# AN ECO-FRIENDLY ALTERNATE METHOD OF STONE-WASHING OF INDIGO-DYED DENIM JEANS-GARMENTS

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**Abstract**
The climate change induced by the emissions of greenhouse gases is considered as one of the most important global environmental issues facing the world today. It is now widely recognized as having significant potential to seriously affect the integrity of our ecosystems and human welfare, hence consistent action is required. Cleaner Production could fit in to the drive for a sustainable development by focusing on the economic, environmental and socio-cultural aspects of Cleaner Production which is the case in this study. The objective of this work is to apply the concept of Cleaner Production for the purpose of reducing pollution and minimizing Climate Change, to the Egyptian Textile Wet Processing particularly small and medium-sized enterprises (SMEs). In order to achieve this goal, a case study which was concerned with Eco-friendly stone-washing of jeans-garments was investigated. A raw material-substitution option was adopted whereby the toxic potassium permanganate and sodium sulfide were replaced by the environmentally compatible hydrogen peroxide (60%) and glucose (0.2%) respectively at an operating time of 60min. In addition, a process-rationalization option involving four additional processes (Red/0, Red/Red, Ox/0 and Redox) was investigated. By means of criteria such as: product quality, effluent analysis, material balance, heat balance as well as cost estimation data revealed that the Redox process was the superior and it ought to reduce the annual cost by about $10^5$ EGP relative to the currently used conventional method.
**Keywords:** Climate Change, Sustainability, Cleaner Production, Textile Industry, Textile Wet Processing, Eco-friendly of jeans garments, Stone washing.

## 1. INTRODUCTION

Stone washing is a textiles manufacturing process typically utilized by the fashion industry, in order to give a newly-assembled cloth garments a worn-out appearance. Stone-washing also helps to increase the softness and flexibility of otherwise stiff and rigid fabrics such as canvas and denim. The process does literally use large stones to roughen up the fabric being processed. The garments are placed in a large horizontal industrial clothes washer that is also filled with large rocks. As the wash cylinder rotates, the cloth fibers are repeatedly pounded and beaten as the tumbling stones ride up the paddles inside the drum and fall back down onto the fabric. Stone washing is similar in operation to a ball mill, except that this is a wet process. Stonewashed jeans are jeans that have been treated to produce a faded, worn appearance. This is usually accomplished either by washing the jeans with pumice in a rotating drum, or by using chemicals to create the appearance without the use of a rotating drum. Stonewashed jeans were a popular fashion trend in the 1990s. [1]
An enterprise is considered to be an SME if it has fewer than 250 employees and the annual turnover does not exceed 40 million dollars. A further basic criterion for an enterprise to be characterized as an SME is its independence, meaning that it may not be more than 25 percent owned or controlled by another enterprise or jointly by several enterprises which are not themselves SMEs[2].

Many developing countries are promoting industrialization because it is effective for enrichment of national economy, increase of profit of company, or increase of employment opportunity. But, industrialization can produce high value added products that consume a lot of material, fuel, or energy under good production management; when management is poor, a lot of material, fuel or energy is consumed ineffectively. As a result, it is difficult to attain the objective of industrialization. As industry is one of the biggest pollution sources, Cleaner Production (CP) is a very effective measure to improve poor global environment. In fact, there is no special technology called CP. As the core of CP is to utilize material, fuel energy etc. without loss, effective production activities based on the standardized operation is the basis. The main aim of CP is a production system which does not use harmful material and utilizes material, fuel and energy without loss. As a result, material productivity is improved, profit of company is increased and environmental impact is minimized[3]. CP concepts have been successfully introduced in many companies all over the world. Many countries have established CP and energy efficiency centers to achieve the level needed for the dissemination of cleaner concepts and principles in industry and in society[4]. CP is a forward-looking, 'anticipate and prevent' philosophy. It protects the environment, the consumer and the worker while improving industrial efficiency, profitability, and competitiveness[5]. CP is the continuous application of an integrated preventive environmental strategy to processes, products and services to increase the overall efficiency, and reduce risks to humans and the environment. It can be applied to the processes used in any industry, to products themselves and to various services provided in society[6].

A fabric made at 100% cotton and having twill construction is called denim. Denim having a stone washed appearance is produced without stones by treating with a cellulase enzyme. Unsewn dyed denim fabric or a newly manufactured garment made of dyed denim fabric is contacted with an aqueous composition of cellulase, and subjected to mechanical action. The aqueous may also contain an electrolyte, a buffer, a builder salt a cellulase activator, an antioxidant and a solubilizer[7].

The basic process sequence of denim processing is:

1. Desizing
2. Stone wash/ Enzyme wash
3. Decolorization
4. Neutralization
5. Brightening
6. Finishing[8]

## 2. OVERVIEW OF THE PLANT

The Bio-finishing department in the finishing sector at a plant called Masr in Mahalla El-Kubra. It processes around 300kg of finished jeans fabrics and about 3000 towels per day. The plant works 7 days a week, 3 shifts/day with labor of about 5-7 persons per shift. It is composed of one building located on an area of 300m$^2$. The plant performs the chemical treatments on 100% pure cotton.

## 3. EXPERIMENTAL WORK

### 3.1. Materials

Commercially available 100% cotton substrates, Code No. 4010, code given to the type of cotton according to the enterprise.

Siligen MM (silicon based) and Basoft (fatty softener) were used in the softening process as textile auxiliaries.

Potassium permanganate, sodium sulfide, hydrogen peroxide (35%), glucose, detergent and sodium carbonate, all of reagent grade, were used.

### 3.2. Tests

As Cleaner Production is concerned with both process and product, its testing procedures will fall into two main categories:

#### 3.2.1. Product Testing

**1. Color Strength**

The color strength of dyed fabric samples, expressed as K/S values, was determined as described elsewhere[9].

**2. Tensile Strength and Elongation at Break**[10]

**3. Percent Loss in Weight**

Weight loss was expressed as percentage of the initial dry weight.

**4. Wettability**[11]

It is the time required for a drop of water to be absorbed into the fabric.

**5. Abrasion Resistance**[12]

**6. Crease Recovery Angle**[13]

**7. Stiffness**[14]

**8. Fabric pH-value**

The procedure of this test is based on ISO Test method ISO3073-1980(E).

### 3.2.2. Effluent Testing

**1. Effluent pH-value**

**2. Chemical Oxygen Demand, COD test**[15]

COD was analyzed by the potassium dichromate closed reflux method.

**3. Biological Oxygen Demand, BOD test**[15]

BOD was analyzed using the closed reflux , colorimetric method.

**4. Total Suspended Solids, TSS test**[15]

After drying at 103 – 105$^{o}$C.

**5. Total Dissolved Solids, TDS test**[15]

## 3.3. Methods

### 3.3.1. State-of-the-Art

The currently adopted process of jeans garments finishing –herewith identified as the conventional process (Conv) – is outlined by the simplified flow diagram shown in Fig. (1). It runs as follows: First, the machine is filled with pumice stones (imported from Turkey with a size of 1-3, 2-4, or 4-6 cm). Then, the stones are partially wetted by potassium permanganate (1kg/3liters). This procedure involves three successive stages with repeated stirring. The machine is now ready to be loaded with the untreated garments (20kg).

After 45 minutes of continuous stirring, the garments are removed from the machine and washed on cold for 5 minutes, then washed with sodium sulfide (reducing agent) (3%owf) for 10 minutes at 60$^{o}$C. Then, they are washed again on cold using a non-ionic wetting agent (2g/l) at 70$^{o}$C for 10 minutes. Another washing step, on cold, is performed to be followed by a softening step where a softener (3%owf) is added at 45$^{o}$C for 10 minutes. Finally, garments so treated are taken to the centrifuge to dry out.

### 3.3.2. Modifications

Raw material-substitution, one of the CP options, was chosen to be implemented in this plant since the conventionally used raw materials namely; potassium permanganate and sodium sulfide are dangerous and toxic. Potassium permanganate is a strong oxidizer that acts as a corrosive agent the pernicious effects of which include: eye irritation, skin stains, cancer if inhaled, and toxicity if swallowed. Likewise, the reducing agent of sodium sulfide is a corrosive (to pipelines) chemical that causes skin allergy, burning of skin, irritates eyes, coughing, wheezing and/or shortness of breath. Both potassium permanganate and sodium sulfide are on the Hazardous Substance List as the former is regulated by OSHA[1] whereas the latter is on the Special Health Hazard Substance List and cited by DOT[2] and NFPA[3]. Since

[1] Occupational Safety and Health Administration

[2] Department of Transportation, the federal agency that regulates the transportation of chemicals

these two materials have harmful effects on the employees, customers as well as the environment, huge quantities of washing water are usually used to get rid of them. The raw materials substitution option in this case can provide better circumstances in terms of cost, process efficiency, and reduced health and safety related hazards. In addition it requires moderate investments to be put in as well as moderate technology.

The proceedings took on two stages as follows:

### 3.3.2.1. Chemical Modification

This is primarily a raw materials substitution option where potassium permanganate and sodium sulfide are respectively substituted by hydrogen peroxide and glucose [Table (1)]. This requires a decision as to both the concentration of commercial 35% $H_2O_2$ (glucose was used as 2g/l) and the length of the operating time. Resorting to %color strength as indicator for product quality and to COD for effluent analysis, their values were obtained with the following two series:

a- 20, 40, 60 and 80% $H_2O_2$ at an arbitrary time of 45min.

b- 30, 45, 60 and 75min at an arbitrary $H_2O_2$ concentration of 60%.

It is worth noting that below those ranges there was no remarkable effect on the jeans garments and above the range of the $H_2O_2$ concentration, the garments were damaged while above the 75min there was no change in garment properties.

The two values so obtained (see Results and Discussion) for time and $H_2O_2$ concentration were used to test for 10 properties of product quality and 5 properties of effluent analysis by the same procedure adopted by the conventional method and the results are to be denoted by (Ox/Red) meaning that oxidation takes place in step I by $H_2O_2$ and reduction in step III by glucose.

**Table (1):** The material substitution option adopted.

| | Raw Materials | | Operating Time (min) |
|---|---|---|---|
| | **Oxidizing Agent** | **Reducing Agent** | |
| **Conv** | **Potassium Permanganate** ($KMnO_4$) (3%owf) | **Sodium Sulfide** (3%owf) | 45 |
| **Ox/Red** | **Hydrogen Peroxide** ($H_2O_2$) (20, 40, 60 and 80%)* | **Glucose** (2g/l) in presence of **Sodium Carbonate** ($Na_2CO_3$) (2g/l) | 30, 45, 60 and 75 |

***** Equivalent to 200, 400, 600 and 800ml of commercial $H_2O_2$ (35%) per liter solution. Two and a half liters of solution were used in each case.

### 3.3.2.2. Process Modification

An additional CP option, Process Rationalization, was chosen to be undertaken at the process conditions of both concentration and time (c.f. Results and Discussion). This option was implemented by applying the following four processes:

i. Oxidation process only **(Ox/0)**, where steps III and IV in Fig. (1) are eliminated and $H_2O_2$ is used in step I.

ii. Reduction process only **(Red/0),** where steps III and IV in Fig. (1) are eliminated and glucose in presence of sodium carbonate is used in step I in Fig. (1).

[3] National Fire Protection Association

iii. Reduction/Reduction process **(Red/Red)**, where glucose in presence of sodium carbonate is used in both steps I and III in Fig. (1).

iv. Combined oxidation/reduction process **(Redox)**, where steps I and III in Fig. (1) are merged together leading to Fig. (2).

## 4. RESULTS AND DISCUSSION

### 4.1. Evaluating the $H_2O_2$ Concentration and Operating Time

Although the chemical modification involves both the oxidant ($H_2O_2$ in lieu of $KMnO_4$) and the reductant (glucose in lieu of $Na_2S$) the latter is to be used in conjunction with $Na_2CO_3$ each at a fixed concentration of 2g/l. As for the oxidant, $H_2O_2$, The outcome is better appreciated pictorially through Figures (3) and (4), where color strength (a product quality property) and COD (effluent analysis property) are shown to vary with $H_2O_2$ concentration.
Since the employed product quality improves with decreasing color strength, it is clear from Figure (3) that the minimum $H_2O_2$ concentration of 60% satisfies this condition. Figure (4) also shows that this same concentration minimizes COD in the effluent, which is environmentally desirable.

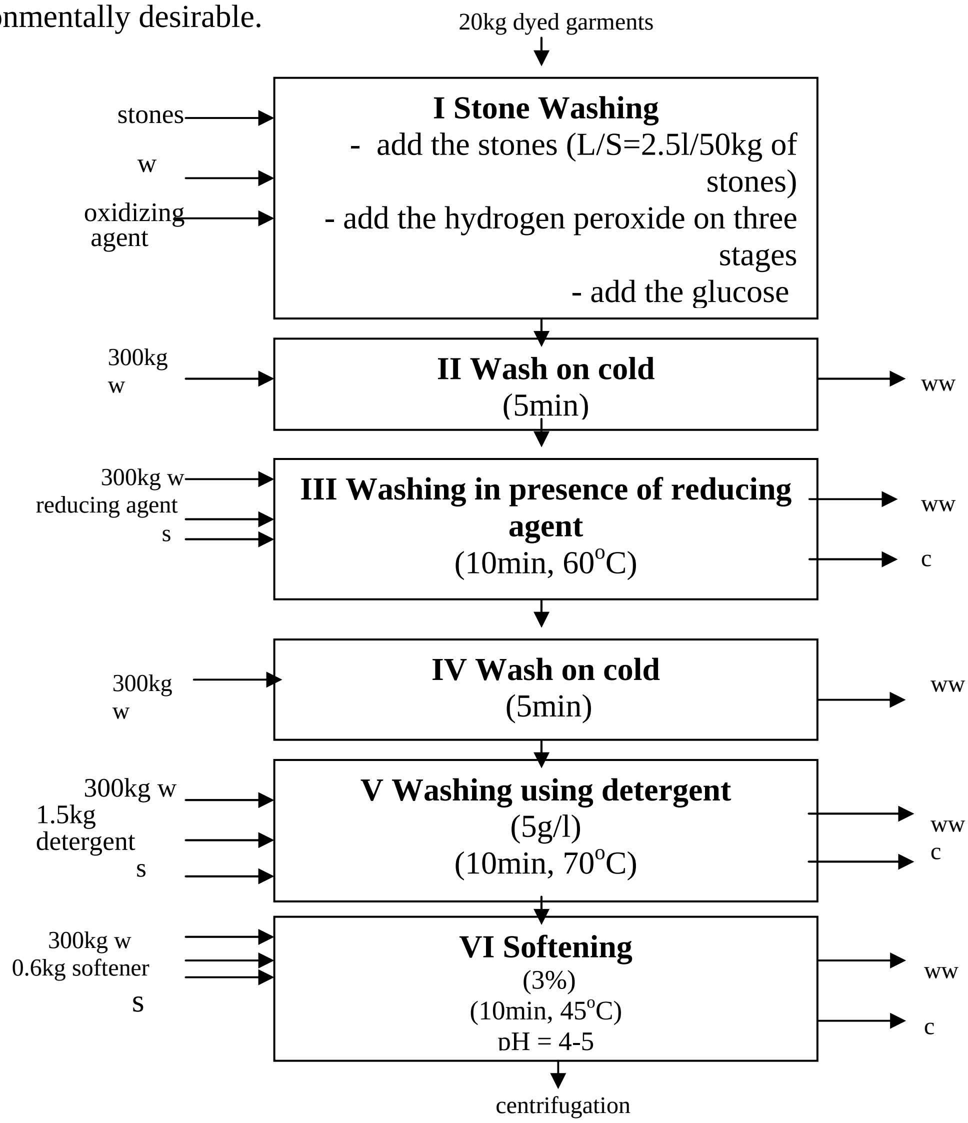



**Fig (1):** Flow diagram of stone washing of jeans garments per a batch of 20kg
(where: w: water, s: steam, ww: wastewater and c: condensate)

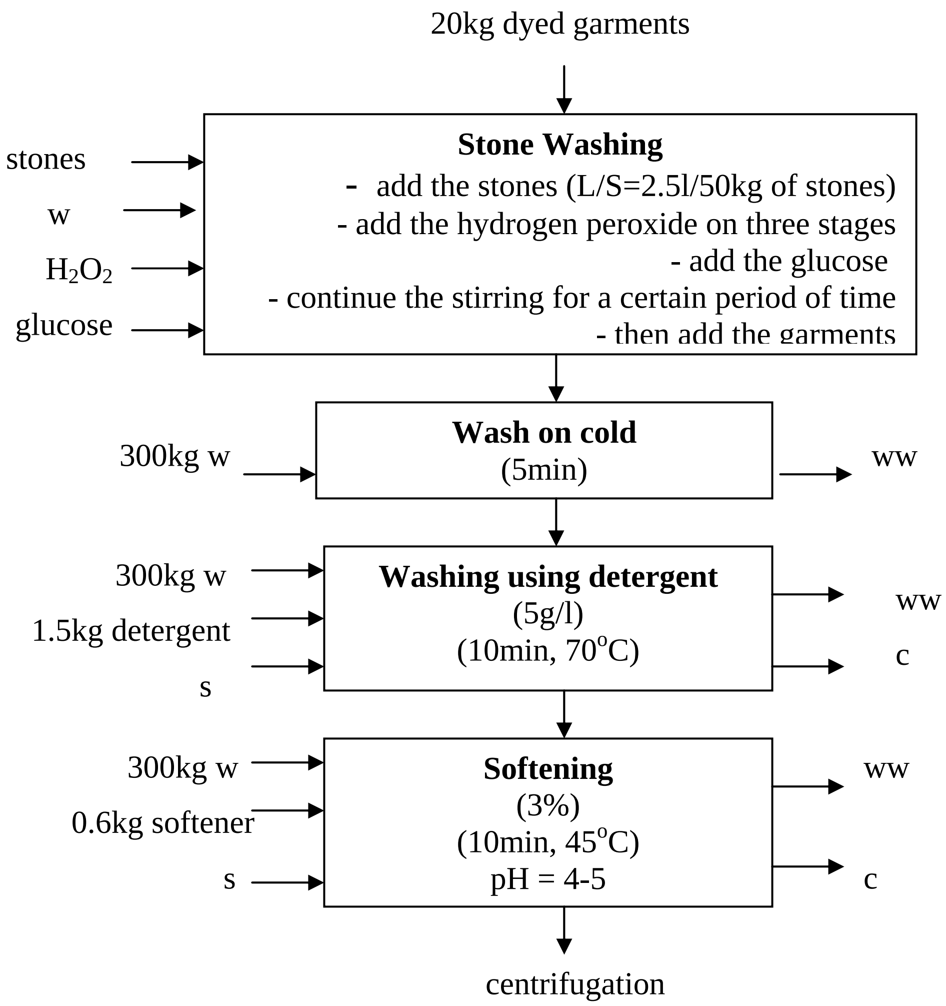



**Fig (2):** Flow diagram of stone washing of jeans garments by the Redox process per a batch of 20kg (where: w: water, s: steam, ww: wastewater and c: condensate)

The above two indicators were also used to pin point the operating time. From Figures (5) and (6) it is deduced that 60minutes is the appropriate operating time to be used.

As shown in Figures (3) and (5), both the percentage of hydrogen peroxide concentration and time, both decreased the percentage of color strength. At 60% $H_2O_2$ concentration and at operating time of 60min, the change in color strength was almost negligible as no remarkable change has occurred, which indicates that the aforementioned conditions are the optima.

It is clear from Figures (4) and (6) that the COD content increases as both the H2O2 concentration and time increase and the minimum values of COD are deduced to be at 60% $H_2O_2$ and 60min. It should be noted that the sudden and huge increase in COD that takes place as shown in the same figures is probably due to the decomposition of the garments into minute fibers as a result of the oxidizing agent over time.

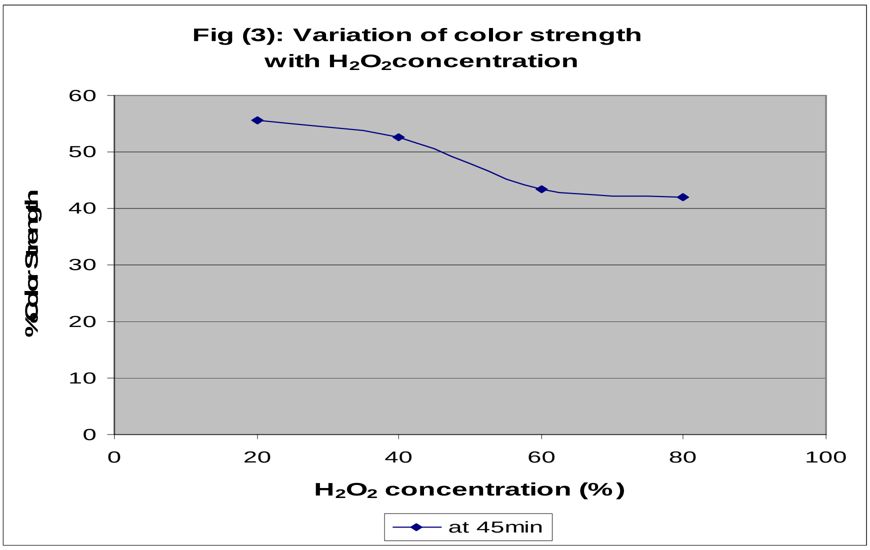


Fig (3): Variation of color strength with H2O2concentration
60
50
40
30
20
10
0
%Color Strength
0
20
40
60
80
100
H2O2 concentration (%)
at 45min

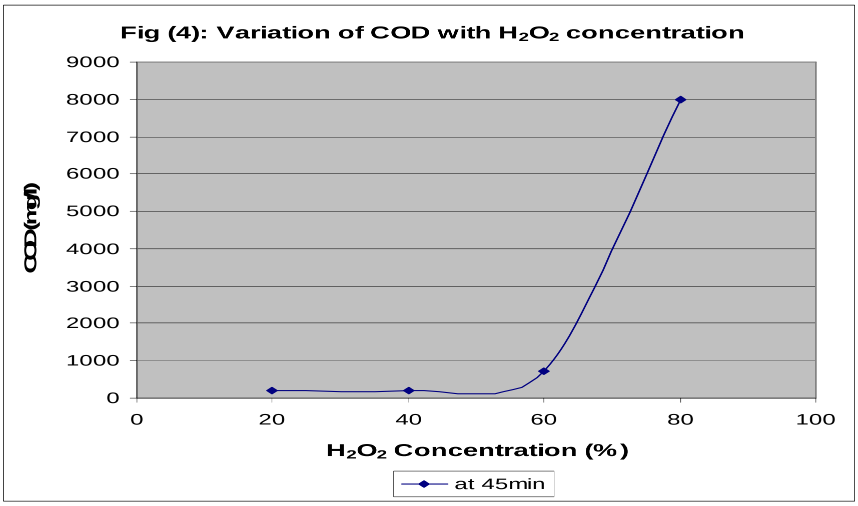
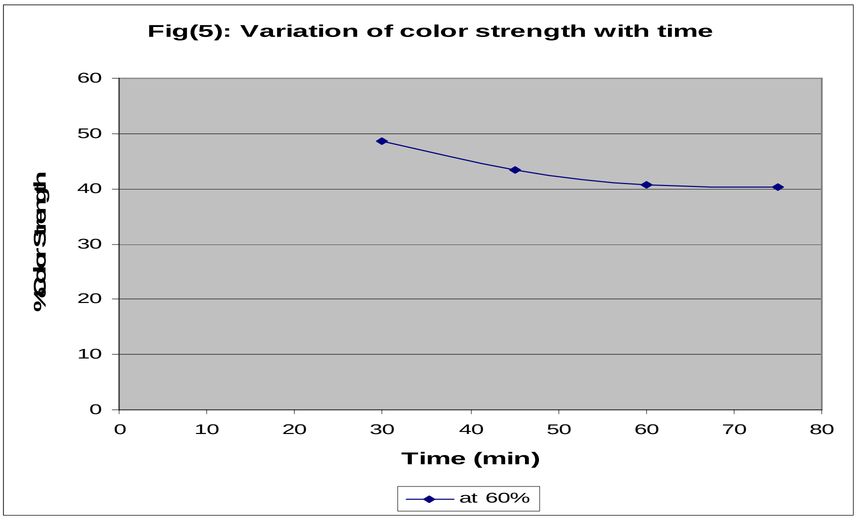
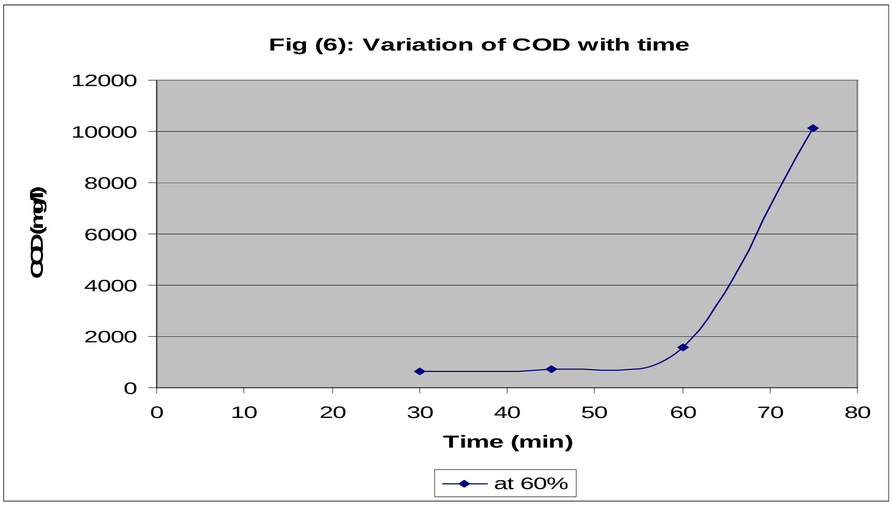


Fig (4): Variation of COD with H2O2 concentration
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
COD(mg/l)
0
20
40
60
80
100
H2O2 Concentration (%)
at 45min


Fig(5): Variation of color strength with time
60
50
40
30
20
10
0
%Color Strength
0
10
20
30
40
50
60
70
80
Time (min)
at 60%




## 4.2. Searching for a Suitable Process

This will be investigated in light of the data obtained for the relevant factors affecting the choice of the process, namely:

- properties of both product quality (jeans garments tests) and effluent analysis (wastewater tests) as shown in Table (2),
- Mass balance (MB) for the various treatments in Table (3),
- Energy balance (EB) data in Table (4), and
- Cost analysis data in Table (5).

**Table (2):** Product quality and effluent analysis for the different treatments.

| | Property | Treatments | | | | | |
|---|---|---|---|---|---|---|---|
| | | Conv | Ox/Red | Ox/0 | Red/0 | Red/Red | Redox |
| Product Quality | %Color Strength | 43.8 | 40.6 | 42.3 | 44.4 | 46.5 | 27.2 |
| | %Loss in Weight | 11.3 | 10.02 | 12.5 | 8.5 | 15.02 | 7.1 |
| | Wettability (sec) | 60.0 | 10.0 | 13.0 | 20..0 | 4.0 | 8.0 |
| | %Elongation | 18.0 | 22.0 | 19.0 | 17.0 | 21.0 | 20.0 |
| | Tensile Strength(kg) | 71.5 | 74.0 | 72.0 | 54.0 | 75.5 | 83.0 |
| | Abrasion Resistance (cycles) | 3721.0 | 4397.0 | 5143.0 | 5962.0 | 7567.0 | 6782.0 |
| | Crease Recovery Angle (dry) | 75.0 | 95.0 | 98.0 | 89.0 | 72.0 | 104.0 |
| | Crease Recovery Angle (wet) | 125.0 | 167.0 | 210.0 | 130.0 | 153.0 | 238.0 |
| | Stiffness (mgm) | 3916.0 | 2848.2 | 3983.1 | 3382.0 | 3203.6 | 5198.2 |
| | pH-value | 7.4 | 8.1 | 7.2 | 8.6 | 9.0 | 6.7 |
| Effluent | COD(mg/l) | 995.1 | 1559.8 | 3541.0 | 2993.2 | 3452.0 | 480.2 |
| | BOD(mg/l) | 300.2 | 890.3 | 2533.2 | 1996.5 | 2184.6 | 197.9 |
| | TDS(mg/l) | 2578.9 | 6529.2 | 4098.0 | 3691.6 | 3875.4 | 2391.0 |
| | TSS(mg/l) | 1489.8 | 5271.7 | 3374.4 | 2864.0 | 3162.1 | 1372.3 |
| | pH | 5.8 | 7.2 | 6.9 | 7.5 | 7.9 | 6.5 |

***Blank sample***

%Loss in Weight : 10.48
Wettability (sec) : 63.00
%Elongation : 24.00
Tensile Strength (kg) : 86.00
Abrasion Resistance (cycles) : 6782.00
Crease Recovery Angle (dry) : 63.00
Crease Recovery Angle (wet) : 110.00
Stiffness (mgm) : 5235.00

**Table (3):** MB per a batch of 20 kg for the different treatments.

| | | Treatments | | | | | |
|---|---|---|---|---|---|---|---|
| | | Conv | Ox/Red | Ox/0 | Red/0 | Red/Red | Redox |
| Inputs (kg) | Fabrics | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| | W | 1802.5 | 1801.0 | 1201.0 | 1202.5 | 1802.5 | 1201.0 |
| | Oxidizer | 1.0 | 1.5 | 1.5 | - | - | 1.5 |
| | Reducer | 0.6 | 0.6 | - | 0.6 | 1.2 | 0.6 |
| | Detergent | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |
| | $Na_2CO_3$ | - | 0.6 | - | 0.6 | 0.6 | 0.6 |
| | Softener | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| | Steam | 57.8 | 58.14 | 37.5 | 37.4 | 58.0 | 37.5 |
| | **Total** | **1884.0** | **1883.9** | **1262.1** | **1263.2** | **1884.4** | **1263.3** |
| Outputs (kg) | Wet fabrics | 38.0 | 38.0 | 38.0 | 38.0 | 38.0 | 38.0 |
| | WW+Ch | 1785.7 | 1786.8 | 1185.6 | 1185.3 | 1785.9 | 1186.8 |
| | C | 57.8 | 58.1 | 37.5 | 37.4 | 58.0 | 37.5 |
| | Losses | 2.5 | 1.0 | 1.0 | 2.5 | 2.5 | 1.0 |
| | **Total** | **1884.0** | **1883.9** | **1262.1** | **1263.2** | **1884.4** | **1263.3** |

*where:* W: water; WW: Wastewater; C: Condensate; Ch: Chemicals; WW + Ch: Wastewater + chemicals

**Table (4):** EB per a batch of 20 kg for the different treatments.

| | | Treatments | | | | | |
|---|---|---|---|---|---|---|---|
| | | Conv | Ox/Red | Ox/0 | Red/0 | Red/Red | Redox |
| Inputs(*$10^3$kcal | Fabrics | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 |
| | W+Ch | 45.20 | 45.10 | 30.10 | 30.14 | 44.15 | 30.14 |
| | Vapor | 38.50 | 38.70 | 25.00 | 24.90 | 38.54 | 25.00 |
| | **Total** | **83.86** | **83.96** | **55.40** | **55.20** | **83.90** | **55.30** |
| Outputs(*$10^3$kcal) | Wet fabrics | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |
| | WW | 74.40 | 74.50 | 48.91 | 48.90 | 74.42 | 48.96 |
| | C | 5.80 | 5.80 | 3.80 | 3.70 | 5.80 | 3.80 |
| | Losses | 3.20 | 3.10 | 1.90 | 2.10 | 3.10 | 2.00 |
| | **Total** | **83.86** | **83.96** | **55.20** | **55.20** | **83.90** | **55.30** |

**Table (5):** Cost analysis data (EGP) per a batch of 20 kg for the different treatments.

| Treatments | | | | | | |
|---|---|---|---|---|---|---|
| Redox | Red/Red | Red/0 | Ox/0 | Ox/Red | Conv | Chemicals |
| 1.2 | 1.8 | 1.2 | 1.2 | 1.8 | 1.8 | Water |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| - | - | - | - | - | 30.0 | **$KMnO_4$** | **Chemicals** |
| - | - | - | - | - | 2.4 | **$Na_2S$** | |
| 10.5 | - | - | 10.5 | 10.5 | - | **$H_2O_2$** | |
| 1.4 | 2.9 | 1.4 | - | 1.4 | - | **Glucose** | |
| 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 | **Detergent** | |
| 1.5 | 1.5 | 1.5 | - | 1.5 | - | **$Na_2CO_3$** | |
| 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | 9.0 | **Softener** | |
| 3.0 | 3.5 | 3.0 | 3.0 | 3.5 | 3.0 | **Energy*** | |
| **34.1** | **26.2** | **23.6** | **31.2** | **35.2** | **53.7** | **Total** | |

* at 15 HP (horsepower) machine (=15*0.75 KW)

**Table (6):** Percent changes for the different treatments with respect to Ox/Red process.

| | Property | Treatments | | | |
|---|---|---|---|---|---|
| | | Ox/0 | Red/0 | Red/Red | Redox |
| Quality | %Color Strength | +4.1 | +9.3 | +14.5 | **-33.0** |
| | %Loss in Weight | +24.8 | -15.2 | +49.9 | **-29.2** |
| | Wettability (sec) | +30.0 | +100.0 | **-60.0** | -20.0 |
| | %Elongation | -13.6 | -22.7 | **-4.5** | -9.1 |
| | Tensile Strength(kg) | -2.7 | -27.0 | +2.0 | **+12.2** |
| | Abrasion Resistance (cycles) | +17.0 | +35.6 | +72.1 | **+54.2** |
| | Crease Recovery Angle(dry) | +3.2 | -6.3 | -24.2 | **+9.5** |
| | Crease Recovery Angle(wet) | +25.7 | -22.2 | -8.4 | **+42.5** |
| | Stiffness (mgm) | +39.9 | +18.8 | +12.5 | **+82.5** |
| | pH-value | -11.1 | +6.3 | +11.1 | **-17.3** |
| Effluent Analysis | COD(mg/l) | +127.0 | +91.9 | +121.3 | **-69.2** |
| | BOD(mg/l) | +184.6 | +124.3 | +145.5 | **-77.8** |
| | TDS(mg/l) | -37.2 | -43.5 | -40.6 | **-63.4** |
| | TSS(mg/l) | -36.0 | -45.7 | -40.0 | **-74.0** |
| | pH | -3.6 | +4.7 | +10.3 | **-9.2** |
| Material Balance | | **-33.00** | **-32.90** | +0.03 | **-32.9** |
| Energy Balance | | **-34.30** | **-34.30** | -0.07 | **-34.10** |
| Cost Estimate | | -11.50 | **-33.00** | -25.70 | -3.10 |

**Table (7):** Mean and standard deviation values of the studied factors for the different treatments.

| | Property | Treatments | |
|---|---|---|---|
| | | Mean Value | Standard Deviation |
| Quality | %Color Strength | 40.800 | 6.953 |
| | %Loss in Weight | 10.740 | 2.847 |
| | Wettability (sec) | 17.667 | 21.805 |
| | %Elongation | 19.500 | 1.871 |
| | Tensile Strength(kg) | 71.666 | 9.600 |
| | Abrasion Resistance (cycles) | 5595.333 | 1454.911 |
| | Crease Recovery Angle(dry) | 88.833 | 12.860 |
| | Crease Recovery Angle(wet) | 170.500 | 45.046 |
| | Stiffness (mgm) | 3755.200 | 827.781 |
| | pH-value | 7.833 | 0.882 |

| | | | |
|---|---|---|---|
| Effluent Analysis | COD(mg/l) | 2170.167 | 1327.352 |
| | BOD(mg/l) | 1350.417 | 1015.468 |
| | TDS(mg/l) | 3860.667 | 1483.750 |
| | TSS(mg/l) | 2922.333 | 1431.146 |
| | pH | 6.973 | 0.735 |
| Material Balance | | 1573.4830 | 340.2638 |
| Energy Balance | | 69.6033 | 15.6687 |
| Cost Estimate | | 34.0000 | 10.6431 |

In all these Tables, it is to be noted that the slash used in the caption of the treatment separates between steps I and III in the process of stone-washing as outlined in Fig. (1) thus (Ox/Red) implies that $H_2O_2$ was used in step I and glucose was used in step III.

### 4.2.1. The Chemical Substitution Option

This appertains only to the (Ox/Red) treatment since it is clearly carried out by the same procedure as the conventional method (Conv) with the new materials. Relative to (Conv) this option shows no significant difference as far as MB and EB [Tables (4) and (5)]. However, striking differences are presented by cost-estimate (about 34% reduction) [Table (6)] and the property tests in Table (2). Most prominent are those belonging to effluent which were undesirably augmented. As to the product quality, it should be noted that of the ten properties used the top three improve through declining. While this decline is shown to be great with wettability it is slight with the other two properties. Whereas the increase exhibited by the next five quality properties in Table (2) is desirable that of pH is not; and the decrease in stiffness is in the wrong direction. These results necessitate modifying the process.

### 4.2.2. Process Rationalization

The other four treatments in Tables (2 thru 5) are modifications on the process. Thus, (Ox/0) and (Red/0) are two treatments in which steps III and IV of the stone-washing process lack application of either $H_2O_2$ or glucose. In the (Red/Red) treatment glucose was applied both in step I and step III. These two steps are merged together in the (Redox) process [Fig. (2)].

If we are to compare anyone of these four treatments with the conventional process (Conv) as was done with (Ox/Red) we ought to realize that the difference now reflects not only the effect of chemical substitution but also that of process modification.

On the basis of MB and EB tests alone, we may reject the (Red/Red) process even though it entails saving of about one half of the cost of (Conv). Appealing now to the effluent-analysis tests, two additional processes, (Ox/0) and (Red/0), will be rejected on account of environmental hazard. This leaves the (Redox) process, which shows also superior product quality properties (except maybe for %elongation), to claim preference to the conventional method.

Both the mean and the standard deviation values of the studied factors for the different treatments are shown in Table (7).

### 4.2.3. The Process Modification Option

Replacing the conventional method by the (Ox/Red) process as a basis of comparison, the outcome ought to reflect solely the effect of modifying the process. For that purpose the relevant data in Tables (2 thru 5) were expressed in terms of (Ox/Red) as a frame of reference and the results were recorded in Table (6) as percent changes due to process modification. The most striking feature in this Table is presented by the effluent analysis test where the (Redox) modification is shown to be superior to all others, an environmentally desirable objective.

With respect to jeans garments quality tests the (Redox) process appears to maintain superiority with all properties except for %elongation and wettability.

Therefore, the (Redox) modification is our preferred choice notwithstanding the fact that the three other processes surpassed it in reducing the cost.

Relative to the currently used conventional method, the saving may be of the order of EGP $10^5$ per year.

## 5. CONCLUSIONS AND RECOMMENDATIONS

For the stone-washing process of jeans-garments:

- Regarding the raw material substitution option, the conditions of $H_2O_2$ and time were experimentally determined to be 60% and 60min.
- Concerning process rationalization, the Redox process was found to be the most favorable among the other tested processes (Ox/0, Red/0 and Red/Red).
- By the superior process, the cost saving per annum was found to be EGP of $10^5$ assuming a plant working days 300days/annum and a raw material consumption rate of 300kg/day.
- In light of the above observations, it is thus recommended to employ the Redox process.

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