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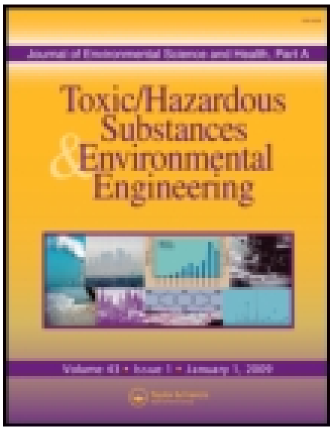

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# Feasibility Analysis of In-Plant Control for Water Minimization and Wastewater Reuse in a Wool Finishing Textile Mill

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# Feasibility Analysis of In-Plant Control for Water Minimization and Wastewater Reuse in a Wool Finishing Textile Mill

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## ABSTRACT

This study evaluates the feasibility of water minimization and wastewater reuse for a wool finishing textile mill. The evaluation process is based upon a detailed analysis on water use, process profile and wastewater characterization, indicating a potential for 34% reduction in water consumption and for 23% of wastewater recovery for reuse. Wastewater reuse requires treatment and results in a remaining wastewater stream with stronger character and consequently more costly to treat. The feasibility includes technical considerations for appropriate treatment alternatives and related cost factors for water consumption, treatment for reuse and for discharge either to sewer or to receiving media.

*Key Words:* In-plant control; Sewer charge; Treatment cost; Wastewater reuse; Water minimization; Wool finishing textile industry.

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## INTRODUCTION

Appropriate in-plant control for the textile industry provides a potential for the reduction of water use, raw material and energy consumption, and wastewater generation. The latter is a natural consequence of water minimization. The amount of wastewater to be treated and discharged may also be decreased by appropriate wastewater recovery and reuse. In-plant control practice generally involves one or more of the following applications: (i) reduction in water usage (*water conservation*), (ii) wastewater recovery and reuse, (iii) substitution of process chemicals, and (iv) recovery of valuable substances (*material/waste reclamation*). Wastewater minimization by water conservation and/or wastewater reuse is the most readily achievable in-plant control strategy and yet it is often overlooked. One of the major features of the textile industry is the high water usage. Significant reductions however can be achieved simply by identifying and preventing the unnecessary water consuming points throughout the production processes. On the other hand, a part of the wastewater originating from one operation may be of sufficient quality to be reused in a second operation, directly or after appropriate treatment. The use of inefficient washing equipment, poor housekeeping practices, feeding freshwater at all operations requiring water, and the application of longer washing cycles than what is required, leading to excessive amounts of water consumption constitute major factors for elevated wastewater generation.

One of the main concerns in efforts to minimize water consumption is the possible adverse effect on wastewater quality. When the relatively less polluted wastewater fraction is segregated for reuse and unnecessary water consumption is prevented, a stronger wastewater, likely to require a higher level of treatment before discharge is generated.[1,2] Therefore, a comparison between the savings obtained on fresh water demand vs. elevated end of pipe wastewater treatment costs together with cost of treating reusable streams when applicable, must be performed in order to evaluate the feasibility of such in-plant control practices.[3]

In this study the technical and economical feasibility of in-plant control for wool finishing textile industry is investigated on the basis of a survey conducted on a textile mill located in Istanbul, Turkey. The feasibility evaluation included technical considerations for appropriate treatment alternatives and related cost factors for water consumption, treatment for reuse and for discharge either to sewer or to receiving media.

## CHARACTERISTICS OF PLANT OPERATION AND IN-PLANT CONTROL APPLICATIONS

The investigated textile mill is a typical example of wool finishing industry performing previously *dyed wool*, *wool–lycra*, *wool–polyester*, and *wool–polyester–lycra* blends fabric finishing operations. Batch-wise processes with fill and draw and/or shower baths are used in the plant to obtain the required finishing on three types of previously dyed fabric namely: *X type*, *Y type*, and *Z type* fabrics. When a dyeing process is applied to fabric, such fabrics are defined as *Z* type of fabrics.

The fabrics manufactured from dyed yarns are named as *X* type of fabrics. Lastly, *Y* type fabrics are the fabrics produced from dyed fibers.

The methodology adopted for in-plant control to assess the unnecessary water consumption points and to identify the reusable wastewater streams, first of all involves a detailed evaluation of the production schemes. By doing so every step of the production using water and/or generating wastewater was identified. Then each wastewater stream is characterized in terms of polluting parameters. By considering this quality analysis in the light of the reuse criteria given in literature and specific demands of the manufacturer on product quality, the production steps where water consumption may be reduced and reusable wastewater streams are identified. The last part of this approach is to evaluate the effect of envisaged water conservation and reuse practice on product quality in order to prevent possible negative outcomes.

The following items are recommended for water conservation and reuse by applying the mentioned methodology to the investigated plant:

(i) Water conservation: Shower rinsings can be stopped at a point where the soluble COD of the segregated wastewaters reach under $50\,\mathrm{mg\,L^{-1}}$. However, due to the observed deterioration in product quality, shower rinsings must not be lowered below 5 min even though soluble COD values of the wastewaters obtained within this period can reach under $50\,\mathrm{mg\,L^{-1}}$.

(ii) Reusable wastewater streams: Wastewater streams having soluble COD values lower than $650\,\mathrm{mg\,L^{-1}}$ can be directed to reuse. Discharges of 1st fill and draw rinsings and fill and draw rinsings with auxiliary addition must not be added to reusable wastewaters as they might contain contaminants originating from previous dyeing operations or coming from the usage of different brands of auxiliaries.

Further information on the details of the adopted methodology and the application of in-plant control for this industry can be found in literature.[4]

The present water consumption in different major steps of the production is summarized in Table 1. The result of the comprehensive analysis has indicated that a rational in-plant control has the potential of reducing water consumption by 34% and to recover 23% of the selected wastewater streams for reuse after appropriate pretreatment as given in Table 1.[3]

## Technical Basis of the Feasibility Analysis

### Basic Data

At the time of the evaluation, the water consumption in the plant was calculated as $444.4\,\mathrm{m^3\,day^{-1}}$ for an average of 5475 kg of fabric processed, yielding a unit water consumption rate of $81\,\mathrm{m^3}$ of water per ton of fabric, a typical level for similar textile mills.[5,6] The proposed in-plant control measures indicate that a $150\,\mathrm{m^3\,day^{-1}}$ reduction in water consumption is possible, decreasing the water usage to $294\,\mathrm{m^3\,day^{-1}}$ and the unit water consumption rate to $54\,\mathrm{m^3\,t^{-1}}$ of fabric; they also

*Table 1.* Detailed analysis of the proposed in-plant control application.

| Process | Processed product (kg fabric (day)$^{-1}$) | Water usage, wastewater generation | | Water conservation | | Reusable streams | |
|---|---|---|---|---|---|---|---|
| | | (m$^3$ (ton fabric)$^{-1}$) | (m$^3$ day$^{-1}$) | (m$^3$ day$^{-1}$) | (%) | (m$^3$ day$^{-1}$) | (%) |
| 100% wool and 96% wool + 4% lycra | | | | | | | |
| *X* type dyed fabric finishing | 483 | 73.3 | 35.4 | 11.3 | 32 | 4.8 | 14 |
| *Y* type dyed fabric finishing | 1,256 | 76.7 | 96.3 | 33.5 | 35 | 12.6 | 13 |
| 50% wool + 50% PES and 48% wool + 48% PES + 4% lycra | | | | | | | |
| *Z* type dyed fabric finishing | 1,135 | 50.0 | 56.8 | 26.5 | 47 | 18.9 | 33 |
| *X* type dyed fabric finishing | 1,263 | 96.7 | 122.1 | 25.3 | 21 | 37.9 | 31 |
| *Y* type dyed fabric finishing | 1,338 | 100.0 | 133.8 | 53.5 | 40 | 26.8 | 20 |
| Total | 5,475 | — | 444.4 | 150.1 | 34 | 101 | 23 |

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allow for the reuse of 100 $m^3$ $day^{-1}$ of the wastewater stream bringing down the water consumption to 194 $m^3$ $day^{-1}$, which ultimately corresponds to a 35 $m^3$ $t^{-1}$ of fabric. This way, the proposed plan intends to achieve a reduction of around 60% in water consumption and consequently in wastewater generation, if technically and economically feasible.

## Wastewater Quality

The textile mill generates a highly colored wastewater effluent, somewhat weak in character due to excessive water use, with an average COD content of 687 mg $L^{-1}$ and a TSS content of only 85 mg $L^{-1}$.

Water conservation involves a proportional increase in the wastewater strength. Segregation of the reusable streams generate a stronger wastewater with a COD of 1460 mg $L^{-1}$, likely to be much more complex in nature for biological treatability.[2] Detailed characterization of (i) the raw wastewater before in-plant control application (*wastewater A*), (ii) the wastewater after water conservation (*wastewater B*), and (iii) the remaining wastewater after water conservation and segregation of reusable streams (*wastewater C*) is presented in Table 2 with relevant effluent limitations for discharge to sewer and to receiving waters.

The reusable wastewater stream is obviously much weaker in character with a COD of less than 200 mg $L^{-1}$, a total dissolved solids (TDS) of 340 mg $L^{-1}$ and very low in color. The analysis conducted on this portion is given in Table 3 together with two sets of reuse criteria suggested in the literature for textile wastewater reuse in the process.

***Table 2.*** Flowrates and characterization of different types of wastewaters likely to be generated from the mill and discharge standards.

| | Wastewaters | | | Discharge standards | |
|---|---|---|---|---|---|
| Parameter | A | B | C | Receiving water | Sewer |
| Flowrate ($m^3$ $day^{-1}$) | 444 | 294 | 194 | — | — |
| Total COD (mg $L^{-1}$) | 687 | 1,038 | 1,460 | 300 | 800 |
| Soluble COD (mg $L^{-1}$) | 455 | 687 | 970 | — | — |
| TSS (mg $L^{-1}$) | 85 | 128 | 190 | 100 | 350 |
| VSS (mg $L^{-1}$) | 80 | 121 | 180 | — | — |
| TDS (mg $L^{-1}$) | 380 | 574 | 640 | — | — |
| TKN (mg $L^{-1}$) | 20 | 29 | 30 | — | — |
| $NH_4$-N (mg $L^{-1}$) | 8 | 12 | 18 | — | — |
| TP (mg $L^{-1}$) | 0.8 | 1.0 | 1.2 | — | 10 |
| Conductivity (μS $cm^{-1}$) | 620 | 635 | 655 | — | — |
| Alkalinity (mg $CaCO_3$ $L^{-1}$) | 108 | 106 | 106 | — | — |
| Color (Pt–Co) | 220 | 332 | 440 | — | — |
| pH | 7.1 | 6.9 | 6.2 | 6–9 | 6–10 |

*Table 3.* Reusable wastewater characterization and reuse criteria for textile wastewaters.

| Parameter | Raw reusable wastewater | Reuse criteria: Li and Zhao[7] | Reuse criteria: Hoehn[8] |
|---|---|---|---|
| Flowrate ($m^3\,day^{-1}$) | 101 | — | — |
| Total COD ($mg\,L^{-1}$) | 180 | 0–160 | <50 |
| Soluble COD ($mg\,L^{-1}$) | 120 | — | — |
| TSS ($mg\,L^{-1}$) | 15 | 0–50 | <500 |
| TDS ($mg\,L^{-1}$) | 340 | 100–1,000 | — |
| Total hardness ($mg\,CaCO_3\,L^{-1}$) | 0 | 0–100 | 90 |
| Chloride ($mg\,L^{-1}$) | <100 | 100–300 | <150 |
| Total chromium ($mg\,L^{-1}$) | <0.5 | — | 0.1 |
| Iron ($mg\,L^{-1}$) | <1 | 0–0.3 | 0.1 |
| Manganese ($mg\,L^{-1}$) | <0.3 | <0.05 | 0.05 |
| Conductivity ($\mu S\,cm^{-1}$) | 550 | 800–2,200 | — |
| Alkalinity ($mg\,CaCO_3\,L^{-1}$) | 135 | 50–200 | — |
| Color (Pt–Co) | 20 | — | — |
| pH | 7.1 | 6.5–8.0 | 6.5–7.5 |

## Appropriate Treatment Alternatives

The *reusable stream* requires only polishing and color removal without adversely affecting the TDS content. Membrane treatment is generally not desired because of cost and extra care needed for operation. Previous experimental studies showed that satisfactory removals were not achieved with ozonation.[3] Chemical treatment with either alum or bentonite was efficient in providing total color removal and removing COD below $100\,mg\,L^{-1}$. Table 4 summarizes results of chemical treatability tests conducted with different doses of chemicals. An alum dosage of $75\,mg\,L^{-1}$ or a bentonite dosage of $500\,mg\,L^{-1}$ was observed to be adequate in terms of required COD removal efficiencies and sludge characteristics. Schematic flow diagrams of chemical treatment alternatives using alum and bentonite are given in Figs. 1 and 2.

Appropriate treatment that would apply to *raw wastewater* depends upon discharge alternatives. As previously mentioned the wastewater is weak in character and on the average, it satisfies the discharge to sewer conditions. For discharging directly to the receiving waters, a high rate biological treatment (sludge age < 4 days) would be suitable as activated sludge systems are stated to give often more reliable results than chemical treatment when textile finishing wastewaters are considered. A schematic configuration of such a plant is given in Fig. 3. The same alternatives would be equally applicable for the wastewater generated with water conservation (*wastewater B*), although a conventional activated sludge system (sludge age between 4 and 8 days) would be more reliable to treat a COD level of around $1200\,mg\,L^{-1}$ down to acceptable limits.

For *the remaining wastewater* (*wastewater C*) the only treatment alternative is biological processes as typically applicable to textile wastewaters with a sludge age > 8 days and a hydraulic retention time in the range of 15–20 h.

***Table 4.*** Results of chemical treatability.

| Parameter | Alum | | | Sodium bentonite | | |
|---|---|---|---|---|---|---|
| Dosage (mg $L^{-1}$) | 50 | 75 | 100 | 500 | 1,000 | 1,500 |
| Total COD (mg $L^{-1}$) | 55 | 65 | 30 | 75 | 85 | 55 |
| Total COD removal (%) | 69 | 64 | 83 | 58 | 53 | 69 |
| Conductivity (μS $cm^{-1}$) | 600 | 600 | 600 | 580 | 660 | 900 |
| Alkalinity (mg $CaCO_3$ $L^{-1}$) | 50 | 90 | 65 | 155 | 180 | 240 |
| Color (Pt–Co) | 0 | 0 | 0 | 0 | 0 | 0 |
| TDS (mg $L^{-1}$) | 405 | 405 | 400 | 350 | 455 | 615 |
| SVI (mL $g^{-1}$) | 140 | 105 | 105 | 30 | 25 | 15 |
| pH | 6.03 | 6.26 | 6.26 | 7.63 | 7.07 | 7.59 |

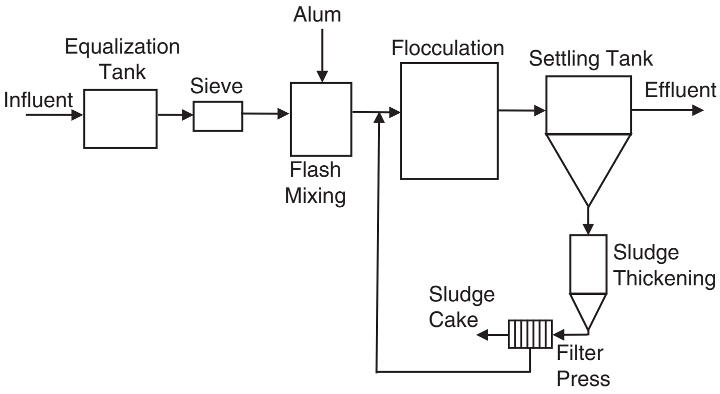

***Figure 1.*** Schematic diagram of chemical treatment using alum.

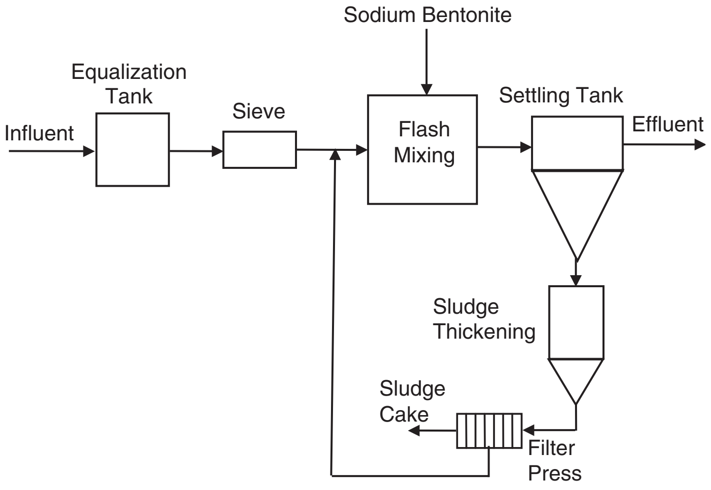

***Figure 2.*** Schematic diagram of chemical treatment using bentonite.

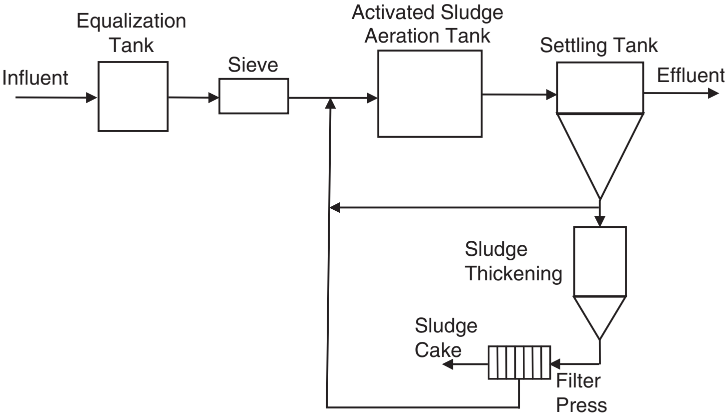

*Figure 3.* Schematic diagram of the activated sludge plant.

*Table 5.* COD fractionation for raw and remaining wastewaters.

| | Raw wastewater (A) | | Remaining wastewater (C) | |
|---|---|---|---|---|
| Influent COD fractions | (mg L$^{-1}$) | (%) | (mg L$^{-1}$) | (%) |
| Total biodegradable COD ($C_{S1}$) | 583 | 85 | 1,244 | 85 |
| Readily biodegradable COD ($S_{S1}$) | 220 | 32 | 485 | 33 |
| Rapidly hydrolyzable COD ($S_{H1}$) | 203 | 30 | 418 | 29 |
| Slowly hydrolyzable COD ($X_{S1}$) | 160 | 23 | 341 | 23 |
| Total inert COD ($C_{I1}$) | 104 | 15 | 216 | 15 |
| Soluble inert COD ($S_{I1}$) | 32 | 5 | 67 | 5 |
| Particulate inert COD ($X_{I1}$) | 72 | 10 | 149 | 10 |
| Total COD ($C_{T1}$) | 687 | | 1,460 | |

The success of biological treatment largely depends on the biodegradable nature of the wastewater. In this context, the data obtained in a previous experimental study indicates that the biodegradable COD accounts for 85% of both raw and remaining wastewaters.[3] Raw and remaining wastewaters have the same ratio of initial soluble inert COD and initial particulate inert COD, 5 and 10%, respectively. Both wastewaters contain hydrolyzable fractions that are similar to each other in percentage. Application of in-plant control practically has no effect on the COD fractionation, although it increases the initial soluble inert COD concentration over 100%. The COD fractions associated with these two type of wastewaters are given in Table 5.

## Feasibility Analysis

The textile mill buys the water from the municipality at a rate of USD 3.00 m$^{-3}$, which also includes the sewer charge, regardless of whether the sewer system is used for discharge or not. The feasibility analysis should include the water charge and the cost of treatment associated with each water management option defined with the relevant in-plant control strategy.

The operating and investment costs involved for the treatment have been requirements for each water management option. Detailed design of different treatment configurations have been made for this purpose. Significant features of the design exercise may be listed as (i) an equalization tank with 1/3 the volume of the daily wastewater flow appropriate for the 3 shift (24 h/day); (ii) mixing of the equalization tank with a submersible pump-ejector system; (iii) a wedge wire type of a static sieve at the outlet of equalization for the removal of fibers before biological treatment; (iv) appropriate selection of the sludge age for activated sludge alternative; (v) mechanical surface aeration of the aeration tank, controlled by dissolved oxygen sensors; (vi) diammonium phosphate feeding in the aeration tank to establish the necessary COD/N/P balance in biological treatment; (vii) a filter press system with a sludge holding tank and lime feeding to ensure 35% dry weight in dewatering; three charges per day for the press filter operation; (viii) a single joint sludge dewatering system for the chemical treatment of the reusable stream and biological treatment of the remaining wastewater.

The detailed cost breakdown of each treatment scheme involved is outlined in Table 6. The analysis presented suggests that there is practically a difference in cost for separate consideration of effluent discharge to sewers or to receiving water as discharge to receiving waters requires a higher treatment efficiency that can be achieved with biological treatment. Consequently, both discharge alternatives were considered for comparison. In this context, the evaluation basically compares three different management options, which translate as *do nothing*; *only conserve water* and *conserve water and reuse a fraction of the wastewater*. Cost implications of the options in both cases are listed in Table 7.

The Net Present Value calculation have been applied to be able to make an appropriate cost analysis. For each of the alternatives the depreciation method have been used linearly on monthly basis and have been deducted as running cost. Monthly libor rate have been applied to calculate the discount factor for the total running cost. Barrowing rate for the total investment cost is assumed to be 8.2% which is 20 year swap rate +3% credit spread. By the same assumption the calculation of the discount factor for the investment cost is done via term structure of the 20 year libor swap curve. Table 8 tabulates the net present values of the investment for both discharges to sewer and to receiving water.

## CONCLUSIONS

The technical and economical feasibility of in-plant control covering water conservation and wastewater recovery and reuse for a wool finishing textile mill is investigated in this study. An examination of the result reveals the following evaluations: By considering discharge to sewers, in the present situation, the daily water consumption of 444 $m^3$ involves a capital investment of $94,057 for the treatment of the wastewater generated and a monthly running cost of $42,668. The price of the water consumed is the major part of the running cost, corresponding

***Table 6.*** Cost breakdown of different treatment schemes.

| Type of WW | Treatment process | Investment costs (USD) | | | | Operation costs (USD $\text{month}^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Construction | Electro-mechanic | Other | Total | Manpower | Chemical | Energy | Total |
| A | Biological[a] | 57,526 | 57,929 | 12,147 | 127,602 | 1,874 | 29 | 765 | 2,668 |
| A | Chemical[b] | 36,910 | 49,000 | 8,147 | 94,057 | 1,874 | 585 | 360 | 2,819 |
| B | Biological[a] | 46,326 | 56,769 | 12,147 | 115,242 | 1,874 | 41 | 765 | 2,680 |
| B | Chemical[b] | 25,258 | 49,000 | 8,147 | 82,405 | 1,874 | 646 | 360 | 2,880 |
| C | Biological[c] | 45,415 | 53,769 | 12,147 | 111,331 | 1,874 | 41 | 765 | 2,680 |
| Reusable | Chemical (alum) | 9,500 | 19,811 | 6,650 | 37,961 | 1,874 | 101 | 270 | 2,245 |
| Reusable | Chemical (bentonite) | 7,500 | 18,595 | 5,650 | 32,109 | 1,874 | 220 | 270 | 2,364 |

[a] Discharge media: receiving water.
[b] Discharge media: sewer.
[c] Discharge media: receiving water or sewer.

*Table 7.* Cost implications of the options.

| | | | | Running costs | | |
|---|---|---|---|---|---|---|
| | Water usage and WW generation | Type of WW treatment | Investment cost for WW treatment (USD) | Operation cost for WW treatment (USD month$^{-1}$) | Water charge (USD month$^{-1}$) | Total running costs (USD month$^{-1}$) |
| Discharge to sewer | | | | | | |
| Present use (wastewater A) | | | | | | |
| Total | 444 | Chemical settling with bentonite | 94,057 | 2,819 | 39,960 | 42,668 |
| Water conservation (wastewater B) | | | | | | |
| Total | 294 | Chemical settling with bentonite | 82,405 | 2,880 | 26,440 | 29,340 |
| Water conservation and WW reuse (wastewater C) | 194 | Biological | 111,331 | 2,680 | 17,460 | 20,140 |
| (Reusable stream) | 100 | Chemical settling with bentonite | 32,109 | 2,364 | — | 2,364 |
| Total | | | 143,440 | 5,044 | 17,460 | 22,504 |
| Discharge to receiving water | | | | | | |
| Present use (wastewater A) | | | | | | |
| Total | 444 | Biological | 127,602 | 2,668 | 39,960 | 42,668 |
| Water conservation (wastewater B) | | | | | | |
| Total | 294 | Biological | 115,242 | 2,680 | 26,440 | 29,120 |
| Water conservation and WW reuse (wastewater C) | 194 | Biological | 111,331 | 2,680 | 17,460 | 20,140 |
| (Reusable stream) | 100 | Chemical settling with bentonite | 32,109 | 2,364 | — | 2,364 |
| Total | | | 143,440 | 5,044 | 17,460 | 22,504 |

*Table 8.* Net present values.

| | Investment cost (USD) | Operation cost (USD month$^{-1}$) | Amortization cost (USD year$^{-1}$) | Amortization cost (USD month$^{-1}$) | NPV of investment (USD) | NPV of investment (USD (kg fabric)$^{-1}$) |
|---|---|---|---|---|---|---|
| Discharge to sewer | | | | | | |
| Present use | 94,057 | 42,668 | 4,703 | 392 | 9,239,668 | 0.23 |
| Water conservation | 82,405 | 29,340 | 4,120 | 343 | 6,397,860 | 0.16 |
| Water conservation and WW reuse | 143,440 | 22,504 | 7,172 | 598 | 5,107,894 | 0.13 |
| Discharge to receiving water | | | | | | |
| Present use | 127,602 | 42,668 | 6,380 | 532 | 9,323,573 | 0.23 |
| Water conservation | 115,242 | 29,120 | 5,762 | 480 | 6,433,566 | 0.16 |
| Water conservation and WW reuse | 143,440 | 22,504 | 7,172 | 598 | 5,107,894 | 0.13 |

to 94% of the monthly expenditure. The capital investment for wastewater treatment represents only a negligible fraction of less than 1% within the overall cost, with the assumption of 20 years service duration for the treatment facility. The unit overall cost may be calculated as $\$262\,t^{-1}$ of fabric processed in the plant.

Water conservation provides an obvious reduction both in the investment cost for treatment and the running costs, bringing down the unit overall cost to $\$180.72\,t^{-1}$ of fabric. This represents a saving of 31.1% or in other terms, an $81.44 reduction of the overall expense per ton of fabric processed.

The clue part of the evaluation is the comparison that will explore the merit of water reuse as a financially feasible option. In fact water reuse option involves a capital investment cost of $61,035 higher than the water conservation alternative, due to the complex nature of the remaining wastewater and the additional treatment of the reusable stream. However, the monthly running cost associated with this option remains at $22,504. Compared to the water conservation alternative, this represents a monthly saving of $6,836, which will pay back the extra capital investment in less than 10 months. This option proves significantly beneficial reducing the unit overall cost to $\$140.78\,t^{-1}$ of fabric, a 25% more less costly solution compared to water conservation alone.

Similar results are also obtained for discharge to receiving water.

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