CHAPTER 5

SUMMARY AND CONCLUSION

5.1 SUMMARY

The scope of the study was to investigate options of pollution prevention in the textile finishing process considering integrated approaches on minimising, reducing, recycling, treatment and disposal of inorganic salts, reactive dyes, additives and chemicals. Tirupur is a classic example of an industrialised region affected by severe pollution due to the cumulative effects. More than 700 textile finishing units are discharging their effluents in and around the industrial cluster of Tirupur.

The total pollution load was assessed. The cumulative pollution was found to be a tremendous burden for the region. The worst pollutant in terms of quantity and impact was identified as the sodium, which severely degrades the soils. The widespread damage affects the crop yield of downstream farmers of the next taluk, Karur (30 km downstream). For almost every unit process in the textile finishing industry sodium containing chemicals are used. A total amount of 163 tonnes of sodium ions per day out of a total of 418 tonnes of TDS reach the soil and water bodies every day.

About 278 units opted to form federations and 8 CETPs were successfully implemented showing the willingness of the textile industry to combat pollution problems, but again inorganic ferrous salts and lime are added in the process and a large quantity of sludge is produced, which again causes major constraints with regard to its disposal. Furthermore the TDS issue was not fully addressed in the CETP
concepts. This was partly due to administrative reasons, because, when the TDS standard of 2,100 mg/L came into force, the planning of the CETPs was already accomplished. As a matter of fact the treated effluent from all the CETPs does not meet the discharge standards of the TNPCB with regard to both TDS 2,100 mg/L and 60% sodium. This was another reason to turn the focus of this work also on the TDS not only, on the colour problem. Colour removal can be realised in many different ways and is not the major problem.

Since the units are mainly small scale units the effluent treatment costs are considered sizable by the industry. This very fact opens the door for cleaner production measures saving resources and the environment. In this study, the main focus is on the prevention, avoidance of pollution at the source itself, followed by reuse and recycling options. In order to make the treatment and recycling options successful, preconditions such as the waste stream segregation were set for this study.

The methods are simple. High pollution load and low volume effluents have to be segregated from low load and high volume (see Figure 5.1). The two effluents are treated separately after segregation. For this very purpose biological treatment methods exploring the option of using extremophile (halophilic) microorganisms to avoid the consumption of chemicals (coagulants, flocculants, complexing agents) and to reduce the treatment costs as well as to eliminate the production of inorganic hazardous sludge were evaluated.

For the reuse and recycling of water as well as the salt (brine) membrane technology was combined with effective reject management methods. Different pre-treatment options (Filter Sheets, MF Cartridges) for bringing down the SDI value was explored. Combined membrane technologies were tested and process water with appropriate quality and quantity could be obtained. The reject (concentrated effluent containing neutral salts) were concentrated up to concentration of 310 g/L of salt in an especially designed 100% solar based High Rate Brine Concentrator (HRBC). The
concentrated salt solution (brine) was used to produce sodium hypochlorite in an electrodialysis cell. Finally the salt becomes a resource for the production of hypochlorite and the worst pollutant is transformed into a product.

5.2 CONCLUSION

5.2.1 Pollution Load assessment

Compared to other industries the emissions of the Textile Finishing Industry (TFI) are rated as comparatively high. Among the emissions the wastewater residuals are dominant containing about 80 % of organic chemicals and 90 % of the inorganic compounds. The remaining part of the organics is emitted as off gases (10%) and solid wastes (10% as mainly sludge from the effluent treatment). Only about 10% of the inorganic compounds are emitted within the solid waste. As the wastewater pollution dominates the overall emissions, this study focused on the TFI wet processing effluents.

The effluent of the Common Effluent Treatment Plants (CETPs) in Tirupur was analysed for the pollutant parameters as well as major anions and cations. The concentration of sodium was found to be in the range of 1,800-2,500 mg/L representing often more than 90% of the cations (the effluent discharge standard in India into public sewers and on land for irrigation 60% is the upper limit).

In the interviews done at the textile units the difference between organic and inorganic TDS was not known by many textile producers. According to the findings the effluent standards in the State may preferably changed, clearly outlining the inorganic character of the Total Dissolved Solid instead of only standard TDS, which may be misleading in case of organic TDS. About 361 tonnes of neutral salts are emitted to the surface and ground water per day in and around Tirupur making the inorganic TDS problem the most challenging one. Chlorides were present in the range of 2,200-3,800 mg/L considering the molecular mass of Chloride, which is more than
50% higher than that of Sodium it indicates that the total molar concentration of Na\(^+\) ions is exceeding the chloride concentration.

The water consumption was determined for kiering/scouring processes as 30,500 L/tonne of textile. Bleaching was found to be in a range of 75,000 L/tonne and dyeing (including washing) depended on type of machine used and shade with 74,000 L/tonne for light upto 161,000 L/tonne for dark shades in open winches and approx. 50% thereof for soft-flow dyeing machines with lower liquor ratios.

5.2.2 Cleaner Production

Cleaner production measures, which are profitable (PCP), will in many cases have the most significant impact because of the direct return on investment. One cleaner production option is to reduce the treatment costs is to segregate waste streams. The dye bath and the first rinsing bath contain high concentrations of TDS and colour as the main contaminants. If they are segregated and treated separately only low concentrated wash water would be treated at lower operating costs.

The study integrated pollution prevention measures in each unit operation of the wet processing for woven cotton fabric finishing has been categorized. Pollution prevention measures were used to explore the possibilities of cleaner production processes so as to generate only the smallest possible amount of waste, for which tailor made solutions must be found.

In conclusion the precondition that was found to be essential for the success of any advanced integrated approach on the pollution problems was that high volume low pollution load and high pollution load and low volume effluent streams have to be segregated. The amounts of different effluent streams are depicted in Figure 5.1.
SANKEY DIAGRAM

Figure 5.1 Sankey Diagram of effluent flows
5.2.3 Biological treatment of segregated dye bath

The biological treatment of segregated effluents from the exhausted dyeing process was investigated because biological treatment steps are economical compared to any chemical or photochemical treatment. Generally this option seemed less favourable due to the low BOD content in the mixed effluents (50-100 mg/L). In general textile effluent is having not a good biodegradability indicated by the BOD/COD ratio. Ratios of 1:2 would imply good potential biodegradability, for textile wastewater this value is usually higher (>1:3) indicating that the effluent pollutants are difficult to biodegrade. The reasons can be of different nature: The COD is really refractory or the BOD culture is just not adapted to the peculiar conditions such as high TDS and complex organic molecules like dyestuff as substrates. This fact is often neglected in other studies.

In this study it could be shown that screened/adapted microorganisms can biodegrade dyes and decolourise the effluents.

For the biological treatment, halophile microorganisms were screened, isolated and utilised. The conformity of halophile bacteria to saline environments makes it possible to use them as biochemical tools for saline industrial effluents. Different kinds of halophile microorganisms were selected from textile effluents, tannery wastewater, salt lakes and estuarine and coastal regions of rivers as well as brackish water zones. These organisms were used for the treatment of the first dye bath effluent containing medium to high concentration of salts (7-28% w/w). Degradation studies were undertaken with low (3.5% w/w) medium (7, 14% w/w) and high salt (21, 28% w/w) tolerant organisms using different co-substrates. Enrichment experiments for halophile or halo-tolerant microorganisms were carried out and 16 enriched cultures were selected. Biological treatments steps were investigated in order to reduce treatment cost, because compared to physico-chemical treatment processes, biological processes are more economical avoiding the consumption of chemicals and
eliminating the production of inorganic hazardous sludge. The values of a series of experiments showed that the halophile or halo-tolerant microorganisms grow even without any co-substrates such as yeast extract, starch, corn steep liquor and others, but the growth with the co-substrates yeast extract showed improved growth rates. From the results it could be seen that the degradation of dyestuff with aerobic halophile microorganisms was not sufficient and the total colour reduction remained well below 50%. The azo- and other chromophore groups are resistant to the aerobic bacterial degradation. It is known that Gram-positive bacteria (except Arthobacters) are inhibited by lower concentrations of triphenylmethane dyes such as crystal violet, basic fuchsin, brilliant green and malachite green and Gram negative micro-organisms and Mycobacter are resistant to the dyestuff.

While conducting the experiments it was observed that after the aeration was stopped and whenever the system became anaerobic the dyestuff started decolourising. Suspended-growth bioreactor was sealed airtight and operated with textile effluent inoculated with halophile micro-organisms out of different saline environments. Three fixed bed reactor systems were designed after the evaluation of the results achieved with the suspended growth reactors. As a co-substrate starch was introduced and the biogas was collected. The attached growth process was applied to minimise shear forces for bacteria immobilising them on a solid carrier matrix. Cylindrical PVC tubes, wood coal and seashells were chosen as matrix. The carriers are available at low costs in the region.

The segregated concentrated dye bath and first rinse could be treated separately by anaerobic digestion. The anaerobic decolourisation of the effluent (concentrated dye bath) showed satisfactory results of 79-90 % colour reduction, but the anaerobic treatment did not contribute to a mineralisation of organic compounds. However, the final spectral absorption coefficient in the red spectrum varied just between 30 and 45 1/m, in the yellow spectrum just between 55 and 80 1/m and in the blue one just between 15 and 25 1/m. If these results were compared to the German
Standards for the discharge of textile effluent the spectral absorption coefficients $e_{436}$, $e_{525}$ and $e_{620}$ were still too high for discharge and the COD/TOC concentration did not reduce significantly (except when there was co-substrate). Only in combination with a post treatment the anaerobic digestion is a feasible treatment option handling comparatively smaller volumes (5%-10% of total volume).

The observed residual colours in the yellow range could be derived from oxidised aromatic amines or Thioacetone compounds which absorb light at $\lambda_{\text{max}}$ 460 nm and which would also resist oxidation. In this study it could be shown that screened/adapted microorganisms could biodegrade dyes and decolourise the textile processing effluents under anaerobic conditions. After the anaerobic reactor an activated carbon reactor should be placed to remove the residual dyestuff. Amines as well as other by-products such as nitrile tri-acetate (NTA), m- Nitro-benzolsulfonate are poorly degradable anaerobically, aerobic degradation occurs readily (Brown 1987). However from a model landfill with sludge from sewage treatment plants treating mostly textile wastewater, neither dyes nor the corresponding amine components could be eluted (Tincher 1988). In the anaerobic experiments no carcinogenic aromatic amines have been detected using High pressure Liquid Chromatographic HPLC (Shenai 2002). However the amines produced in the anaerobic process should be handled with care even if they are not listed as carcinogenic. These amides could be eliminated by aerobic processes (Brown 1987).

From the cost calculation point of view, the anaerobic treatment step seems economically feasible and it would be advisable to size the anaerobic reactor 25-50% bigger because the additional volume does not add much to the total cost, which also represents the present strategy in Germany in the field of anaerobic digesters.
5.2.4 Root-Zone Treatment Plant (RZTP) systems

The Root Zone Treatment was investigated as a low maintenance treatment system. In conventional treatment mixed effluents and even combined effluents have low organic concentrations and COD/BOD ratios above 3:1 indicating that biological treatment of these effluents is exceptionally difficult with classical processes. So far no experiences have been reported in treating segregated textile effluents with root zone treatment plants. Taking these facts into consideration the RZT system was tested. Three small units were set up on the CES rooftop for baseline data generation, but the addition of compost disturbed the analysis and small-scale test units will be operated over a longer period in the ongoing studies. In the case of textile processing effluents the BOD load was taken as a design factor. The design of such RZT units is normally done according to person equivalents (domestic sewage). For the horizontal flow 5 m$^2$/inhabitant or 16 g BOD$_5$/m$^2$·d and for the vertical flow 2.5 m$^2$/inhabitant or 24 g BOD$_5$/m$^2$·d. are prescribed. In line with the results from the aerobic suspended cultures the aerobic arrangement of the vertical root zone treatment was not suitable for the colour removal. The anoxic experiments were done after the wash water was neutralised with acetic acid and then applied to the RZTS varying the retention times. The pilot scale unit with one square meter surface area was set up in a textile unit 45 km away from the city of Chennai. It showed good performance in regard to the colour removal with retention times above 4-5 days. The plants grew well with the wash water input, but showed tendency of drying up once the TDS exceeded the permissible limits of 2,100 mg/L inorganic TDS.

Surprisingly the Silica concentration after the Root zone treatment was lower than the initial one indicating that it would be even possible to combine the natural effluent treatment with the sophisticated membrane technology viz. RO/NF filtration, but the space required for the RZTP is considerable and may hamper the installation of RZTP unit in the industry.
5.2.5 Advanced Oxidation Processes (AOP) UV Excimer Technology

The area identified for AOP research was the application of vacuum-UV-induced photooxidation with a xenon-excimer lamp operating at 172 nm for concentrated dye-baths and its combination with H\textsubscript{2}O\textsubscript{2} dosage.

The photooxidative treatment of mixed effluents from exhausted dye baths neither in colour nor in organic removal achieved sufficient degradation results. It was assumed that no expected water photolysis took place. Probably, the pollutants were photocleaved directly in a concurrent reaction and dyes were more resistant to oxidative destruction.

The constant or only slightly decreasing Total Organic Carbon (TOC) value indicated that the complete oxidation or mineralisation process had not taken place in the experimental period. The very fact that colour removal could be observed during the experiments indicated that large molecules with combined double bonds forming chromophoric groups are degraded into small molecules which are resistant to any further oxidation by the Excimer UV as well as the UV/H\textsubscript{2}O\textsubscript{2} combination.

The wash water UV Excimer treatment was investigated as a polishing step, but the reductions of the spectral absorption coefficients after 120 to 210 min of UV Excimer were minor. Only the addition (at 210 min) of 4 ml hydrogen peroxide with 47% H\textsubscript{2}O\textsubscript{2} (w/w) per litre sample enhanced the reduction in such a way that the spectral absorption coefficients reached the acceptable effluent standards.

Treatment of anaerobically pre-treated effluent did not result in further colour removal. From the observed data it could be concluded that the overall reduction of colour using the UV-Excimer is not sufficient and that only the combination with hydrogen peroxide is effective to meet the acceptable effluent standards. In comparison to the treatment with only hydrogen peroxide the
UV-Excimer was better due to direct photolysis and additional production of HO\(^o\) radicals the performance of the hydrogen peroxide treatment by 35-40\%, but the electricity costs were INR. 263,- per m\(^3\) for VUV treatment and INR. 104,- per m\(^3\) Hydrogen peroxide H\(_2\)O\(_2\) at a dosing rate of 4 L per cubic meter m\(^3\) effluent (not cost effective). The overall treatment costs are too high for this technology to have a chance of implementation in the field of textile effluent treatment. This technology may find application in the Pharma or Electronic (chip production) industries for highly specialised applications.

5.2.6 Membrane Technology

For the solution of the burning problem of Total Dissolved Solids (TDS) membrane technology was investigated, which is already playing a major role in the field of water recovery in many other industrial sectors. The experiments conducted supported the process of finding integrated solutions for the treatment of textile effluents exploring reuse and recycling options.

The NF membrane was mounted onto an existing RO plant and the power requirement cannot be taken as optimal, since it was designed for RO filtration purposes. For a production unit with the proper design, the power demand (costs) are expected to be 20-30\% lower.

5.2.7 Reverse Osmosis

It was found that with proper configuration of the transmembrane pressure, cross flow rate and concentrate removal, it is possible to recover up to 55-65\% of the wash water effluent with a salt rejection of 93-97.5\%. The recovered water (with TDS less than 500 mg/L) is often better than the water brought in tankers (TDS up to 2500 mg/L). Pre-treated wash water with a TDS of 4,000-5,000 mg/L (using conventional dyes) was concentrated with the RO unit into a reject with approx.
8,000-17,000 mg/L of inorganic TDS. The rejects from the RO unit were evaporated using the horizontal brine concentrator (solar evaporation). The permeate water quality was that of bottled mineral water showing TDS values of 180-300 mg/L.

Typical mixed concentrated dye bath effluents (plus first rinse) will have a TDS of 10,000-30,000 mg/l, which was also found to be too high to treat economically using RO technology. For dark shades the TDS in the concentrated dye bath can even rise up to 80,000 mg/L, for such high concentration RO systems were not considered due to economic constraints.

All Membrane units based on the cross flow principle produced rejects of considerable volume with higher inorganic TDS loads. The rejects can be treated in the anaerobic reactor or directly being concentrated and treated with the electrolysis cell as shown in Figure 5.2.

5.2.8 Nanofiltration

The Nanofiltration was applied for wash waters produced in the CES Unit operation laboratory. Nanofiltration membranes are nonporous solution-diffusion membranes like reverse osmosis membranes (Schneider 1993). Nanofiltration could be characterized by two extremely interesting properties: The colour was retained to almost 100% and only in the blue spectra minor passage was noticed. The salt rejection was about 43 %, which proved a low rejection for low molar mass substances. The experiments were conducted at a transmembrane pressure (TMP) of 350-600 kPa and a cross flow rate of 50-250 L/h allowing a permeate flow of 175-210 l/h at a power consumption of 0.9 kWh resulting in a specific power consumption of 4.7 kWh/m³ including the feed pump (21.3 Rs/m³ at 4.5 Rs per KWh).

The Nanofiltration Technology NF was successfully implemented for the wash water treatment and showed that dyestuff can be separated from the brine
solution. Compared to the RO technology the flux rates (L/m²·h) are higher and the transmembrane pressure (TMP) required is lower, providing a water quality in terms of TDS, which is sufficient for the textile process. It was proved that the concentrate flow could be adjusted to the effluent standards of 2,100 mg/L (inorganic) TDS. The permeate water recovered can be reused/recycled in the process or used as RO feed water. The success of membrane technology in the textile effluent field depends on pre-treatment and effective handling of rejects.

5.2.9 Recycling of textile effluents

Within the scope of this study was to prove the fact that obtaining desalinated water from wastewater (reclamation), depending on the specific circumstances, could be more 'economical' as compared to that obtained through conventional sources / methods – more so in the context of stringent regulations and laws. Now-a-days the manufacturers pay 300-700 INR/lorry load (approximately 12,000 m³) of water, which comes to INR. 25 -58 per m³ (0.58-1.35 EURO/m³). Over the past decade the cost of desalting brackish water has become less than the alternative of transferring large amounts of conventionally treated water. In 1990, the total production costs, including capital recovery, for brackish water systems with capacities of 4,000 to 40,000 m³/d typically ranged from EURO 0.26 to EURO 0.63 per m³. The probable costs for seawater desalting for plants in the capacity of 4,000 to 20,000 m³/d was estimated at EURO 1.10 to EURO 4.20 per m³. Available cost figures indicate that for a typical effluent quantity of 200 m³/d, the cost of RO operation could be around INR. 20-25 per m³ and including the capital repayment, depreciation including membrane replacement costs etc. it may come to INR. 35-38 per m³.

The textile finishing industries will be obliged to meet the regulatory requirement in terms of TDS. Water scarcity and rising water (tanker) prices will force the TFI to introduce water recycling systems. The options in this field will be
Nanofiltration and Reverse Osmosis. Once these are installed TDS management systems have to be in place as well. Here the technology with the lowest operational costs will become the best solutions and solar based systems like HRBC will be implemented.

The brine generated will be processed and reused either in the dyeing process or for the production of hypochlorites. The production of hypochlorites will be successful if the cleaning agent market can be tapped, because the use of hypo in textile finishing industry would come down as, the chlorides will and should be eliminated from the textile finishing process due to rising constraints regarding organic halides EOX / AOX.

5.2.10 High Rate Brine Concentrator (HRBC)

For the concentration of RO rejects the horizontal brine concentrator was developed. The reject concentration from brackish water RO -systems is often too high for disposal and too low for further processing. Low salt solutions derived as reject from brackish water RO -systems could be concentrated further, only using solar energy. Other processes using thermal or electrical energy consume large amounts of natural resources such as firewood, diesel, and/or furnace oils.

In the time period from 07:30 till 17:30 and evaporation rate of 1.8–3.5 L/m²*h with an average of 2.5 L/m²*h was observed depending on the temperature, humidity, solar radiation, wind direction and speed. The night data resulted in an evaporation rate of 0.8-1.5 L/m²*h with an average of 1.0 L/m²*h in the time from 17:30 to 07:30 hours

Comparing to multiple stage evaporators the HRBC system is almost corrosion and maintenance free, which is of big advantage to the industry. The leach out of organics is negligible after the initial rinsing with 40 L/m². The evaporation was
stopped at a concentration of 312 g/L since this is the concentration required for the next envisaged unit processing step, the electrolysis. The High Rate Brine Concentrator (HRBC) was developed in Europe for the salt production because of depleted resources in terms of firewood. It has so far never been applied in Asia.

For the reject management a Horizontal Brine Concentrator was designed for the concentration of reject (brine) from concentrations below 5% Sodium chloride NaCl upto 25-30% (w/w) inorganic TDS.

If 100 kg wood is used to erect 1 m$^2$ for a surface area of 1,500 m$^2$, 150 tonnes of wood will be required. A textile unit processing about 3,000 kg of textile a day consumes firewood in the range of 50 to 75 tonnes per month. For the construction of a HBC the firewood quantity of only 3 months is required (150-225 tonnes) for the total design period of 10-15 years.

5.2.11 Chlorine-Alkali Electrolysis

The concentrated brine out of the HRBC with 312 g/L concentration was used in the chlorine-alkali electrolysis process as raw material. The concentrated aqueous solution of sodium chloride (brine) was decomposed electrolytically by direct current, producing Sodium hypochlorite NaOCl.

The effective membrane area of the cell was 0.08 m$^2$. For the anode and cathode power supply a rectifier was used with an ampere rating of 200 A at 0-6 V, with a power consumption of 1.1 kW/h. The salt consumption was 0.47 kg/h of a 310 g/L Sodium chloride (NaCl) solution. For the experiments the brine (1.5 L/h) was mixed with soft water (20L/h) and filled into the cell.

The product produced out of the Electrolysis cell could be taken into the bleaching or post treatment process and/or used a disinfectant cleaner which are
Figure 5.2 Total overview of the integrated approach on treatment of textile finishing industry effluents
already available on the Indian market having concentrations of Sodium hypochlorite (NaOCl) of 0.6% minimum concentration (Commercial name Domex® Manufacturer by Nirmala dyechem GIDC VAPI, Gujarat). The local price is INR 20.- for 500ml. However, to achieve the above objective, it is necessary to ensure the purity of the concentrated brine solution.

5.2.12 Concluding remarks

In conclusion from the foregoing hypothesis, it may be stated that an integrated approach involving the critical problems of the textile finishing industry combined, will contribute to the solution of reducing the overall pollution load. An overview of the integrated approach is depicted in Figure 5.2.

Cleaner production methods, effluent segregation, biological treatment and membrane technology combined with reject management will contribute to the solution of reducing the overall pollution load. An integrated approach was chosen because once the measures are implemented the production depends on the water recycling and therefore, water reuse gains the same importance as the production itself.

5.3 SCOPE FOR FUTURE STUDIES

The textile industry in India will grow further and many textile finishing units are now firmly established in the global market. Globalisation will further increase competitiveness and cleaner production methods along with Environmental Management System (EMS) and ISO 14000 norms will become more and more popular.
The energy costs are comparatively high in India, so it is imperative that solar based technologies gain prominence over the next few years.

With regard to cleaner production new dyes like the low salt dyes will penetrate the market. On a mid-term basis the dyes will still require salt for fixation when winches or soft flow machines are used. Higher quality salts with less impurities will be used.

In future the bacteria population responsible for the degradation of the dyestuff shall be identified. The root-zone technology may be implemented for wash water treatment but high retention times and space constraints may hamper their application in the field. They could however, find application as final polishing steps and act as a bio-indicator as well, since some species do not grow in water containing more than 2100 mg/l of salt. So if they would be made compulsory for the final treatment step, the TDS can be monitored by the plants themselves, because they dry up if the TDS levels are too high.

The VUV- Excimer technology proved unsuitable for the field of effluent treatment. Further degradability studies with the excimer lamp application could be carried out with different substances.

For the desalination, electrodialysis technologies could provide an alternative to the reverse osmosis membranes.

The RO technology will be developing the terms of becoming more cost effective. New pumps consisting of pumping units with post Pelton-turbines with which excess pressure can be transformed into pumping energy again will enter the market. The concentrated pressure in the RO systems is often as high as 6,000 kPa and has to be brought down to lower pressures anyhow for its further uses. The pressure difference will be utilised in future to recover energy and improve the overall
efficiency of RO plants and bringing down operational costs by up to 30%. In future it should be investigated if the Nanofiltration (NF) system can be applied for concentrated dye-baths in order to remove the colour and TOC and utilise the permeate for direct reuse of the brine.

With the technologies set up in Centre for Environmental Studies, further research can be conducted to study the effect of membrane technology which will dominate the water reuse and reclamation field of environmental engineering in the years to come.