16.9.3 Step 3: Identify & implement economically feasible water conservation measures

- Realistically assess the cost of water used in factory.
- Estimate the cost of water conservation/recycling measures including capital cost amortization.
- Implement those measures proved to be economically beneficial.

16.9.4 Step 4: Long term planning for stricter environmental regulations

- Review possibility of restrictions of water extraction by regulators and plan remedial measures.
- Make a realistic estimate of indirect costs due to effluent discharge.
- Review possibility of ZLD norm implementation by regulatory agencies and plan a timeline.
- Plan water recycling strategies considering techno-economical demands of ZLD in future.

16.9.5 Step 5: Adoption of partial recovery options as the last step

- Though cheaper than ZLD, even partial recovery of effluent will not be cheap.
- A proper cost-benefit analysis, considering the advantage due to reduction of ground water extraction and other benefits and weighing them against the likely costs, may be done before venturing into this decision.
- The fact that option of partial recovery may need special permission from DoE too need to be considered while taking the decision on effluent recycling.
- At the same time, Industry should consider the possibility that effluent recovery or even ZLD may be become a necessity in future, either due to water scarcity or enforcement by Government/compulsion from Brands.
- Hence a road map for effluent recovery should be prepared by each industry based on their current situation.

17 CONCLUSION

It is undeniable that for the protection of industry, its employment and export revenue, water security needs to be ensured. On one hand, the issue of water scarcity increases, on the other, complaints regarding environmental pollution by the textile industry too is on the rise.

Eventually, water consuming industries like textile processing in Dhaka will be forced to adopt ZLD, either by regulators or by water scarcity. It makes sense to plan for effluent recovery in stages, leading to final stage of ZLD, over a period of time.

Considering the various challenges, proper care needs to be taken in effluent recovery design, factories should be careful about the offers they receive since many of the suppliers do not have proper idea about the requirement. But many of those who have experience with operational effluent recovery systems have not much quality control.

Incorporation of proper tertiary treatment, pre-treatment to RO and good quality membranes in desalination may make the effluent recovery system reliable and affordable.

Management of residual salt/saline liquor from RO is an issue still to be resolved. Option of salt recovery need to be carefully evaluated since it has a bearing on the quality of product.

Cost implications of effluent recovery necessitates that the industry may need support from buyers & brands.

With proper, systematic and well informed planning, a basket of options ranging from water conservation, in-house water recycling, effluent recovery & salt recovery/ re-use may be implemented and such an action will ensure sustainable water management.

It is hoped that with water security assured, the textile industry in Dhaka can flourish in their business, scaling new heights in exports, earn more of valuable foreign exchange to the country and safeguard & increase employment of millions who are dependent on this industry for their livelihood.

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