OVERVIEW OF WASTEWATER TREATMENT AND RECYCLING IN THE TEXTILE PROCESSING INDUSTRY

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ABSTRACT

The main aim of this paper is to give a review on the state of the art of available processes for the advanced treatment of wastewater from a Textile Processing Industry (TPI). After an introduction to the specific wastewater situation of the TPI the paper reviews the options of process and production integrated measures. The available unit processes and examples of applied combinations of unit processes are described. A special place is given to the in-plant treatment, the reuse of the treated split flow or mixed wastewater and the recovery of textile auxiliaries and dyes. As a conclusion the paper gives some examples of applied and effective end-of-pipe-steps. © 1999 IAWQ Published by Elsevier Science Ltd. All rights reserved

KEYWORDS

End-of-pipe-measures; process-integrated measures; production-integrated measures; textile wastewater.

INTRODUCTION

The textile processing industry (TPI) is characterised by its fairly high specific water consumption and its large amount of wastewater discharges. Due to processing in aqueous solutions or suspensions, wastewater is by far the dominating waste stream. Both wastewater quality and wastewater quantity depend to a considerable degree on the technique used for a certain substrate – such as wool or cotton. Also, the production method used and other general factors influence the output of wastewater. The specific wastewater discharge, for example, varies according to the production method, between 40 m³ and 300 m³ per ton of finished substrate. The composition of wastewater shows similar variations. The composition of raw mixed wastewater in the TPI can be characterised as follows (Schönberger and Kaps, 1994):

- intense colouring, caused by large amounts of unfixed remaining dyes
- high temperatures, since many reactions require high temperatures
- pollution with organic materials corresponds in average to the pollution of domestic wastewater. If water-saving techniques are applied though, it can be much higher
- a large amount of refractory COD, caused by high-molecular synthetic textile auxiliaries (TA) and dyes
- high conductivity because of the salt character of many TAs
- high AOX-, sulphide- and heavy metal concentrations due to chlorinated bleaching agents and halogen-, sulphur- or heavy metal contained in dyes in some cases
- high phosphate contents, when polyphosphates for conditioning are added because of the use of hard process water.
The practised processing steps in TPI like, for example, desizing, bleaching, dyeing or finishing differ very strongly with regard to water consumption and use of chemicals. Another characteristic of TPI is the strongly differing composition and amount of split flow wastewater in different processing steps. Many processing steps are carried out discontinuously. They can be divided in the actual treatment, with relatively high concentrated fleets, and in the subsequent rinsing and washing steps to remove surplus dyes and textile auxiliaries (TAs). This is the reason why each split flow itself can be subdivided again in separate split flows. Certain split flows reach a concentration of organic compounds of 100,000 mg/l COD, normally though, only very small quantities are produced. On the other hand, rinsing techniques produce large amounts of wastewater with only a low organic content. By dimensioning wastewater treatment or processing plants, intense and short fluctuations of wastewater discharges and composition should be taken into consideration. These fluctuations must be equalised by large pre-connected buffer volumes.

IMPLEMENTATION APPROACHES

To solve the problems of wastewater of the TPI, both strategies of integrated and of additive environmental protection are pursued (Rott and Minke, 1995; Minke and Rott, 1998). The aim of additive measures is to detoxify and to dispose of the emissions in subsequent treatment plants. The aim of process-integrated measures is to avoid and to reduce the amount of emissions already in production processes. This is achieved by changing or replacing processes in production methods. Production-integrated measures occupy an intermediate position: with them, the recycling and reuse of emissions of particular processes within the framework of total turnout is striven for. In practice this is achieved by selective separation, concentration and regeneration methods, which are post-connected to production and lead to closing of circuits.

Process-integrated and production-integrated measures

When process-integrated or production-integrated measures should be taken to avoid and to reduce water consumption and wastewater discharge, remaining dyes, refractory COD and AOX, heavy metal and sulphide, the causes and sources of an individual wastewater load should be located through an exact analysis of the production and wastewater situation.

Process-integrated measures in TPI can be organised as follows (Minke and Rott, 1998):

- Further development of machine technique, e.g.:
  - short liquor ratio processes
  - continuous cold staying technique instead of discontinuous methods
  - minimal task engineering as foam or lambency task
  - automation of the extension stations
- dry cleaning technique at the taking and truss cleaning
- optimisation of the washing and rinsing processes, e.g.:
  - consistent counter-flow principle
  - additional squeeze rollers
- optimisation of processing steps, e.g.:
  - hot mercerising instead of cold mercerising
  - optimised H2O2-bleaching techniques
- substitution of dyes with low exhaustion
- substitution of textile auxiliaries (TA) which are not or poorly biodegradable, e.g.:
  - sizing agents based on starch and galactomannans instead of not biodegradable synthetic sizing agents based on polyacrylate and polyvinyl alcohols as well as those based on carboxymethylcellulose
- substitution of AOX- or sulphide-causing TAs, e.g.:
  - H2O2 instead of NaOCl and NaClO2
  - Glucose instead of NaHS
- substitution of AOX-, heavy metal- or sulphide-containing dyes
In TPI, the aim to reduce not recyclable residues and the wastewater amount to be discharged and therefore the wastewater pollutant loads can be achieved by conversion of the following production-integrated measures (Minke and Rott, 1998):

1. Reuse residual dyebaths, printing pastes and small burdened rinsing waters without treating, e.g.:
   - Residual dyebaths deal with disperse, direct, acid, vat and sulphide dyes
   - Residual printing pastes
   - Residual finishing baths, e.g. plasticizer baths and polymer dispersion baths
   - Rinsing waters from discontinuous colouring processes
   - Rinsing waters from discontinuous bleaching processes

2. Process water recycling of mixed wastewater, e.g.:
   - Activated sludge process supported by lignite coke – precipitation/flocculation, filtration, adsorption
   - Activated sludge process supported by lignite coke – precipitation/flocculation, sedimentation, biofilter, reverse osmosis
   - Activated sludge process supported by lignite coke – precipitation/flocculation, filtration, adsorption, reverse osmosis, ozonation
   - Electro-flotation - reverse osmosis
   - Ozonation, precipitation/flocculation, flotation, filtration, ion exchange

3. Process water recycling of split flow wastewater, e.g.:
   - Ultrafiltration – nanofiltration
   - Ultrafiltration – nanofiltration, reverse osmosis

4. Evaluating material recycling of split flow wastewater, e.g.:
   - Sizing agent recycling with ultrafiltration
   - Caustic soda lye recycling with ultrafiltration and evaporation
   - Indigo recycling with ultrafiltration
   - Dye and process water recycling with reverse osmosis

Table 1: Available unit processes applicable in TPI listed according to their major effect (Rott and Minke, 1995)

<table>
<thead>
<tr>
<th>Biodegradation: aerobic, anoxic and anaerobic</th>
<th>Physico-chemical processes</th>
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<tbody>
<tr>
<td>Activated Sludge</td>
<td>Destructive processes:</td>
</tr>
<tr>
<td>fixed film processes</td>
<td>- chemical oxidation</td>
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<tr>
<td>fixed bed</td>
<td>- electrochemical processes</td>
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<tr>
<td>fluidised bed</td>
<td>- reductive transformations</td>
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<tr>
<td>Process granular fixed bed reactors</td>
<td>Separation processes:</td>
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<tr>
<td>rotating biol. contactors</td>
<td>- filtration</td>
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<tr>
<td>trickling filters</td>
<td>- membrane filtration</td>
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<tr>
<td>aerobic anoxic</td>
<td>- precipitation/flocculation</td>
</tr>
<tr>
<td>anoxic anoxic</td>
<td>- evaporation</td>
</tr>
<tr>
<td>aerobic anoxic</td>
<td>- adsorption</td>
</tr>
<tr>
<td>aerobic anoxic</td>
<td>- ion exchange</td>
</tr>
<tr>
<td>aerobic anoxic</td>
<td>- complex formation</td>
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</table>

The examples of reuse of residual dyebaths, residual printing pastes and rinsing waters mentioned under digit 1 of the overview above all make requirements on logistics and do not require treatment techniques. A great number of techniques and technique combinations for the treatment necessary in the case of concept 2 to 4 are available. These techniques can be organised as shown in Table 1 according to their major effects. All biological techniques can be taken as material destructive processes that show obvious differences concerning efficiency in particular in elimination of poorly biodegradable substances, like e.g. dyes. In such
a way, the decolorization effect is so small with aerobic activated sludge processes, that normally a further physico-chemical procedural step, the transition to fixed film processes or the pre-switching of an anaerobic step, is necessary. Through adding of support media, periphyton faces for sessile micro-organisms will be created and in addition, such materials can unfold adsorptive cleaning efficiency. Under anaerobic conditions, an extensive decolorization and a digestion of aerobic refractory substances can be achieved. With the physico-chemical material destructive processes an extensive oxidation or reduction of substances is achieved by use of strong oxidising agents like O₃ or H₂O₂, partially in combination with UV-radiation and/or under high pressure or through electrolytic processes. The material separating processes produce concentrates for which, provided that reuse is not possible, a material destroying step or disposal must be post-connected.

Process water recycling requires, because TPI makes high requirements for process water (Egbers et al., 1983), a total decolorization and an extensive elimination of all organic and inorganic contents, like e.g. tensides, hardness creators and salts. As already shown in the overview this can only be realised in multi-stage technique combinations.

Figure 1. Schematic diagram of effluent treatment and recycling for a medium-size textile finishing factory in Tuttlingen, Germany.

The combination mentioned in the overview in first place for the implementation concept "process water recycling of mixed wastewater" is an example for application of conventional biological and physico-chemical processes. It exists, as shown in Figure 1, from the procedural steps lignite coke supported aerobic biological treatment, precipitation/flocculation with sedimentation and filtration as well as final adsorption. The efficiency of each treatment step as well as the accessible process water quality becomes clear by considering the parameter COD (see Figure 2 left) and the removal efficiencies computed from the average values (see Figure 2 right). The main elimination of COD is achieved in the biological step, while this only contributes to the decolorization at 15-18%. The main part of the dye is removed in the precipitation/flocculation step. The COD-elimination is 31% and mainly restores to the separation of washed
out activated sludge as well as lignite coke particles. The subsequent activated carbon filters contribute only insignificantly to the elimination of both the COD and the Spectral absorption coefficient (SAC). Their performance is limited to a "police filter" function.

It follows from the comparison of the TPI quality requirements and the clear water quality achieved by the wastewater treatment plant that neither limits concerning the parameters remaining colour and COD or salinity are kept. On account of its quality the prepared water can be used as a cooling water for dyeing-machines, as a rinsing water for the first rinsing steps as well as for dark dyeing without loss of quality of the finished textiles. Fresh water is used as a feed water in the boiler house, for the sanitary systems, for bright dyeing as well as a rinsing water for the last rinsing step. This illustrates that considerable cutbacks for the high requirements in the practice of an TPI factory quite can be made, if the recycling water is only used for specific, precisely defined production steps. As the residue during this treatment process results in a wet sludge, which is dewatered by means of a compartment type filter press to a TSS-content of about 35% and then deposited in a sanitary landfill. The sludge discharge is controlled by about 2 kg of TSS per m³ recycled wastewater. The operating costs of the plant run up to about 3.30 DM per m³ recycled wastewater.

The example of the represented multi-stage process combination shows the possibilities but also the limits of the concept "process water recycling of mixed wastewater". If you renounce a final refining, cleaning and desalination step, such as reverse osmosis as shown in the example it is possible to recycle about 40 % of the mixed wastewater economically according to today's cost follow. That means with costs that lie in the range of today's freshwater and wastewater costs. This is already combined with immense procedural expenditure, because mixed wastewater shows a large number of organic and inorganic contents. Another problem represents the gradual increase in salinity of the recycling water. If a specific maximum is achieved, a part of the recycling water must be discharged and be replaced by fresh water, which further lowers the recycling rate. Another disadvantage of all process combinations practised up to now is the production of sludge by application of precipitation/flocculation or lignite coke as an adsorbent.

The process water recycling of split flow wastewater listed in the overview can manage relief through membrane techniques here. Figure 3 shows a concept with the use of ultra and nanofiltration as well as reverse osmosis. In the TPI factory three split flows are separated and treated differently. The split flow of pre-treatment is not planned for reuse and introduced indirectly after equalising quantity and concentration. The split flows from exhaustive dyeing processes, continuous dyeing and finishing are recycled and reused. For this, the wastewater is first cleaned of particles by sieves, then treated by ultra filtration to remove organic compounds with high molecular mass and cleaned finally by nanofiltration to remove organic compounds of small molecule size. Ultrafiltration is designed for a COD-removal of 30%, nanofiltration for 90% COD-removal. Wastewater of continuous dyeing and finishing is finally desalted by means of reverse osmosis because of its high salinity. In the factory the permeates of the nanofiltration and of the reverse
osmosis can be inserted as recycling water almost universally again on account of their high quality - they are dull, almost salt free and show a COD of approximately 70 mg/l. The concentrates from the ultrafiltration and the nanofiltration show, since these steps are operated with extremely high filtrate outputs, TSS-contents of 12 % and COD concentrations higher than 200,000 mg/l and must be disposed of as waste. The concentrates of reverse osmosis can be introduced indirectly. Referring to split flow wastewater planned for reuse a process water recycling rate of approximately 95% can be reached. Operating costs are about 6.50 DM per m³ recycled wastewater (van Clewe, 1997).

Figure 3. Schematic diagram for recycling of split flows by means of ultra and nanofiltration as well as reverse osmosis (van Clewe, 1997).

Desizing

Figure 4. Process flow sheet for the recovery of PVA by means of ultrafiltration (Porter, 1997).
All process-combinations of the concept "recycling of evaluating materials from split flow wastewater" have the aim of selectively separating TAs or dyes from split flow wastewater, to concentrate and/or to clean and so enable reuse. As a technique for selective separation of TAs and dyes, the use of membrane processes such as ultrafiltration and reverse osmosis has spread. The process flow sheet for sizing agent recycling from desizing wastewater with ultrafiltration is shown in Figure 4. The desizing wastewater is pre-cleaned after the wash boxes by a sieve filter and then concentrated by ultrafiltration. The permeate can be reused for washing and rinsing. The concentrate is supervised with a refractometer concerning its concentration of sizing agent, picked up with sizing agent and then reused. The shown technique allows a recovery of more than 90% of the used sizing agent. The use of resistant synthetic sizing agents based on polyvinyl alcohols (PVA) and polycrylates is necessary. The investment and operating costs of this technique were regarded as very high, as in the USA up to now however, is yet calculated with relatively short repayment times of less than 5 years (Porter, 1997).

Additional measures

TPI wastewater is often treated together with domestic wastewater after indirect introduction in a mechanical and biological way. Characteristics for effluents of wastewater treatment plants with a COD load of more than 20% from TPI are a visible colouring as well as increased refractory COD concentrations compared with wastewater treatment plants without the influences of TPIs. In individual cases problems because of high concentrations of AOX, heavy metals or sulphide occur (Abwassertechnische Vereinigung, 1997).

Common additional measures for the elimination of remaining colour, refractory COD and AOX, as well as problems caused by high heavy metal and sulphide concentrations are (Abwassertechn. Vereinigung, 1997):

- Further biological steps with extension of the retention period
- Post-switching of wastewater lagoons
- Post-switching of an adsorption step with powdered activated carbon, the so called adsorption-flocculation-filtration technique
- Post-switching of biologically efficient filter plants with bentonite or activated carbon
- Pre- or post-switching of precipitation/flocculation
- Simultaneous addition of activated carbon into the aeration tank

The use of such central end-of-pipe steps however should be taken into account only then if first the possibilities of process- and production-integrated measures for the reduction of pollutant loads are tested and if a big central solution shows significant technical and economical advantages compared to a great number of smaller systems on account of a great number of operations.

DEVELOPMENT TRENDS

The development of the wastewater situation of the TPI is influenced by the following aspects:

- Further dyeing and printing methods are developed in order to make wastewater-free and printing paste consumption minimised techniques practicable (Schönberger and Kaps, 1994).

- Technical developments as well as cost reductions of membrane techniques enable a technically and economically reasonable application of membrane techniques both for TA and dye recovery and for process water recycling. By implementing membrane steps in existing treatment or processing plants both the recycling rates and the achieved process water qualities may be increased (Schönberger and Kaps, 1994).

- The advantages of split flow treatment compared to mixed wastewater treatment, like for example economic advantages due to material recovery, higher recycling rates and higher process water qualities with a smaller procedural expenditure, are obvious. This will lead in an increased manner to the conversion of split flow concepts (Abwassertechnische Vereinigung, 1997).
Further development of TAs and dyes for better biological degradability and/or smaller inhibitant contents increase the degree of efficiency of biological techniques for process water treatment. In combination with the use of concentration techniques like membrane techniques or with separation of highly concentrated split flows the use of anaerobic biological techniques is getting more and more reasonable. Compared with aerobic biological techniques they have the additional advantages of much higher colour removal, reduced residues and smaller energy demand (Rott and Minke, 1996; Minke and Rott, 1997).

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