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A Multiple-Objective Environmental Rationalization and Optimization for Material Substitution in the Production of Stone-Washed Jeans- Garments

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Abstract**—**As the Textile Industry is the second largest industry in Egypt and as small and medium-sized enterprises (SMEs) make up a great portion of this industry therein it is essential to apply the concept of Cleaner Production for the purpose of reducing pollution. In order to achieve this goal, a case study 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 and glucose respectively where the concentrations of both replaced chemicals together with the operating time were optimized. In addition, a process-rationalization option involving four additional processes was investigated. By means of criteria such as product quality, effluent analysis, mass and heat balance; and cost analysis with the aid of a statistical model, a process optimization treatment revealed that the superior process optima were 50%, 0.15% and 50min for H_2O_2 concentration, glucose concentration and time, respectively. With these values the superior process ought to reduce the annual cost by about EGP 10^5 relative to the currently used conventional method.

Keywords**—**Cleaner Production, Eco-friendly of jeans garments, Stone washing, Textile Industry, Textile Wet Processing.

I. INTRODUCTION

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 [1]. 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 [2]. 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 [3]. 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 [4]. 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 [5]. A fabric made at 100% cotton and having twill construction is called denim.

The basic process sequence of denim processing is:

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

II. 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

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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.

III. EXPERIMENTAL WORK

A. Materials

Commercially available 100% cotton substrates, Code No. 4010.

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.

B. Tests

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

Product Testing

- *Color Strength*

The color strength of dyed fabric samples, expressed as K/S values, was determined as described elsewhere [7].

- *Tensile Strength and Elongation at Break* [8]

- *Percent Loss in Weight*

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

- *Wettability* [9]

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

- *Abrasion Resistance* [10]

- *Crease Recovery Angle* [11]

- *Stiffness* [12]

- *Fabric pH-value*

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

Effluent Testing

- *Effluent pH-value*

- *Chemical Oxygen Demand COD test* [13]

COD was analyzed by the potassium dichromate closed reflux method.

- *Biological Oxygen Demand BOD test* [13]

BOD was analyzed using the closed reflux, colorimetric method.

- *Total Suspended Solids TSS test* [13]

After drying at 103 – 105°C.

- *Total Dissolved Solids TDS test* [13]

C. Methods

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). 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°C. Then, they are washed again on cold using a non-ionic wetting agent (2g/l) at 70°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°C for 10 minutes. Finally, garments so treated are taken to the centrifuge to dry out.

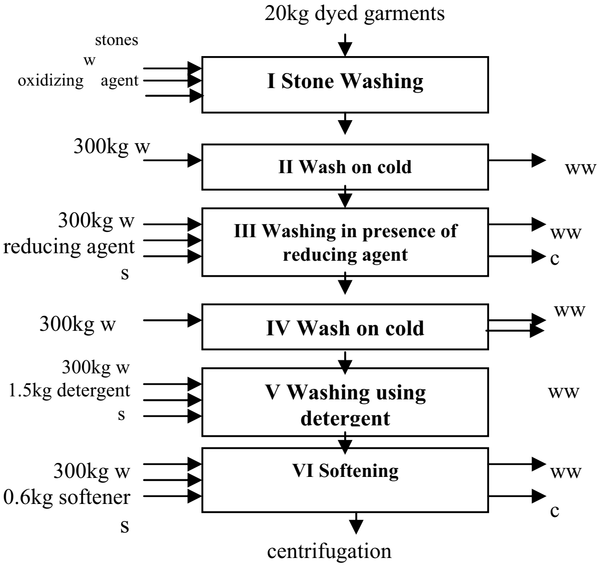

Fig. 1 Flow diagram of stone washing of jeans garments (where: w: water, s: steam, ww: wastewater and c: condensate)

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 (Occupational Safety and Health Administration) whereas the latter is on the Special Health Hazard Substance List and cited by DOT (Department of Transportation, the federal agency that regulates the transportation of chemicals) and NFPA (National Fire

Protection Association). Since 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.

TABLE I
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.

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.

i. 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.
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.

ii. Finding Optima for the Redox Process

Anticipating the outcome to be presented in the forthcoming 'Results and Discussion' section, the Redox process proved to be superior to all others with even over-qualified results. This raises the question of whether optimizing for this process will be beneficial. The relation to be optimized may be epitomized in the following function:

$$CS = f\,[T, (H_2O_2), (G)] \qquad (1)$$

where:

- the dependent variable on the LHS, is the %color strength as indicator of product quality,
- the three independent variables on the RHS, are the operating time (min) T; concentration of the oxidant % (H_2O_2) and that of the reductant % glucose (G).

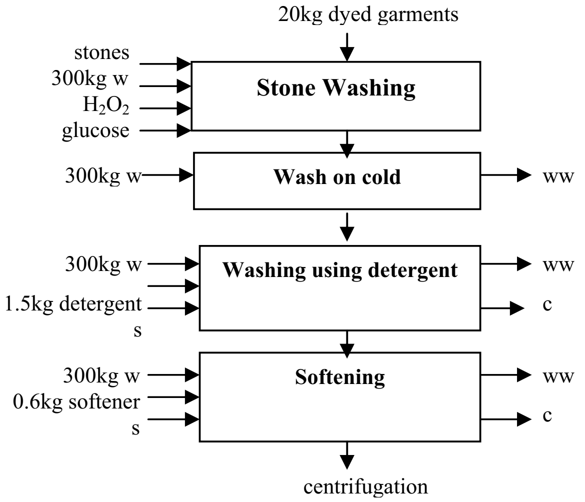

Fig. 2 Flow diagram of stone washing of jeans garments by the Redox process
(where: w: water, s: steam, ww: wastewater and c: condensate)

Inclusion of other independent factors such as amount of stone and temperature was deemed unwarranted on account of the fact that the former was found to be insignificant and the latter was kept constant so as not to destroy the stones.

A statistical model due to Kafarov et al. [14] was adopted for the purpose. It makes use of a full factorial design and the Steepest Ascent technique. A full factorial design is one in which all possible combinations (N) of the factors (k) at all levels (n) in the experiment are used. For relation (1) k=3, the number of independent variables each of which was rested at two levels, i.e, n=2.

From the formula:

$$N = n^k \qquad (2)$$

The number of all possible combinations (N) to be performed during the experiment is obviously 8 (2^3). The resulting design matrix may be tabulated as shown in Table (2) next section.

IV. RESULTS AND DISCUSSION

A. 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 Figs. 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 Fig. 3 that the minimum H_2O_2 concentration of 60% satisfies this condition. Fig. 4 also shows that this same concentration minimizes COD in the effluent, which is environmentally desirable

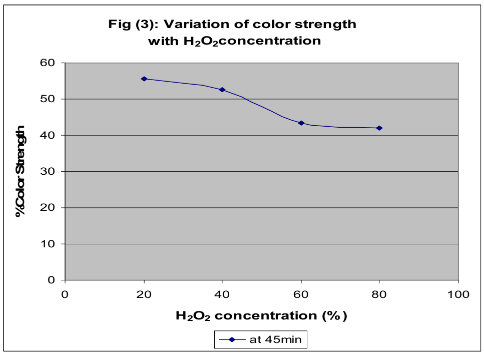

Fig. 3 Variation of color strength with H_2O_2 concentration

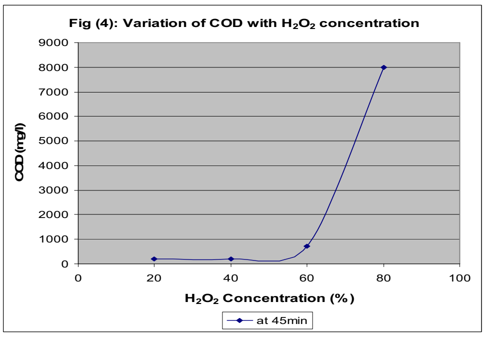

Fig. 4 Variation of COD with H_2O_2 concentration

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

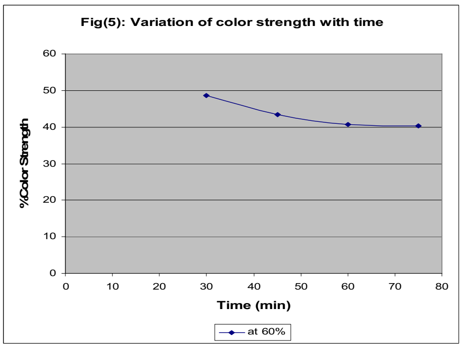

Fig. 5 Variation of color strength with time

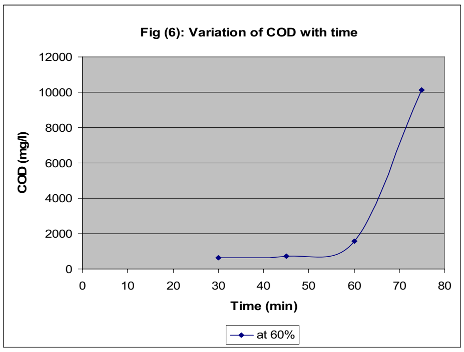

Fig. 6 Variation of COD with time

B. *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 II,
- Mass balance (MB) for the various treatments in Table III,
- Heat balance (HB) data in Table IV, and
- Cost analysis data in Table V.

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

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.

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 HB [Tables III and IV]. However, striking differences are presented by cost-estimate (about 34% reduction) [Table IV] and the property tests in Table II. 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 II is desirable that of pH is not; and the decrease in stiffness is in the wrong direction. These results necessitate modifying the process.

TABLE II
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)	37 21.0	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)	39 16.0	2848.0	3983.0	3382.0	3204.0	5198.2
	pH-value	7.4	8.1	7.2	8.61	9.0	6.7
Effluent Analysis	COD(mg/l)	9 95.0	1 560.0	3541.0	2993.0	3452.0	480.0
	BOD(mg/l)	300.0	890.0	2533.0	1996.5	2185.0	198.0
	TDS(mg/l)	2579.0	6 529.0	4098.0	3692.0	3875.0	2391.0
	TSS(mg/l)	14 90.0	5 272.0	3374.0	2864.0	3162.0	1372.0
	pH	5.84	7.2	6.9	7.5	7.9	6.5

TABLE III
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**

* WW+Ch: wastewater and chemicals

TABLE IV
HB PER A BATCH OF 20 KG FOR THE DIFFERENT TREATMENTS

		Treatments					
		Conv	**Ox/Red**	**Ox/0**	**Red/0**	**Red/Red**	**Redox**
Inputs(*10^3kcal)	**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(*10^3kcal)	**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**

* W+Ch: water and chemicals

TABLE V
COST ANALYSIS DATA (EGP) PER A BATCH OF 20 KG FOR THE DIFFERENT TREATMENTS

		Treatments					
Chemicals		**Conv**	**Ox/Red**	**Ox/0**	**Red/0**	**Red/Red**	**Redox**
Water		1.8	1.8	1.2	1.2	1.8	1.2
Chemicals	**$KMnO_4$**	30.0	-	-	-	-	-
	Na_2S	2.4	-	-	-	-	-
	H_2O_2	-	10.5	10.5	-	-	10.5
	Glucose	-	1.4	-	1.4	2.9	1.4
	Detergent	7.5	7.5	7.5	7.5	7.5	7.5
	Na_2CO_3	-	1.5	-	1.5	1.5	1.5
	Softener	9.0	9.0	9.0	9.0	9.0	9.0
Energy*		3.0	3.5	3.0	3.0	3.5	3.0
Total		**53.7**	**35.2**	**31.2**	**23.6**	**26.2**	**34.1**

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

TABLE VI
PERCENT CHANGES FOR THE DIFFERENT TREATMENTS WITH RESPECT TO OX/RED PROCESS

	Property	**Treatments**			
		Ox/0	**Red/0**	**Red/Red**	**Redox**
Product 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**
Heat Balance		**-34.30**	**-34.30**	-0.07	**-34.10**
Cost Estimate		-11.50	**-33.00**	-25.70	-3.10

TABLE VII
EXPERIMENTAL VALUES FOR THE STUDIED VARIABLES AND THEIR CORRESPONDING CODED VALUES IN ADDITION TO THE % CS.

Increment	**Time**	**(G)**	**(H_2O_2)**	**X_o**	**X_1**	**X_2**	**X_3**	**X_1X_2**	**X_2X_3**	**X_1X_3**	**$X_1X_2X_3$**	**%CS**
1	30	0.10	20	+1	-1	-1	-1	+1	+1	+1	-1	50.30
2	30	0.10	60	+1	-1	-1	+1	+1	-1	-1	+1	60.36
3	30	0.20	20	+1	-1	+1	-1	-1	-1	+1	+1	50.90
4	30	0.20	60	+1	-1	+1	+1	-1	+1	-1	-1	65.73
5	60	0.10	20	+1	+1	-1	-1	-1	+1	-1	+1	58.40
6	60	0.10	60	+1	+1	-1	+1	-1	-1	+1	-1	69.70
7	60	0.20	20	+1	+1	+1	-1	+1	-1	-1	-1	56.14
8	60	0.20	60	+1	+1	+1	+1	+1	+1	+1	+1	72.76
9	45	0.15	40	+1	0	0	0	0	0	0	0	68.90
10	45	0.15	40	+1	0	0	0	0	0	0	0	69.60
11	45	0.15	40	+1	0	0	0	0	0	0	0	70.50

TABLE VIII
REGRESSION COEFFICIENTS AND THEIR CORRESPONDING VALUES

b	**t**
$b_o = +60.50$	213.03
$b_1 = +3.72$	13.10
$b_2 = +0.85$	2.98
$b_3 = +6.64$	23.38
$b_{12} = -0.65$	2.30
$b_{23} = +1.26$	4.44
$b_{13} = +0.38$	1.33
$b_{123} = +0.07$	0.24

TABLE IX
DATA USED FOR CALCULATING S^2_{RES}

yi	**X_1**	**X_2**	**X_3**	**X_2X_3**	**$\hat{y}_i$**	**(yi – $\hat{y}_i$)**	**(yi – $\hat{y}_i$)^2**
50.30	-1	-1	-1	+1	51.69	-1.39	1.94
60.36	-1	-1	+1	-1	62.45	-2.09	4.40
50.90	-1	+1	-1	-1	51.69	-0.79	0.63
65.73	-1	+1	+1	+1	62.45	3.28	10.75
58.40	+1	-1	-1	+1	56.61	1.79	3.20
69.70	+1	-1	+1	-1	72.41	2.71	7.30
56.14	+1	+1	-1	-1	56.61	-0.47	0.22
72.76	+1	+1	+1	+1	72.41	-0.35	0.12

In all these tables, the corresponding data for both the conventional process (Conv) and the (Redox) process prior to optimization were inserted for comparison. However, for estimating the effect of optimization, only the two Redox processes are relevant. Thus, optimization has:

- Evidently improved all of the properties in Table X except for the first three properties which improve by declining.
- Practically no effect on either MB or HB.
- Reduced the cost by about EGP 2.5 per 20kg-batch, or rather 2.5*16=EGP 40 per day, amounting to 40*300=EGP $12*10^3$ per year (assuming 300 working days).

V. CONCLUSION 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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REFERENCES

[1] M. Ilomaki, M. Melanen, "Waste Minimization in Small and Medium-sized Enterprises – Do Environmental Management Systems Help?". *J. Cleaner Production* 9 (2001), 209-217.
[2] KITA, APEC Virtual Center for Environmental Technology Exchange, Cleaner Production by Kitakyushu International Techno-cooperative Association, October 2004.
[3] J. Petek, P. Glavic, "Improving the Sustainability of Regional Cleaner Production Programs", *Resources Conservation and Recycling* 29 (2000), 19-31.
[4] Unepi, "www.unepi.org/pc/cp/understanding_cp/home", UNEP, Cleaner Production – Key Elements, December 2004.
[5] SEAM Programme, "A Guide of Cleaner Production, Opportunity Assessments in Small and Medium Enterprises", September 2004, p. 6-9.
[6] D. Mahato, Denim Processing. *J. Colourage*, August 2005, 79-80.
[7] P. Kubelka, F. Munk, *Tech. Physik*, December 1931 p. 593.
[8] ASTM, D1682 – 1924, "Standard Test Method for Determination of Tensile Strength".
[9] AATCC Test Method 39-1980, "Wettability of Fabric Method".
[10] ASTM, D4158 – 2001, "Standard Guide for Abrasion Resistance of Textile fabrics".
[11] AATCC Test Method 66 – 1990, "Wrinkle Recovery of Fabric: Recovery Angle Method".
[12] ASTM, D1388-1996, "Standard Test Method for Determination of Stiffness".
[13] APHA, "The American Standard Methods for Examination of Water and Wastewater", sections 5210B, 2540C, 2540D, 5220D, 1998.
[14] Z. Kafarov, S. Achnazarova, "Experiment Optimization in Chemistry and Chemical Engineering", Mir Publisher, 1982, p. 151-158, 167-171.