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## **Efficient use of water in the textile finishing industry**

### **ABSTRACT**

Identification and exploitation of non-conventional water sources is a priority for many industrial sectors, especially for the textile finishing industry. Therefore a multicriteria integrated and coherent methodology to support the implementation of sustainable water reuse is essential.

The methodology conceived within the EU project TOWEF0 (TOWards Effluent zero) is presented in this paper, together with the tools to carry out all the steps required by its application.

A process data collection for technical/economical evaluation in textile companies was performed and integrated with a characterisation of the process effluents in terms of treatability and reusability. Feasibility evaluations of effluents treatment for reuse were performed and reuse tests in textile processes were carried out. These information allowed for the design of optimised water reuse schemes by Water Pinch application, whereas the Life Cycle Assessment (LCA) permitted the evaluation and comparison of water reuse scenarios. Physical-chemical and eco-toxicological monitoring campaigns of textile discharges and receiving water bodies were conducted as well.

All these specific results, valuable and applicable independently, when integrated into the TOWEF0 methodology, generate viable solutions in accordance with the fundamentals of the IPPC Directive.

### **INTRODUCTION**

The value of water resources is universally recognised and water shortage is increasing in many countries. The need to preserve this resource is the driving force behind the identification and exploitation of non-conventional water sources. For industry, in particular textile production, wastewater reclamation appears a technically feasible solution, whose interest is proved by the vast literature produced [1].

Furthermore, European Directive CE 61/96 “Integrated Pollution Prevention and Control” (IPPC) requires that the industrial sectors change their production techniques according to Best Available Techniques (BAT), defined with the objective to reduce the impacts on the environment as a whole. In this context water reuse strategies, being potentially responsible for relevant changes in the wastewater composition and pollution transfers among the various environmental compartments (i.e. reclamation technology causing increasing energy consumption), need to be analysed thoroughly.

The elaboration of a multicriteria integrated and coherent methodology to support the implementation of sustainable water reuse in textile finishing processes is therefore a priority in this sector. This was the main objective of the EU research project TOWEF0 (TOWards EFfluent zero) whose achievements are presented in this paper.

In order to identify an optimal solution between minimisation of environmental impacts of the industrial activity and maximum recovery of resources, several competencies had to be integrated in the methodology, specific innovative tools had to be developed and existing ones had to be adapted to the specific application. The development and adaptation of the tools was carried out on real companies, where process data were collected, effluents were sampled to be characterised and treated and whose Waste Water Treatment Plant (WWTP) and corresponding receiving water bodies were monitored. Based on a questionnaire distributed in sample companies, that allowed for the collection of preliminary data, 10 companies (5 in Italy and 5 in Belgium) were selected taking into account the criteria of good environmental performance and significant representation of the European textile finishing industry. All the results presented in the next sections refer to these companies.

The questionnaire results were also used as one of the primary data sources for the preparation of the Reference Document on Best Available Techniques for Textiles Industry (BREF) [2].

In the following, the main scientific achievements and the methods set up in the different sectors covered by the project are summarised. Complete documentation is available at the project web-site <http://spring.bologna.enea.it/towefo/>.

## RESULTS AND DISCUSSION

### Process identification and data collection

In order to identify relevant processes and to collect data from textile industries, a specific procedure has been studied and defined. It consists of an audit inside the company, with the involvement of the company management, and it leads to a document called "Process Identification and Data Collection Sheet", referred to as "PIDACS". The companies involved in the project, described it as a positive experience to collect all these data. The fact that the necessary data have to be gathered from different persons in the company hinders an easy collection. Once the data are filled in the PIDACS some interesting conclusions can be drawn immediately.

The company activity is split in relevant departments and, for each of these, relevant processes are identified according to the Company Production Model. This model is a matrix reporting machine operations in terms of run per years (batch process) or operating hours per years (continuous process) for all the different textile processes carried out by the company (for example: desizing of cotton, desizing of viscose, light colour dyeing with reactive dyestuff, dark colour dyeing with reactive dyestuff, light colour dyeing with acid dyestuff, ...). For a specific process unit (process carried out by each different equipment), this leads to the determination of the total production in terms of processed textile material for each process unit and for the whole company.

Each relevant process is evaluated and defined in terms of manufactured fibres quantity, number of processed runs, equipment, process features and related chemistry. The process is divided into steps and for each step, all chemicals and their dosage are reported as an input, as well as the used water type and steam fluxes. The discharged water per step is reported as an output and characterised by the following parameters: temperature, pH, conductivity, COD and TSS according to the analytical data of the samples collected.

Processes used as facilities (filtration, softening, demineralisation, steam production) are analysed as well as manufacturing processes.

Process data are reported in schemes and are the basis of mass balances elaboration leading to identification of the weight of each process in the total water usage and in the total pollution load.

Other environmental information, such as solid wastes produced, discharge treatments, energy consumption, gas emissions and age of the used equipment are reported because of their importance with respect to the environmental impact as a whole.

The ten companies selected, identified by an alphanumeric code, are briefly characterised in Table 1.

Table 1: Main characteristics of the selected companies.

| Company code | Type of mill    | Manufactured fibre  | Type of fibre | Market segment                  |
|--------------|-----------------|---|---------------|---------------------------------|
| I06          | Dyeing          | Polyester   | Fabric        | Interior textile                |
| I09          | Dyeing          | Silk  | Yarn          | Clothing - interior textile     |
| I02          | Printing        | Viscose   | Fabric        | Clothing textile                |
| I15          | Dyeing-printing | Silk  | Fabric        | Clothing - interior textile     |
| I04          | Dyeing          | Viscose   | Fabric        | Clothing - interior textile     |
| B01          | Dyeing          | Cotton, wool, viscose, polyester: pure and mixtures                       | Yarn/fabric   | Commission finisher             |
| B02          | Dyeing          | Cotton, polyester/cotton  | Yarn/fabric   | Clothing textiles               |
| B03          | Dyeing-printing | Polyester/cotton, polyamide/cotton  | Fabric        | Clothing textiles               |
| B04          | Dyeing          | Cotton  | Yarn/fabric   | Clothing - interior textiles    |
| B05          | Dyeing          | Cotton, mixtures of cotton with polyester, polyamide, flax, wool, viscose | Fabric        | Clothing and technical textiles |

The main conclusions from the data collection can be summarised as reported in Table 2.

Table 2: Department water consumption and organic load

| Department         | Water consumption<br>(% of company total consumption) |         |     | Organic load<br>(% of company total organic load) |         |     |
|--------------------|---|---------|-----|---|---------|-----|
|                    | max   | average | min | max   | average | min |
| General Facilities | 6   | 14      | 33  | 0,1   | 2       | 8   |
| Preparation        | 16  | 36      | 54  | 45  | 61      | 77  |
| Dyeing             | 4   | 29*     | 53  | 4   | 23*     | 47  |
| Printing           | 42  | 55*     | 38  | 42  | 59*     | 75  |
| Steaming           | 0,3   | 0,4     | 0,6 | 0,0   | 0,1     | 0,1 |
| Fabric washing     | 3   | 28      | 52  | 1   | 13      | 25  |
| Finishing          | 0,3   | 1       | 4   | 0,1   | 3       | 7   |

\* average values calculated including only the companies where dyeing or printing department were present

For some processes different pollution levels could be correlated with different qualities of the same type of raw material. Important features determining the pollution load of the wastewater are not only the chemicals used in the process under study, but also the type and amount of size on the fabric, the amount of warps per meter, the way of weaving, the type of machinery used to perform the process, etc.

Quite unexpected conclusions came from the analysis of the pollution level of the different processes: in some companies process streams contained a much higher or much lower pollution level than expected.

The PIDACS data were used for characterisation and design of effluents, effluents treatment selection, Water Pinch analysis and Life Cycle Assessment (LCA).

### **Effluents characterisation and design**

Characterisation of textile process effluent streams is very important to develop strategies for water treatment and reuse. A literature survey was conducted to gain insight on the characteristics of effluents originating from different textile processes [3]. The streams show large differences in terms of concentration and composition, not only between types of processes (e.g. scouring, dyeing, etc) but also between similar processes conducted with different textile fibres (e.g. cotton, wool, synthetics, etc) or process ingredients (e.g. reactive dyeing, acid dyeing, etc.).

To optimise treatment and reuse possibilities, textile industry waste streams should be in principle considered separately. When the characteristics of the separate streams are known, it can be decided which streams may be combined to improve treatability and increase reuse options. For instance, the combination of acidic and alkaline streams might make pH correction by adding extra chemicals unnecessary.

The combination of process effluent streams to produce a stream with an optimal composition for further treatment and reuse is known as “wastewater design”. An example of wastewater design in the textile industry is the addition of waste size liquid (high biodegradable content) to dyeing effluent for anaerobic biological decolourisation. This approach has been experimentally tested and results are very promising. Two dyeing effluents have successfully been decolourised in both batch and continuous experiments using waste size liquid as co-substrate for the biomass.

For effective treatment and reuse of all kinds of different textile process water, an on-line characterisation technique is imperative. Using on-line characterisation inside the company would make it possible to send each effluent to its appropriate treatment just shortly after its discharge from the equipment. Respirometry and microcalorimetry were considered as techniques for the assessment of aerobic biodegradability, whereas a novel technique using mid-infrared spectroscopy was tested for on-line COD measurement. It was shown that, under certain conditions, microcalorimetry does provide similar information as respirometry. However, application outside a laboratory is not practical with the very sensitive calorimeter used in the project. With respirometry as a basis, an on-line characterisation technique was

developed. Respirometry makes it possible to on-line determinate the short-term biochemical oxygen demand ( $BOD_{ST}$ ) of a wastewater. This is a measure for organic material present in the wastewater, that can readily be degraded by activated sludge. Infrared COD measurements in textile effluent proved possible, provided that the COD concentration is sufficiently high. The treatability of the effluent can be determined by evaluating the  $BOD_{ST}/COD$  ratio: the higher the value the better the treatability. The potential of using a neural network to automate the analysis of respirograms was investigated, and results were promising. With these three elements (infrared spectrometry, respirometry and analysis by a neural network) a complete on-line characterisation technique is created.

### Feasibility of effluents treatment

Feasibility assessment of textile effluents reclamation technologies was performed and the treatability of the final discharge in WWTPs was evaluated. [4]

The proper technology option has to comply with the following requirements: integration with production processes, high removal of colour, organics and where needed salts, constant effluent quality, automatic operation and control, low weight and space, modularity, capability of dealing with small and intermittent water flows, reliability as required to be BAT. All considering, membrane filtration was selected as the most suitable technology.

Membrane treatment tests were performed on 17 different process effluents selected by focusing on the most important effluent streams in the textile finishing industries from pre-treatment, dyeing and printing operations, both from the whole processes and from the rinsing phase only. The streams tested are characterised by high variability in dissolved organic carbon content as well as in colour and salinity.

Several membranes were tested for ultrafiltration treatment (UF), nanofiltration (NF) and reverse osmosis (RO) to select the proper membrane for each effluent. According to the different characteristics of the effluents, the following treatment configurations were tested on pilot scale using spiral wound polymeric membranes: UF, NF, NF after UF and RO after UF.

Tests on real effluents, simulating the real full scale operative conditions, permitted the evaluation of the maximum obtainable permeate fluxes, the determination of the main chemical and physical properties of the permeates and the effect of the feed concentration. Characterisation of the membrane before and after the treatment gave indication on the membrane flux performance and its duration, and made it possible to estimate fouling effects on the membranes.

Based on the tests, data were elaborated to estimate the membrane/effluent affinity, the recovery factor (permeate recovered on total feed) and the hours of operation before chemical washing is needed. These are key factors to allow for a continuous and cost-effective plant operation. A preliminary design of treatment works was made to perform a cost analysis on various scenarios referring to small, medium and large companies.

In conclusion, the UF treatment alone does not normally assure a quality of the permeate suitable for reuse. NF resulted to be the best compromise between the need of having high

flow rates (consequently reducing treatment costs) and good quality permeates. The colour was almost completely removed and residual values never affected the reusability. The salinity abatement was variable and, in the effluents of certain dyeing operations (i.e. reactive and direct dyeing of silk and cotton), where mono-valent salts are used in large amounts, the removal was low and it hampered the reuse. The removal of organic matter was high, typically 80 -90%, nevertheless treatment of effluents with a high organic content (COD > 1000 mg l<sup>-1</sup>) did not produce reusable permeates.

Direct NF treatment was feasible only on the most diluted effluents of rinsing operations. The removal percentage in these cases was lower but sufficient to produce a permeate reusable in any process. Costs are also promising, ranging between 0.57 and 0.63 €/ m<sup>3</sup> in a scenario of 50,000 m<sup>3</sup>/year of effluent to be treated.

The treatment configuration UF + NF seems in most cases technically and economically feasible, except for the silk polymer charge, polyester double scouring and cotton bleaching line which evidenced very low permeate fluxes and/or relevant material accumulation on the membrane surface. In the hypothesis of 50,000 m<sup>3</sup>/year of water to be treated, the cost range would be 0.67 –1.04 €/ m<sup>3</sup>.

RO treatment of the tested effluents always required an UF preliminary treatment and despite the very high removal of contaminants, it resulted to be scarcely promising because of the very low fluxes and, consequently, high costs.

To evaluate alternative ways of treatment, effluents with important colour and organic content (i.e. cotton reactive and acid dyeing effluents) were tested in continuous experiments in two EGSB (Expanded Granular Sludge Blanket) type anaerobic reactors as preliminary treatment step for membrane filtration. Anaerobic treatment did confirm its good potential in removing colour, but it did not improve the performance of the subsequent membrane treatment [5, 6].

As for the evaluation of concentrates toxicity, a method was set up to measure the inhibition of the nitrifying activity of the concentrates. Inhibition was measured on raw effluents and concentrates produced by membrane filtration. The results obtained, combined with the biological treatability evaluated by BOD<sub>5</sub>/COD ratio gave a preliminary confirmation of the feasibility of final wastewaters disposal in conventional WWTPs.

### **Evaluation of the reusability**

In each of the participating companies textile processes were selected of which the effluents could be treated and reused for the same or for another process. In Table 3 and 4 an overview is given of the samples collected and reuse tests performed respectively for the pre-treatment and the dyeing operations.

Table 3: Pre-treatment: samples collected, treatment and reuse tests performed.

| Fibre used for tests | Process sampled    | Step                | Wastewater treatment             | Pre-treatment performed     | Efficiency tests                            |
|----------------------|--------------------|---------------------|----------------------------------|-----------------------------|---|
| PES                  | Scouring at 60°C   | Rinsing             | Nanofiltration                   | Scouring                    | Degree of whiteness                         |
| SILK YARN            | HT scouring        | Rinsing             | Nanofiltration                   | Degumming<br>Polymer charge | Degumming efficiency<br>Charge efficiency   |
| SILK FABRIC          | Dark acid dyeing   | Rinsing             | Nanofiltration                   | Degumming                   | Degumming efficiency<br>Degree of whiteness |
| VISCOSE              | Dark direct dyeing | Rinsing             | Nanofiltration                   | Scouring                    | Degree of whiteness                         |
| COTTON               | bleaching          | Bleaching + rinsing | Ultrafiltration + nanofiltration | Bleaching                   | Degree of polymer.<br>Degree of whiteness   |

Table 4: Dyeing: samples collected, treatment and reuse tests performed.

| Fibre used for tests | Process sampled        | Step                            | Wastewater treatment             | Dyeing processes performed                    | Efficiency tests                                |
|----------------------|------------------------|---------------------------------|----------------------------------|---|---|
| PES                  | Scouring at 60°C       | Rinsing                         | Nanofiltration                   | Light disperse dyeing<br>Dark disperse dyeing | colour difference<br>colour fastness to washing |
| PES                  | Medium disperse dyeing | Rinsing                         | Nanofiltration                   | Light disperse dyeing<br>dark disperse dyeing | colour fastness to rubbing                      |
| PES                  | Disperse printing      | Rinsing                         | Ultrafiltration + nanofiltration | Light disperse dyeing<br>dark disperse dyeing |   |
| SILK YARN            | HT scouring            | Rinsing                         | Nanofiltration                   | Light acid dyeing<br>Dark acid dyeing         |   |
| SILK FABRIC          | Dark acid dyeing       | Rinsing                         | Nanofiltration                   | Light acid dyeing<br>Dark acid dyeing         |   |
| PA                   | Dark acid dyeing       | Mixed sample: dyebath + rinsing | Ultrafiltration + nanofiltration | Light acid dyeing<br>Dark acid dyeing         |   |

| Fibre used for tests | Process sampled    | Step                              | Wastewater treatment             | Dyeing processes performed   | Efficiency tests |
|----------------------|--------------------|-----------------------------------|----------------------------------|--|------------------|
| VISCOSE              | Dark direct dyeing | Rinsing                           | Nanofiltration                   | Light direct dyeing<br>Dark direct dyeing<br>Light reactive dyeing<br>Dark reactive dyeing |                  |
| COTTON               | Bleaching          | Mixed sample: bleaching + rinsing | Ultrafiltration + nanofiltration | Light direct dyeing  |                  |
| COTTON               | Reactive dyeing    | Mixed sample: dye bath + rinsing  | Ultrafiltration + nanofiltration | Light direct dyeing<br>Dark direct dyeing<br>Light reactive dyeing<br>Dark reactive dyeing |                  |

The reuse tests were performed on lab scale pre-treatment and dyeing processes both on yarn and fabric. To be able to evaluate the treated textile material, a reference test was carried out with fresh process water.

The reuse options of the different permeate streams were tested both with 100% permeate or with a combination of permeate and fresh process water. In a full scale operation it is advisable to dilute the permeate to avoid an increased concentration of some of the components. Membrane filtration results always in a permeate and a concentrate streams, which means that fresh process water is anyhow necessary to compensate this loss of water.

In contrast, using a 100% permeate solution for the reuse tests is a way of simulating a worst case scenario and it is a compensation for the fact that the reuse cycle has only been performed once (i.e. production of effluent, treatment and reuse).

The quality evaluation of the textile material has always been linked to the differences in water quality: fresh process water versus permeate. The membrane filtration had no effect on the pH and on the monovalent salts in the water. This means that effluent containing a high content of NaCl results in a permeate with a comparable concentration. Since NaCl regulates the speed and the depth of reactive and direct dyeing of cotton, a higher concentration has a significant effect on the colour of the dyed cotton. The fastness properties were not negatively influenced. The pH of the permeate is easy to adapt, the salt content however is not easy to change.

On the contrary, textile processes in which little or no salt (NaCl) is dosed, the quality of the permeate is comparable to fresh process water and the quality of the treated (pre-treatment/dyeing) textile material is as good as the reference.

As a conclusion, the permeate can be reused for pre-treatment and/or dyeing of some of the most used textile raw materials, i.e. polyester (PES), polyamide (PA), silk, viscose. The presence of salt (NaCl) however hampers the reusability for the dyeing of cotton.

## Water Pinch technology evaluations

The analysis was carried out to design alternative water schemes for the textile finishing companies, in order to minimise water consumption in a cost effective way.

Starting from the PIDACS, all the useful information for water minimisation was put into data survey sheets. At this stage, these were used for first summarising calculations: effluents from similar processes were grouped and their mixed contamination was calculated. Based on these sheets the water network was visualised in the dedicated software WaterTracker<sup>®</sup>. Finally, all schemes were optimised by implementation of membrane filtration technology. The removal efficiencies for this water regeneration equipment were extracted from the treatment test results reported above.

The water saving, compared to the initial situation, was calculated by the software. Furthermore, the changed concentration of the feeding water towards the processes (due to mixture with membrane permeate) was determined, as well as the increased contamination of the final effluent, as a result of the obtained water saving. Figure 1 illustrates how all this is visualised.

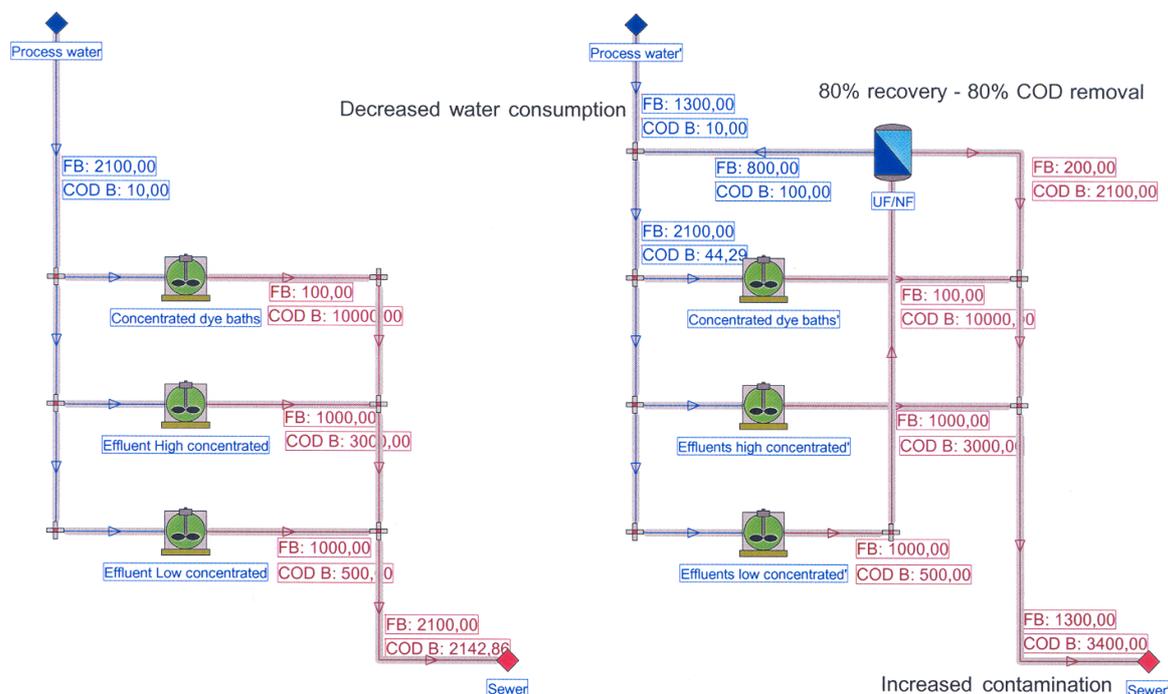


Figure 1: Initial (left) and alternative (right) water scheme in WaterTracker

Based on the results of the economical evaluation of membrane plants, the costs of the implemented technology were compared to the costs of fresh water.

It was concluded from this study that within a pre-treatment department water savings from 30 to 70% can be obtained. In dyeing sections, the savings by implementing regeneration technologies will be within a range of 15 to 40%.

For the overall companies this would mean a reduction in water consumption between 15 and 30%. As a result, the contamination of the final effluent will increase proportionally.

The costs for implementation of membrane filtration units are still high (around 0.7 €/m<sup>3</sup>) when compared to the actual low costs of industrial or ground water (around 0.1 €/m<sup>3</sup>). This gap can be reduced or increased by the variation in the cost of final effluents treatment and disposal, which depends on local factors. Only when the use of industrial or ground water requires an extensive and therefore expensive treatment, implementation of a regeneration technology will be economically feasible. It can be expected that in the near future costs of the actual used industrial and ground water will increase, permits on pumping ground water will become more stringent and prices for membrane filtration will drop, due to the increasing production.

## Decision making using LCA

Life Cycle Assessment is one of the most known and internationally accepted methodologies to compare the potential environmental impacts of processes and systems and to evaluate their relative sustainability in the entire life cycle. In this project LCA has been applied to selected textile products manufactured within Belgian and Italian textile finishing companies to evaluate water reuse scenarios, generated by Water Pinch assessments. The boundaries of the studied system included the textile wet processing and the subsequent wastewater treatment in WWTP, the energy and chemicals production and the transport of wastewater sludges and auxiliary materials (Figure 2).

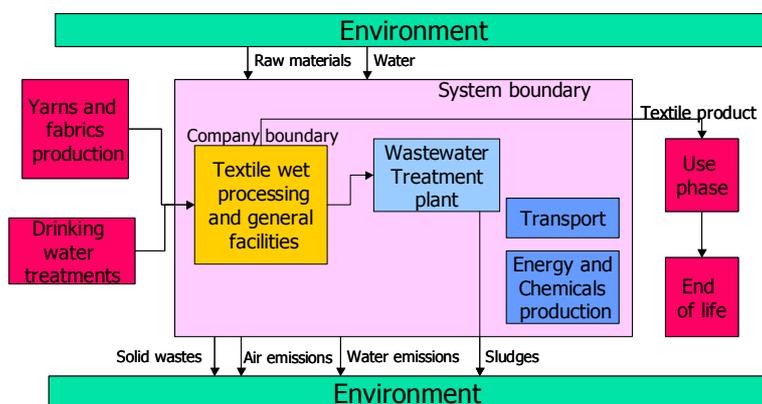


Figure 2: System boundaries of the LCA case studies.

The study identified the key environmental issues within the finishing processes of a variety of natural (cotton, silk) and man-made (polyester, acetate, viscose) fibres and fabrics. The water consumption observed in the selected companies ranges between 5 and 24 m<sup>3</sup> per 100 kg of treated fabric, depending on the type of operation, the equipment efficiency and the type of fibre. The water used outside the company for energy and chemicals production is only a small fraction of the water used within the companies. The methane combustion for generating steam, which is used to heat up the process baths, and the production of the electricity needed by the equipment are the determinants of the main environmental impacts on air related categories (greenhouse effect, acidification) in all the companies involved in the study. This confirms the importance of reducing water use to minimise, at the same time, water and energy consumption. The impact of chemicals production is a small, but not negligible, fraction of the textile products life cycle impact for all the environmental impact categories. A severe shortage of eco-profiles of the production of chemicals used by textile industry was evidenced by the study.

Two alternative water management scenarios implementing water reuse were analysed according to the results of Water Pinch. In the first, named “Innovative scenario”, ultrafiltration and nanofiltration technologies were applied to selected process effluent streams (mainly rinsing water), with a total water saving of 10-55%. In the second, named “Effluent zero scenario”, ultrafiltration and reverse osmosis were applied to all process effluents, with a water saving of about 80%. In both cases LCA results confirmed the environmental friendliness of these technologies, showing that these improvements can be reached with a slight increase in the energy used (less than 1% for the “Innovative scenario” and 12% for the “Effluent zero scenario”) and, consequently, in energy related environmental impact categories.

Another major result of this project is a LCA database, containing quantitative data on processes/products used in textile processing companies. The database can be used by LCA practitioners to complement the existing LCA commercial databases with specific information on textile processing and, by non LCA experts, in conjunction with the web based LCA software (specifically designed in the project) to conduct Life Cycle Assessments in the textile industry.

The software uses a web-based interface that enables users to access it, without requiring the installation of any software on their workstation. It can be accessed at <http://192.107.65.184/>. Registration is possible by ordering an access to Ecobilan ([info@ecobilan.com](mailto:info@ecobilan.com)). The user will be attributed a login and password giving him access to his own work environment, within which he will be able to store his own data and projects. The software offers user profile management that ensures the confidentiality of all implemented information, with support of Ecobilan.

The purpose of the software is three-fold:

- to enable data management in the textile industry and manage databases;
- to establish benchmarks from one year to another or between sites that have the same processes;

- to draw out comparisons between different processes layout with the aim to identify improvements.

The description of the Towef0 software architecture is summed up in the diagram (Figure 3):

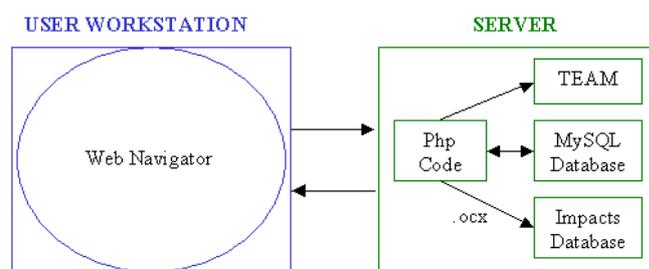


Figure 3: TOWEF0 software architecture

The TOWEF0 software contains different models: 29 processes, including 13 manufacturing processes, 6 general processes and 10 wastewater treatment processes. Furthermore, the software contains over 100 modules, over 1000 fluxes, and over 1000 objects. The user is able to customise the model to his own data and processes.

The steps to carry out an analysis by the software are as follows:

- **Goal definition:** choice of the purpose that the user wants to achieve in the study.
- **Access:** Registration after having ordered an access to Ecobilan. The user will be attributed a login and password, giving him access to his own work environment within which he will be able to store his own data and projects.
- **System modelling:** preparation of a flow chart of the system using the generic industry processes and wastewater treatments modelled in the software – a user guide is available online for self-training.
- **Data gathering:** data collection for each process, using data that is consistent with the software structure (flow definition, etc.).
- **Data implementation:** data implementation into the software.
- **System implementation:** building of the system in the software by assembling the defined processes.
- **Inventory and impact calculation:** calculation of the LCA reports by launching table and graph reports.

Once the LCA calculations are performed, it is up to the user to establish his own ranking of the different categories of environmental impacts among themselves according to his priorities and then to draw out his conclusions (e.g.: increase in electricity consumption as compared to increase in chemical products utilisation).

## **Environmental impact assessment by integration of chemical analysis and ecotoxicological methods**

As mentioned in the introduction, the objective of the IPPC Directive 96/61/EC is to prevent or reduce industrial emissions into the environment; Article 14 especially demands the monitoring of releases affecting the environment. Therefore, chemical analysis methods for organic micropollutants in water samples were developed, optimised and validated and ecotoxicological tests were adapted to assess hazardous effects in discharges and receiving waters [7, 8, 9]. Moreover, biological screening methods for endocrine disrupting activity were applied [10, 11]. Pollutant-specific monitoring and physical-chemical characterisation of effluents from textile industries, WWTPs and the corresponding receiving waters was performed simultaneously with the eco-toxicological effect-based characterisation both in Belgium and Italy.

By chemical analysis, the following pollutant types were identified in the water samples: phenols (nitrophenols, bisphenol A, nonylphenol (NP), octylphenol (OP)), nonylphenol-ethoxylate (NPEO) surfactants and their metabolites with endocrine disrupting potential (NPE<sub>1</sub>C, NPE<sub>2</sub>O, OPE<sub>2</sub>O, etc.), different aromatic sulfonates, LAS surfactants, dyes (colorants), pesticides and pharmaceuticals. The eco-toxicological characterisation consisted of the application of multiple acute and/or chronic toxicity tests with organisms from different trophic levels (bacteria, algae, invertebrates and fish). The estrogenic activity was measured by use of two cellular hER-gene reporter assays, which allowed to quantify the presence of chemical substances which bind to the receptor for the natural hormone, 17 $\beta$ -oestradiol.

Emphasis was placed on alkylphenolic endocrine disrupting compounds (EDCs). NPEOs, NP and NPECs are released into the environment from textile industry WWTPs in considerable amounts. The highest NP levels were found in the receiving waters, the highest NPEC concentrations, however, in the WWTP effluents and the highest NPE<sub>2</sub>O level in Belgium in a textile plant effluent. The predicted no-effect concentration (PNEC) for NP of 0.33  $\mu$ g/L for water species was frequently exceeded in Belgian and Italian effluents and receiving waters (up to 2.5  $\mu$ g/L). The concentrations for the non-regulated NPEOs and NPECs were even higher. For NP and the measured estrogenic activity in Belgian and Italian waters, a significant correlation was found (Figure 4). This points to the concern for adverse effects of EDCs in the aquatic environment and the need to improve water quality by cessation of toxic emission into the environment. Measurement data did show that the NP quality standard was regularly exceeded and that estrogenic activity in Italian and Belgian surface waters was of that order of magnitude that normal fish reproduction could be hampered. It is confirmed that the European strategy with regard to EDC should be of high priority and that chemicals with known endocrine disrupting activity should better be phase out and be part of monitoring programmes, as a follow-up. In addition to these alkylphenol EDCs, in Belgium especially high pesticide concentrations were found in the surface waters.

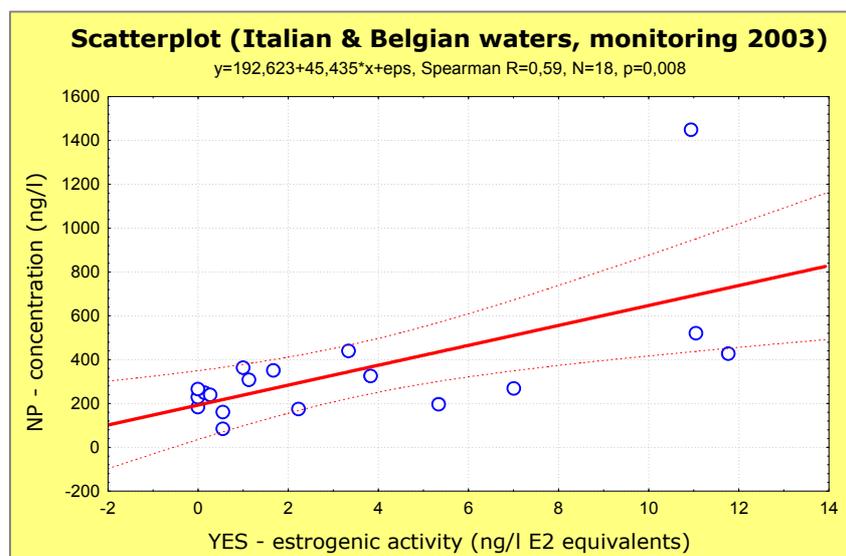


Figure 4: Significant correlation between the estrogenic activity, measured with the YES-assay and the concentration of NP based on data from Italy and Belgium

Moreover, discharges of Belgian textile companies did show median to high acute toxicity (range 10-75 toxic units). Treated effluents of Belgian textile industry showed reduced acute toxicity (< 10 toxic units). Discharges of Italian textile industry WWTPs did show no acute toxicity.

In conclusion it appears that acute toxicity is not problematic, if the final wastewater treatment is performed correctly. On the contrary, NPEO surfactants are still used in textile industry. They are of environmental concern because of their degradation products (NP, short-chain NPEOs, and carboxylated NPECs) formed in WWTPs and the receiving waters, with clear evidence for endocrine disrupting potential.

## CONCLUSIONS

All the specific results described, besides being valuable and applicable independently, were meant to be synergically combined to create an integrated multicriteria methodology. The methodology can be described as a four steps analysis process:

1. Complete data collection to be carried out in the companies.
2. Analysis of all (or at least the most important) process effluents to identify and characterise all their possible destinies (direct reuse, reuse after on site treatment, discharge to WWTP after on site preliminary treatment, direct discharge to WWTP or alternative disposal), following the path represented in Figure 5.

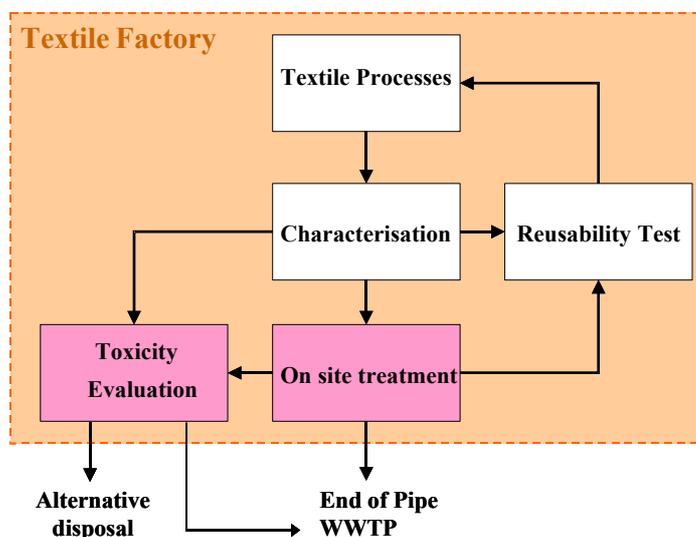


Figure 5: Effluents path

3. Elaboration of all the data gained in step 2 in a Water Pinch assessment, resulting in the definition of optimised water reuse scenarios.
4. Comparison of the scenarios by LCA to support the decision making leading to the implementation.

Beside the implementation of the new water reuse scenarios in the companies, continuous monitoring of the impacts on receiving water bodies should be made, comparing the results with the previously existing situations.

The project has generated useful tools to carry out all the steps of the analysis shown. On this basis a company can, on the one hand, make preliminary evaluations using the methodology and the data produced by the project and, on the other hand, design detailed water reuse schemes producing ad hoc data as input to the methodology.

The project results can give an effective contribution to the application of the IPPC directive and, enabling a sustainable use of the water in crucial industrial sites, represent a good methodology for similar approaches in other industrial sectors.

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