Textile Waste Water Treatment With Membrane Bioreactor

Introduction

Textile waste water treatment for industrial reuse remains as a complicated problem due to several reasons. Among them are: 1) Higher levels of Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Total Dissolved Solids (TDS) content of the waste water; 2) Non-biodegradable nature of organic dye stuffs present in the effluent. Thus, any adopted treatment system, especially with respect to primary treatment, should be able to address these issues. To solve these problems, many technological advancements were made, and here we describe one of the most important advancement namely, the Membrane Bioreactor (MBR).

As far as textile waste water treatment for industrial reuse is concerned, colour removal, reduction of Total Suspended Solids (TSS), BOD and COD are the main problems to be addressed in the primary treatment. Most commonly utilized primary treatment processes are: i) Conventional physico-chemical treatment utilizing lime and ferrous/alum; ii) Conventional biological treatment with aeration to reduce BOD and COD; iii) Chlorination; iv) Ozonation (with/without ultra violet irradiation). However, certain problems are associated with these treatment techniques, which are described here:

1) Conventional physico-chemical treatment with lime and ferrous/alum generates huge quantity of hazardous waste in the form of sludge, and its safe handling and storage is another problem. Further, conventional physico-chemical treatment methods are not highly effective in the removal of colour, TSS, BOD and COD.

2) Though chlorination shall remove colour and result in the reduction of BOD and COD, the chemical reaction of dissolved chlorine with the organics present in the waste water shall result in the production of chloro-organic compounds. These chloro-organic compounds may find their way into the environment, and they are potential carcinogenic compounds even under a few parts per million (ppm) concentration. Therefore chlorination may not be an eco-friendly treatment method. Further, chlorine has to be either stored in containers or, produced on-site. In both the cases, safety measures are very essential since accidental release of chlorine could severely impact the health of workers.

3) Ozone is highly reactive and potential oxidant than chlorine. Further, the reaction rate of ozone with organics present in the effluent is around 30 times faster than with chlorine. Ultra violet (UV) irradiation of ozonized waste water shall further increase the rate of reaction in addition to increasing the oxidation potential by the generation of hydroxyl radical (OH^-). Therefore, even non-biodegradable molecules shall broken down into smaller ones, resulting in better colour removal and reduction of BOD and COD. In addition, dissolved trace elements in the textile waste water shall be oxidized and precipitated as their respective hydroxides. This shall greatly reduce the risk of membrane poisoning in the

reverse osmosis system, especially with respect to dissolved iron. Though many advantages are there with the use of UV-Ozonation process, the system has to be highly optimized to get best results as ozone generation efficiency is lower even under ideal conditions. Ozone production and transport to the treatment unit requires special techniques as it fastly decomposes into oxygen. Presence of trace elements like Cu, Zn, Fe (which are normally found in the textile waste water) and higher levels of TSS shall affect the UV-Ozonation process. Thus, UV-Ozonation process should be designed to address these problems.

Conventional biological treatment can be considered as an alternative technique. But it also suffers from following problems:

1) Most of the dye stuffs are *non-biodegradable,* which renders conventional biological treatment ineffective or, less efficient [Here the term *non-biodegradable* implies the organic molecules that are resistant to biological degradation as well as those which take disproportionately longer time or, require special conditions for partial or complete degradation].

2) High TDS content of textile waste water, typically in the range of 8,000 – 10,000 mg/L, retards microbiological growth. This is due to the fact that under high concentration of solutes the energy requirement for transfer of solvent (in this case water) across the cell membrane is more due to higher osmatic pressure of the waste water. If biological growth is retarded, then the efficiency of the treatment system to bring down the BOD is affected. Under highly saline conditions, filamental growth shall occur, resulting in poor settleability of suspended solids from the treated effluent in the clarifier. This poses severe problem for the secondary treatment system.

3) The conventional biological treatment system shall not function properly under low F/M ratio (due to low levels of BOD in the raw effluent) typical of textile waste water. Sludge settleability in the clarifier is affected by F/M ratio, and its maintenance is of paramount importance for achieving best results.

4) In conventional biological treatment the MLSS concentration does not exceed 4,000 mg/L; thus the biological activity is less. This results in large aeration tank size, low BOD throughput, higher detention time and increased operating costs.

5) Since most of the dyeing houses uses different dye stuffs, their biodegradability shall be different. Depending on the dye stuff utilized and the shade required, it may be necessary to vary the concentration of dye bath for effective dyeing to take place. As a result, the discharged combined raw effluent (dye bath + wash water) shall have largely fluctuating BOD and COD levels. However, the conventional biological treatment system could not withstand *shocks*, *i.e.*, sudden changes in the raw effluent chemical characteristics. This is due to the fact that the conventional biological treatment system does not have a re-cirulation or, higher biological activity to dampen these variations. Also, due to *substrace specificity*, the

composition of microbial population shall be different depending on chemical composition of the effluent. At a given moment, the microbial population in the aeration tank of the conventional biological system is specific to the chemical composition of the effluent, especially with respect to the organics present in it. Due to low MLSS concentration and ineffective detention of microbial population in the aeration tank, the microbial population shall take some time to respond to the changes in the chemical composition of the textile waste water. Thus, conventional biological system is unable to yield stable treated water output.

6) Compared with MBR sludge production is higher in the conventional biological treatment. This shall require more area for secured land fill.

7) Nutrient removal from the raw effluent is inefficient and that shall encourage growth of microbial organisms on the reverse osmosis membrane utilized in the secondary treatment of the effluent. To prevent biofouling of the reverse osmosis membrane, anti-fouling agents containing chlorine is added. Since free chlorine shall damage the reverse osmosis membrane, the residual chlorine has to be eliminated with the addition of sodium meta bi-sulphite (SMBS). Addition of chemicals invariably increases the operating cost and treatment overheads.

Membrane Bioreactor in Textile Waste Water Treatment

Though MBR technology was develped over a decade ago, its applicability for textile waste water treatment remained elusive due to the involvement of heavy capital investment and the requirement of specific skills for its operation and maintenance. However, as the technology evolved, the costs have been brought down. With process automation, now MBR has found its way into the textile waste water treatment in many parts of the world, including India.

Membrane Bioreactor is an advancement over the conventional *activated sludge* process with the use of ultrafiltration or, microfiltration membrane which helps to maintain higher levels of Mixed Liquor Suspended Solids (MLSS) concentration and attain better treated water quality. Utilization of membrane filtration results in the retention of active micro-organisms, extra cellular enzymes generated by these micro-organisms for degradation of the organics present in the effluent, organics resulting from cell-lysis, and other heavy molecular weight organics typical of textile effluent. Since some micro-organisms, especially nitrifiers, are slowly growing one, their loss shall reduce the efficiency of the treatement system and nutrient removal. Under coventional biological treatment these micro-organisms might escape from the aeration tank and the weirs of clarifier. In the MBR, these organisms are retained and a better treatment is achieved thereof. In addition, retention of active enzymes secreted by mico-organisms taking part in the metabolization of organics present in the textile waste water is an important aspect of MBR technology. Maintenance of higher concentration of these enzymes shall result in rapid and better degradation of complex organic molecules present in the textile waste water. Thus, the overall efficiency of BOD and COD removal is improved, detention time required to achieve specific BOD and COD is brought down, and requird footprint is also minimized.

Though MBRs can be designed with various configurations, in general, submerged MBRs are well suited for textile waste water treatment. Submerged MBR is normally designed to incorporate two zones *viz.*, i) *anoxic*; ii) *aerobic*.[1] The membranes may either be placed inside the aerobic chamber or, kept separately in another compartment. Maintaining a separate compartment for the membranes reduce fouling.

Some bacteria can use oxygen as an electron acceptor when it is available, and in the absence of oxygen the same bacteria can switch the respiration mode to utilize nitrate/nitrite as electron acceptors. These kind of bacteria are called *facultative bacteria*. These bacterias can survive both in anoxic as well as in aerobic conditions unlike other kinds of bacteria that can survive only in anaerobic or aerobic conditions. As MBR configuration involves anoxic, aerobic, and membrane compartments with re-circulation from the membrane zone to the anoxic zone, the anoxic zone shall have very low levels of dissolved oxygen (the condition chemically referred as *sub-oxic*) brought back by the recirculating effluent. Thus, facultative bacteria dominate the microbial population in the MBR.

The bacteria growing under anoxic condition has the capability to break down recalcitrant macromolecules, which is then digested by the aerobic bacterial population persisting in the aerobic zone. In this way, a significant portion of the dye stuff and other organics could be broken down and oxidized. Thus, anoxic biological degradation is an important step if we consider MBR treatment for textile waste water.

Due to the use of membrane resulting in high concentration of active micro-organisms (MLSS is typically in the range of 10,000 – 15,000 mg/L), the MBR treated water has a uniform physico-chemical characteristics and the colour is mostly reduced, making this suitable for further treatment by the reverse osmosis system.

The quality of treated effluent output from Membrane Bioreactor is more stable than what could be achieved by employing other techniques, enabling the optimal functioning of the secondary treatment system. This stabilized output water quality is due to the prevalence of a steady-state condition inside the MBR compartments due to the maintenance of high microbial activity.

Also, the stable output from MBR is due to re-circulation of waste water from the membrane zone into the anaerobic and aerobic compartments, and the maintenance of high MLSS concentration. If X is the inflow, and therefore outflow, anaerobic to aerobic and, aerobic to membrane flow is 4X, with a recirculation from membrane compartment

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1 Any redox reaction involves an *electron donor - electron acceptor* pair. As per definition, the electron donor is oxidized while electron acceptor is reduced. Generally, the terms *anaerobic* and *anoxic* are used interchangeably to represent the absence of oxygen in the waste water. However, there is an important difference as outlined here. Under biological oxidation/reduction processes, the terms anaerobic and anoxic have different notions in the sense that *anaerobic* refers to the general condition where dissolved oxygen is absent in the effluent, and any one or, more of electron acceptors present in the waste water, such as nitrate, nitrite, and sulphate can act as electron acceptors. The term *anoxic* refers to the condition where *nitrate/nitrite* are the only electron acceptors taking part in the biological oxidation/reduction processes.

to anaerobic being 3X to balance. When ever the feed quality changes, its characteristics are dampened by this re-circulation as the feed waste water gets diluted by the re-circulating fluid, and any oscillations in effluent parameters are dampened. The dampening effect shall be linear for all parameters having linear relationship with concentration *viz.*, BOD, COD, TDS, *etc.* For parameters having logarithmic relationship with concentration, for example pH, this relationship shall be more complicated – but still the changes in such parameters due to variations in effluent quality shall be dampened. Similarly, due to the maintenance of higher MLSS concentration, spikes in BOD and COD in the influent shall be dampened within a short residence time due to the maintenance of high MLSS concentration resulting in intense biological activity inside the MBR. Since high biomass concentration with different species of biologically active microbial organisms is maintained in the MBR, sudden changes in the chemical composition of the feed shall not affect the performance of the MBR. Thus, the MBR treated waste water shall have more stabilized chemical characteristics.

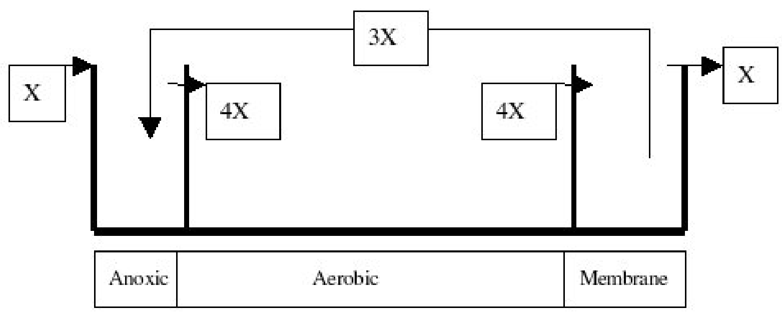

Fig.-1: Recirculation pattern inside MBR compartments.

Availability of food (biologically digestible matter) for the micro-organisms growing in the MBR is another important aspect to be considered. Food limitation is mainly dependent on the amount of food available (which is given by Flow x BOD = organic loading) and the amount of biomass available in the digestion chamber. Thus, for a given BOD level in the effluent, if the number of micro-organisms per unit volume is kept high by recycling the sludge, BOD reduction shall be kept at higher side.

MBRs can be operated effectively under low food/micro-organisms (F/M) ratio[1]. When F/M ratio is low, the settleability of the sludge is increased[2]. This is because, under low F/M ratio the micro-organisms are under food-limited condition. Once food is limiting,

1 Food to micro organism (F/M) ratio – an important parameter to be maintained in the activated sludge process so that optimal TSS removal could be achieved while maintaining necessary level of MLSS concentration. Changes in F/M ratio shall affect the settleability of sludge in the clarifier. But in the MBR, due to the retention of micro organisms by the membrane, F/M ratio can be lowered without concern on settleability. Due to higher SRT and high levels of MLSS, endogenous respiration takes place, resulting in lesser sludge production. Also, the need for secondary clarifier is eliminated. This is one of the main advantages of MBR over the conventional activated sludge process.

2 Gray, N.F. (1999) *Water Technology: An introduction for Environmental Scientists and Engineers*, First Indian Edition, Viva Books Private Limited, New Delhi, pp.548.

the rate of metabolism rapidly declines until the micro-organisms are in the *endogenous respiration* phase with cell lysis and re-synthesis taking place[1]. Since microbial activity remains high due to their retention by the membrane, low food/biomass ratio is maintained, leading to higher BOD removal and good sludge settleability. Even if the sludge fails to settle down, the MBR membrane blocks the suspended flocs (biomass) from leaving the digester. However, in the case of conventional biological treatment, sludge retention is mainly dependant on its settleability in the clarifier.

Thus, the advantages of using MBR can be summarized as follows:

1) Membrane Bioreactors have proven to be quite effective in removing both organic and inorganic contaminants as well as biological entities from waste water. The removal of organic, inorganic, and microbiological organisms along with suspended material present an excellent output from these systems whereby the biofouling and chemical scaling of the reverse osmosis system could be drastically minimized. It also minimizes use of cleaning chemicals in the secondary treatment.

2) Since suspended particles are not lost, total separation and control of the solid retention time (SRT) and hydraulic retention time (HRT) are possible, enabling optimum control of the microbial population and flexibility in operation.

3) With MBR, the required HRT is lower (8-10 hrs) than conventional biological treatment process (15-28 hrs). This results in reduced tank volume.

4) MBRs operate at low F/M ratio and long SRT. This means less sludge generation. This reduces costs of sludge disposal and hassels associated with it. Further, sludge produced in MBR is of better quality that eliminates sludge bulking.

5) Since MBRs are operated under low F/M ratio, it minimizes oxygen consumption since microbes are in endogenous respiration phase and not in growth phase.

6) Under conventional biological treatment the nominal MLSS concentration is from 1,500 to 3,000 mg/L, and it never exceeds 4,000 mg/L. Whereas, with MBR high MLSS concentration (10,000-15,000 mg/L)[2] could be easily achieved which allows more BOD throughput than conventional biological treatment system.

7) Compared to conventional biological treatment, MBR requires smaller footprint per unit BOD loading or per unit feed flow rate. MBR is ideal for expansion of existing facilities without increase in footprint. Normally, the footprint required for MBR is about half or less compared to conventional biological process.

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1 Endogenous respiration shall reduce sludge generation as most of the recalcitrant substances are degraded due to increased SRT.

2 The MLSS concentration in the MBR could be raised to 20,000 mg/L. However, this shall impose operational problems. Thus, normally 15,000 mg/L of MLSS concentration is maintained inside the MBR.

8) Due to membrane separation, the need for clarifier is avoided; at the same time, due to total retention of microbes, slow-growing species (nitrifying bacteria and bacteria capable of degrading complex organic compounds) are allowed to persist in the system, improving nitrification and biological degradation. The membrane not only retains microbes, but also extra cellular enzymes and soluble oxidants synthesized by these organisms, thereby creating a more conducive bio-reactive environment capable of degrading a wider range of organic compounds.

9) Better removal of phosphorus associated with suspended solids (bacteria and colloids) is also archived with the use of MBR.

10) High molecular weight organic compounds, which are not readily biodegradable in conventional systems, are retained in MBR. Thus, their residence time is prolonged and the possibility of biodegradation is improved.

11) Further, MBR eliminates the problems associated with settling, which is most troublesome part of waste water treatment. The potential to operate MBR at very high solid retention times without having the obstacle of settling allows high biomass concentrations in the bioreactor. Consequently, higher strength waste water can be treated and lower biomass yields are realized. This also results in more compact system than conventional processes, significantly reducing plant footprint and making it desirable for water recycling applications.

12) The system is also able to handle fluctuations in nutrient concentration due to extensive biological assimilation and retention of decaying biomass. If some portion of complex organics is not digestible by MBR, they shall be retained by the membrane within the system, and let out as sludge.

13) Membrane Bioreactor shall reject total suspended solids (TSS) in addition to reducing BOD and COD to the desired levels, making the effluent more suitable for direct treatment with reverse osmosis system for desalination. Post treatments, such as sand-filtration, is not necessary. Membranes provide final barrier for pathogens and suspended solids.

14) Process control is easier and more amenable to automation. No more clarifier upsets or, Total Suspended Solids carry-over.

15) Due to efficient retention and recycling of the activated sludge, the MBR system minimizes the energy needed to reduce the BOD and COD to the desired levels when compared with simple aeration or, other primary treatment schemes. Since MBR employs fine bubble diffuser, higher oxygen transfer efficiency is achieved which reduces power consumption. Conventional biological systems can also be desiged to employ fine bubble diffuser. Since required HRT is more with conventional biological systems, the operating cost for aeration shall be higher when compared with MBR.

Thus, Membrane Bioreactor is a suitable alternative for textile waste water treatment as it reduces sludge production, requires less footprint, and addresses most of the problems associated with other treatment systems described above.

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