Textile Processing: Process, Environmental Impact and Advance Methods of Treatment

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Abstract

The textile processing industries has been condemned as being one of the world's most offenders in terms of pollution. This review combines a discussion of waste production from different textile processing methods with a discussion of waste generation and its environmental impact. The main challenge for the textile processing units today is to modify different production methods so that they can be more ecologically friendly at a competitive price by using safer chemicals and dyes and also by reducing the cost of effluent treatment as well as its disposal. This review enlights the different textile processes like desizing, mercerising, bleaching, dyeing, printing and finishing with a discussion of the waste generation and environmental impact.

Keywords: Processing, Finishing, Desizing, Mercerizing, Effluent, Bleaching, Neutralization, Adsorption, Osmosis, Nanofiltration, Ultrafiltration.

Introduction

The textile processing industries consumes a large amount of water in its manufacturing processes used mainly in the dyeing and finishing operations. The waste water from these units is classified as the most polluting of the all industrial sectors, considering the volume generated and the effluent composition. The increase demand for textile products and proportionate increase in production along with use of synthetic dyes and other harmful chemicals contributed to severe pollution problems. Textile waste water is characterized by extreme fluctuations in many parameters chemical oxygen demand (COD), biochemical oxygen demand (BOD), pH, colour and salinity. The composition of the waste water will depend on the different organic based compounds, chemicals and dyes used in the dry wet processing processes. This waste water is often rich in colour, containing residues of reactive dyes and chemicals and requires proper treatment before being released into the environment. This pollution may cause alteration of the physical, chemical and biological properties of aquatic environment by continuous change in temperature, order, noise, turbidity etc that is harmful to public health, live stock, wild life, fish and other biodiversity.

The presence of very small amount of dyes in the water seriously affects the aesthetic quality and transparency of water bodies. During the dyeing process, it has been estimated that the losses of colorants to the environment can reach ten to fifty percent. Some dyes are highly toxic and mutagenic and also decrease light penetration and photosynthetic activity, causing oxygen deficiency and limiting downstream beneficial uses such as recreation, drinking water and irrigation.

In this context, considering the importance of coloured products in present day, it is of relevance to optimize the colouring process with the objective of reducing the environmental impact of the textile industry. For this purpose, liposome's could be used to carry several encapsulated dyes, and hence improve the mechanical properties of textile products, resulting in better wash fastness properties and reducing the process temperature. Another way is to use ultrasonic energy for improving dye productivity and washing fastness reducing both energy costs and water consumption.

Textile Processing Process

Desizing

Desizing is done in order to remove the size from the warp yarns of woven fabrics. Warp yarns are coated with sizing agents (starch) prior to weaving in order to reduce their frictional properties, decrease yarn breakages on the loom and improve productivity. The sizing material present on the warp yarns can act as a resist towards dyes and chemicals in textile wet processing, hence must be removed before any subsequent processing. Starch is removed or converted into simple water soluble products either by hydrolysis (by enzymatic preparations or dilute mineral acids) or by oxidation (by sodium bromide, sodium chlorite, etc.). In general about 50% of the water pollution is due to waste water from desizing, which has a high BOD that renders it unusable. The problem can be mitigated by using enzymes that degrade starch into ethanol rather to anhydroglucose. The ethanol can be recovered by distillation for use as a solvent or fuel, thereby reducing the BOD load. Alternatively, an oxidative system like H_2O_2 can be used to fully degrade starch to CO_2 and H_2O.

Mercerization

In order to impart lustre, increase strength and improve dye uptake, cotton fibre and fabric are mercerized in the grey state after bleaching. Mercerization is carried out by treating cotton material with a strong solution of NaOH (18-24%) and washing out the caustic after 1 to 3 minutes, while holding the material under tension as the cotton material has a property to undergo a longitudinal shrinkage upon impregnation with this solution. The material acquires the desired properties of lustre, increased strength, dye uptake and increased absorbency. The large concentration of NaOH in the wash water can be recovered by membrane techniques. Use of $ZnCl_2$ as an alternative method leads to an increase in the weight of fabric and in dye uptake, and allows easy recovery of NaOH. Moreover, the process is ecologically friendly and does not require neutralization by acetic or formic acid.

Bleaching

Natural colour matter in the yarn imparts a creamy appearance to the fabric. In order to obtain white yarn that facilitates producing pale and bright shades, it is necessary to decolourize the yarn by bleaching. Hypoclorite is one of the oldest industrial agents. The formation of highly toxic chlorinated organic by-products during the process is reduced by adsorbable organically bound halogen. Recently, hypoclorite is being replaced by other environmentally safe bleaching agents like peracetic acid, which decomposes to oxygen and acetic acid which is completely biodegradable. By using peracetic acid, the material aquires higher brightness with less fibre damage.

Neutralization

According to Bradbury et al.(2000), replacement of acetic acid by formic acid for neutralization of fabric after scouring, mercirizing, bleaching, and reduction processes is effective, economical, and environment friendly. The procedure also allows a sufficient level of neutralization in a short span of time, needs low volumes of water and results in low levels of biological oxygen demand (BOD).

Dyeing

Treatment of fibre, yarn and fabric with dyes or pigments to impart colour is called dyeing. The dyes can adhere to the surface by solution, by forming covalent bond or complexes with salts or metals by physical adsorption or chemical retention. Dyes are composed of a group of atoms called chromophores, responsible for the dye colour and auxochrome. In the dyeing process, water is used to transfer dyes and in the form of steam to heat the treatment baths. Once the dyeing operation is over, the various treatment baths are drained, including the highly coloured dye bath, which has high concentration of salts and organic substances. This waste water must be treated before reuse. Coagulation and membrane processes-nanofiltration or reverse osmosis are among processes suggested for treatment of this waste water but these treatments are effective only with very dilute dye baths. Dye baths are generally heavily polluted and this pollution is responsible for the colouration of the effluents, and cannot be recycled. Dyeing auxiliaries or organic substances are non-recyclable and contribute to high BOD/COD of the effluents.

Printing

Printing is a form of dyeing in which the essential reactions involved are the same as those in dyeing. In dyeing, colour is applied in the form of a solution, whereas in printing colour is applied in the form of a thick paste of dye. The fixation of the colour in the printing is brought about by a suitable after treatment of the printed material. Textile fabric printing produces hydrocarbon effluents that must be removed before they reach the atmosphere. Use of kerosene in printing is a common practice in India because of the brilliant prints and ease of application. About 122 millions of kerosene is released in atmosphere annually in India during printing, drying and curing which is harmful to human being, as well as to the flora and fauna. The most common chemical in reactive dye printing is urea, which leads to a high pollution load. Printing is mainly done by a flat or rotary screen, and after every lot of printing some residual paste is left in the waste-water. This can be reused for printing of similar shades by adding fresh stock.

Finishing

Both natural and synthetic textiles are subjected to a variety of finishing processes. This is done to improve specific properties in the finished fabric and involves the use of a large number of finishing agents for softening, cross-linking and waterproofing. All of the finishing processes contribute to water pollution. Among the products that are used in textile finishing, the most ecologically friendly ones are formaldehyde-based cross-linking agents that bestow desired properties, such as softness and stiffness that import bulk and drape properties, smoothness and handle to cellulosic textiles. It can also lead to enhanced dimensional stability. A free surface characteristic of the fabric shows the evolution of un-reacted formaldehyde. This obviates the use of formaldehyde in the product and liberation of chemical products and results in considerable reduction in the amount of formaldehyde during the cross-linking reaction that leads to toxicity and stream pollution. Generation of formaldehyde during vacuum extraction has been used in the storage of resin-finished fabrics and garments. The formaldehyde resin used as a cross-linking agent is a pollutant and a known carcinogen. Much effort has been expended in the search for a substitute for formaldehyde.

Environmental Impact

Due to Colour

The wastewater from the dye house is generally multi coloured. The dye effluent disposed into the land and river water reduces the depth of penetration of sunlight into the water environment, which in turn decreases photosynthetic activity and dissolved oxygen which is unfavourable from an ecological point of view. Many dyes contain organic compounds with functional groups, such as carboxylic (-COOH), amine ($-NH_2$), and azo (-N=N-) groups, so treatment methods must be followed in accordance to the chemistry of the dyes. Waste water resulting from dyeing cotton with reactive dyes is highly polluted and has high BOD/COD and colouration.

Due to Dissolved Solids

Use of common salt and glauber salt etc in processes directly increase the total dissolved solids (TDS) level in the effluent. Disposal of high TDS bearing effluents can lead to increase in TDS of ground water and surface water. Dissolved solids in effluent may also be harmful to vegetation and restrict its use for agricultural purpose.

Due to Toxic Metals

The waste water from the dyeing plant is not free from metal contents. There are mainly two sources of metals in the wastewater. Firstly, the metals like mercury may come as impurity with the chemicals used during the process such as caustic soda, sodium carbonate and salts. Secondly, the source of metal could be dyestuff like metalized mordent dyes. The metal complex dyes are mostly based on chromium.

Due to Residual Chlorine

With the use of chlorine compounds in textile process, residual chlorine is found in the waste stream. This waste water depletes dissolved oxygen in the receiving water body and as such aquatic life gets affected. Residual chlorine may also react with other compounds in the waste water stream to form toxic substances.

Other Impacts

Textile effluents are often contaminated with non-biodegradable organics termed as refractory materials for example detergents. The presence of these chemicals results in high chemical oxygen demand value of the effluent. Organic pollutants are also found in textile effluent and such impurities are reflected in the analysis of bio-chemical oxygen demand (BOD) and chemical oxygen demand (COD).

Effluent Treatment

The conventional treatment systems like physico-chemical treatment and physoco-chemical treatment followed by biological treatment system are installed in almost each textile processing plant. The first step in the waste water treatment is to mix and equalize the waste water streams that are discharged at different intervals from different stages in the processes. Some industries also prefer screening, oil trap prior to equalization for removal of solids and oil-grease. Equalization ensures that the effluent have uniform characteristics in terms of pollution load and pH and temperature. The effluent is then subject to chemical treatment which helps in reduction of colour and suspended solids. A significant reduction in BOD and COD values is also observed. This is further followed by biological treatment process with settling which further reduces BOD and COD values.

The textile effluents may require advanced treatment methods to remove particular contaminant or to prepare the treated effluent for reuse. Some common advanced methods which are being used now a day are as under:

Adsorption

The adsorption process is used to removes colour and other soluble organic pollutants from effluent. The process also removes toxic chemicals such as pesticides, phenols, cyanides and organic dyes that cannot be treated by conventional treatment methods. Dissolved organics are adsorbed on surface as waste water containing these is made to pass through adsorbent. Most commonly used adsorbent for the treatment is activated carbon. It is manufactured from carbonaceous material such as wood, coal, petroleum products etc. The adsorption on activated carbon without pre-treatment is impossible because the suspended solids rapidly clog the filter. The combination with flocculation-decantation treatment or a biological treatment permits a reduction of suspended solids and organic substances, as well as a slight reduction in the colour.

Ion Exchange

Ion exchange process is normally used for the removal of inorganic salts and some specific organic anionic components such as phenol. All salts are composed of a positive ion of a base and a negative ion of an acid. Ion exchange materials are capable of exchanging soluble ions and cations with electrolyte solutions. For example, a cation exchanger in the sodium form when contacted with a solution of calcium chloride will scavenge the calcium ions from the solution and replace them with sodium ions. This provides a convenient method for removing the hardness from water or effluent. Ion exchange resins are available in several types starting from natural zeolite to synthetics like phenolic, sulphonic styrene or other complex compounds. The divalent ions such as calcium and magnesium have high affinity for the ion exchange resins and can be removed with high efficiencies. In the ion exchange method, the impurities from the effluent streams is transformed into another one of relatively more concentrated with increased quantity of impurities because of the addition of regenerated chemicals. This process cannot be used for removal of non-ionic compounds.

Membrane Processes

Membrane processes of effluent treatment provide possibilities for the separation of hydrolyzed dye stuffs and dyeing auxiliaries that simultaneously reduce colouration and BOD/COD of the waste water. Depending upon the quality of the final product, different types of membrane processes of effluent treatment are being used- reverse osmosis, ultrafiltration, nanofiltration or microfiltration.

Reverse Osmosis

The process of reverse osmosis is based on the ability of certain specific polymeric membranes usually cellulose acetate or nylon to pass pure water at high rates and to reject salts. In the process, waste water stream is passed at high pressure through the membrane. The pressure should be high enough to overcome the osmotic pressure of the stream and to provide a pressure driving force for water to flow from the reject compartment through the membrane into the clear water compartment. Reverse osmosis membranes have a retention rate of 90% or more permits the removal of all mineral salts, hydrolyzed reactive dyes and chemical auxiliaries. It can be used as end-of-pipe treatment and recycling system for effluent as further purification by removal of organics and dissolved salts is possible after using primary, secondary, or tertiary treatment of effluent.

Ultrafiltration

This process is like reverse osmosis process but ultrafiltration membranes retain only macro molecules and suspended solids. Thus salts, solvents and low molecular weight organic solutes pass through ultrafiltration membrane with the permeate water. Even in the best of cases, the quality of the treated wastewater does not permit its reuse for the sensitive processes like dyeing of textile but can be recycled to feed processes like rinsing, washing etc.

Nanofiltration

Nanofiltration can be positioned between reverse osmosis and ultrafiltration. Nanofiltration is essentially a lower pressure version membrane where the purity of permeate water is less important. This process is used where the high salt rejection of reverse osmosis is not required. The nanofiltration is capable of removing the hardness elements such as calcium and magnesium together with bacteria, viruses or colour. This process is operated at lower pressure than reverse osmosis and hence the cost is low. Nanofiltration process is preferred when permeate has TDS without colour, and COD, and hardness acceptable. Feed water to nanofiltration process should be of similar qualities as in case of reverse osmosis with low turbidity and colloids. Also the feed water should be disinfected to remove micro-organism.

Ozonation

Ozone is one of the strongest oxidizers commercially available and popular for disinfection of potable water. Large, complex organic molecules, detergents, phenols etc. can be broken into simpler compounds by ozonation. Oxidation of organics and inorganics, deodorisation and decolourisation are the main uses of ozone in industries. Ozone is a unstable gas which has to be produced at site for most industrial processes. The corona discharge method is the widely used procedure among the several methods by which ozone can be generated. An ozone generation unit incorporates a series of electrodes fitted with cooling arrangements mounted in a gas tight container. Here when air and oxygen gas is passed through narrow gap separating electrodes, the oxygen gets converted into ozone. Ozone is applied to waste water by means of diffuser tubes or turbine mixture. Ozone doses in level of 2 mg/l have been reported to result in virtually complete removal of colour and hard pollutants like detergents. The treated water after sand filtration becomes clean for reuse.

Evaporation and Crystallization

Evaporation is another method to minimize effluent disposal problem. Different methods of evaporation like multiple effect evaporation, mechanical vapour compression and direct contact evaporation are being used for the purpose. Crystallization refers to the formation of solid crystals from a homogeneous solution. It is a solid- liquid separation technique used to crystallise salts and recover them from its mother. The crystallizers may be single stage or multi-stage for extracting useful chemicals like sodium sulphate, calcium sulphate, sodium chloride, calcium chloride etc. from process solutions and effluents.

Conclusions

Any industrial activity causes pollution in one form or the other and so is the textile industry. The impact of textile production on the environmental aspects such as air, water, land and human must be considered. Although there are environmental hazards during the entire production chain, the textile wet processing possesses serious environmental problems. Large number of chemicals in large quantities are used in wet textile processing to satisfy consumers demands of certain properties like colour, feel, etc. Some of these chemicals such as dyes and finishing agents, remain attached to the textiles, whereas a substantial proportion of these chemicals remain in the processed water, causing air and water pollution. Hence, waste minimization is of great importance in decreasing pollution load and production costs. This article enlights that various methods can be applied to treat textile effluents and to minimize the pollution load. Traditional technologies to treat textile waste water include various combinations of biological, physical and chemical methods, but these methods require high capital and operating costs. Technologies based on membrane systems are among the best alternative methods that can be adopted for large scale ecologically friendly treatment processes. A combination methods involving adsorption followed by nanofiltration has also been advocated, although a major drawback in direct nanofiltration is a substantial reduction in pollutants, which causes permeation through flux.

It is found that in an ideal treatment process for satisfactory recycling and reuse of textile effluent water, following steps should be followed:

1. Initially, refractory organic compounds and dyes may be electrochemically oxidized to biodegradable constituents before the waste water is subjected to biological treatment under aerobic conditions.
2. Colour and odour removal may be accomplished by a second electro-oxidation process.
3. Microbial life, if any may be destroyed by a photochemical treatment.
4. The treated water may be used for rinsing and washing purposes however an ion-exchange step may be introduced if the water is desired to be used for industrial processing.

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