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Anova method and T-test method as statistical tools for monitoring performance of pilot plant water used in textile wet processing

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ABSTRACT

Textile industry is one of the water intensive industry and now facing water scarcity problem due to increasing civilization, industrialization and depleting natural water resources. Municipal treated wastewater is a drought proof source which can be utilized for processing of textiles and reducing water scarcity. This paper reveals that Municipal wastewater further treated through pilot plant is technically suitable for usage in textile wet processing. Suitability of this pilot plant water is analyzed through statistical methods like Analysis of variance (ANOVA) and paired T-test methods. Analysis of variance (ANOVA) allows to test quality of pilot plant water and its usage in textile wet processing. This research paper focuses on Anova method and Paired T-test method for monitoring performance of pilot plant water in textile wet processing.

Keywords: Analysis of variance (ANOVA), paired t-test, k/s values, pilot plant water.

1. INTRODUCTION

Continued population growth, contamination of both surface and ground waters, uneven distribution of water resources, and periodic droughts have forced water agencies to search for innovative sources of water supply as well as recycle, reuse and reduce the water. Use of highly treated wastewater effluent, which is now discharged to the environment from municipal wastewater treatment plants, is receiving more attention as is reliable source of water. Waste water reuse is viable option, but water conservation, efficient use of existing water supplies, and development of the new water resources are alternatives that must be evaluated. The study has been carried on treated municipal wastewater which is retreated with appropriate treatment using pilot treatment plant. This retreated water is used for textile wet processing. Technical and statistical analysis has been carried out to check suitability of treated water for processing. Technical suitability has been checked by comparing values with I.S. standard. Statistical suitability has been verified with Anova method (Two factors without replication) and paired T –test (Paired two samples for means) [1].

2. METHODOLOGY

Pilot treatment plant was prepared and treatment was given to treated municipal wastewater. Figure No. 1 Shows photograph of pilot treatment plant [2].

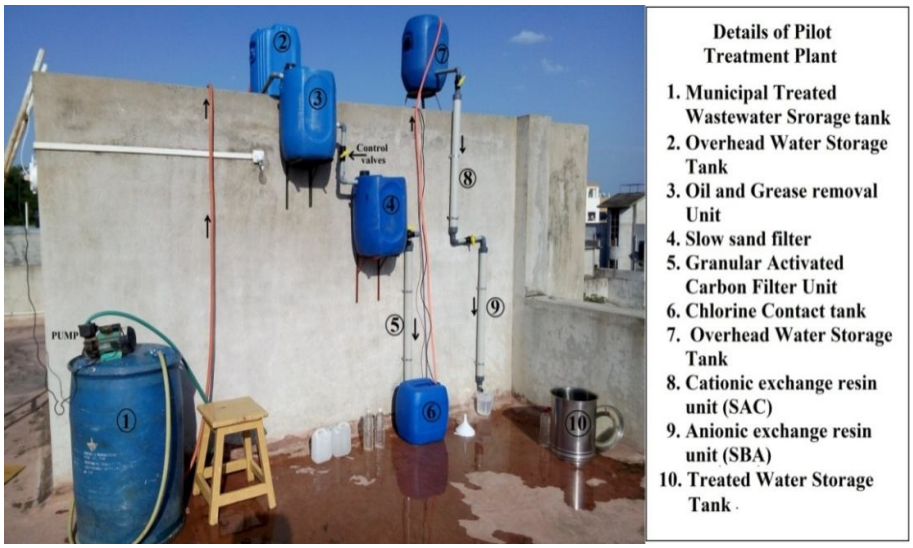


Figure 2: Photograph of Pilot Treatment Plant

In pilot plant experimentation parameters of inlet and outlet are studied like Total Dissolved Solids, Total Hardness, Oil and Grease, P^H, Chlorides, Nitrates, Sulphates, Aluminium, Alkalinity, Iron, Manganese, Chlorine, Suspended solids, Electrical conductivity, Colour, Odour, Most Probable Number (/100 ml.) and Chemical Oxygen Demand. Outlet parameter values are compared with (IS 201:1992) for textile wet processing. All values found suitable for textile wet processing. Textile processing units are using tap water or ground water in processing of fabric. Comparison is carried out between use of pilot plant water, tap water and ground water in processing of cotton fabric. Use of treated water from the pilot plant in textile processing along with various dyes has analyzed through various laboratory tests. Table No.1 to 14 shows various parameters studied. Experimentation was carried out for eight days using pilot plant. Values observed day wise are shown below.

Table No.1: T.D.S. mg/l

Day	Inlet Value	Outlet value
1.	791	412
2.	998	421
3.	856	423
4.	985	457
5.	888	402
6.	986	438
7.	877	423
8.	985	419

Table No.2: Total Hardness mg/l

Day	Inlet Value	Outlet value
1.	270	31
2.	223	31
3.	265	24
4.	254	24
5.	265	15
6.	233	22
7.	229	18
8.	250	19

Table No. 3: Oil and Grease mg/l

Day	Inlet Value	Outlet value
1.	86	0
2.	81	0
3.	73	0
4.	92	0
5.	81	0
6.	86	0
7.	79	0
8.	91	0

Table No. 4: P^H

Day	Inlet Value	Outlet value
1.	7.16	7.06
2.	7.05	7.03
3.	7.12	7.05
4.	7.3	7.04
5.	7.14	7.07
6.	7.09	7.03
7.	7.11	7.09
8.	7.2	7.09

Table No.9: Suspended Solids mg/l

Day	Inlet Value	Outlet value
1.	116	0
2.	89	0
3.	112	0
4.	84	0
5.	56	0
6.	112	0
7.	123	0
8.	81	0

Table No. 10: E.C. (µmhos/cm)

Day	Inlet Value	Outlet value
1.	0.92	0.68
2.	0.73	0.49
3.	0.76	0.67
4.	0.87	0.74
5.	1.01	0.58
6.	0.79	0.48
7.	0.74	0.46
8.	0.81	0.51

Table No. 5: Chlorides mg/l

Day	Inlet Value	Outlet value
1.	60	53
2.	72	59
3.	56	46
4.	78	48
5.	56	46
6.	74	44
7.	55	41
8.	71	43

Table No. 6: Nitrates mg/l

Day	Inlet Value	Outlet value
1.	0.0128	0.0122
2.	0.0124	0.0111
3.	0.022	0.021
4.	0.0174	0.0122
5.	0.0135	0.0115
6.	0.0189	0.0103
7.	0.027	0.017
8.	0.0166	0.0154

Table No. 7: Sulphates mg/l

Day	Inlet Value	Outlet value
1.	80	62
2.	74	51
3.	91	52
4.	76	59
5.	89	58
6.	73	49
7.	79	51
8.	69	56

Table No.8: Alkalinity mg/l

Day	Inlet Value	Outlet value
1.	230	125
2.	186	133
3.	189	136
4.	183	145
5.	233	123
6.	153	129
7.	158	126
8.	186	139

Table No. 12: M.P.N. values after disinfection

Day	Inlet Value	Outlet value
1.	41	0
2.	33	0
3.	51	0
4.	52	0
5.	51	0
6.	48	0
7.	53	0
8.	58	0

Table No. 13: B.O.D. mg/l

Day	Inlet Value	Outlet value
1.	18	6
2.	19	7
3.	23	8
4.	22	5
5.	23	7
6.	21	6
7.	23	8
8.	22	8

Table No. 11: M.P.N. (/100 ml.)

Day	Inlet Value	Outlet value
1.	120	41
2.	117	33
3.	96	51
4.	82	52
5.	126	51
6.	111	48
7.	98	53
8.	89	58

Table No.14: C.O.D. mg/l

Day	Inlet Value	Outlet value
1.	82	18
2.	76	19
3.	69	25
4.	73	12
5.	76	17
6.	89	18
7.	56	20
8.	72	20

3. EXPERIMENTATION AND ANALYSIS

From above parameters, here detailed study of parameter total hardness is carried out. Testing of hypothesis and estimation are the two important parts of statistical inference. Here Statistical techniques like ANOVA and Paired t-test method are used to analyze the treatment quality. M.S. Excel Software has been used for statistical analysis.

3.1 T-Test: Paired Two Sample for Means

A paired t-test looks at the difference between paired values in two samples, takes into account the variation of values within each sample, and produces a single number known as a t-value [6]. It can be found out how likely it is that two samples from the same population (i.e where there should be no difference) would produce a t-value as big, or bigger, than yours. This value is called a p-value. So, a t-test measures how different two samples are (the t-value) and tells how likely it is that such a difference would appear in two samples from the same population (the p-value). Using the Significant (2-tailed) value, it can be determined that whether the Correlation is a significant one or not. Null hypothesis (H0) and alternate hypothesis (H1) are two types of hypothesis. The Null Hypothesis is that the Correlation Coefficient is zero (or close enough to be taken as zero), and we reject this at the 5% level if the significance is less than 0.05. Here calculations are shown for Total hardness in Table No.15 where P(T<=t) two-tail for hardness is 6.05919E-09 which is less than level of significance 0.05. T- stat value is 33.01206861which is positive value denotes that outlet values of Total hardness have decreased significantly if compared with their inlet values.

Table No15: Total Hardness (mg/l) inlet and outlet value of pilot plant

Description	**Inlet Value**	**Outlet value**
Mean	248.625	23
Variance	329.9821429	33.71428571
Observations	8	8
Pearson Correlation	-0.047404307	
Hypothesized Mean Difference	0	
df	7	
t Stat	**33.01206861**	
P(T<=t) one-tail	3.02959E-09	
t Critical one-tail	1.894578604	
P(T<=t) two-tail	**6.05919E-09**	
t Critical two-tail	2.364624251	

3.2 K/S Value and its Importance: The Kubelka-Monk Theory

When the light that is shined on a sample, as from the light source of a spectrophotometer, some is reflected back to the instrument detector, some is absorbed by the colorants in the sample, and some of it is scattered in all directions within the sample [3]. For samples with opacities greater than 75%, the Kubelka-Monk equation defines a relationship between spectral reflectance (R in %) of the sample and its absorption (K) and scattering (S) characteristics, as follows:

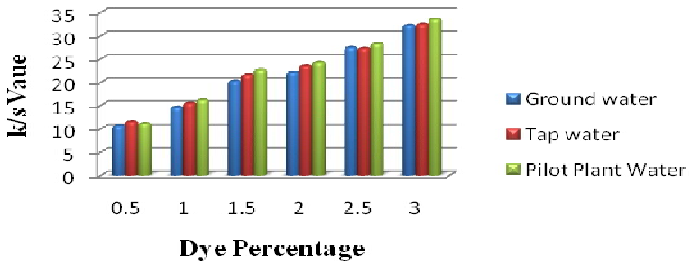
$K/S = [1-0.01\ R]^2 / 2[0.01R]$ K/S values for the sample measured are calculated separately for each wavelength read. K/S may only be calculated for measurements made in a reflectance mode. K/S is a spectral data type, meaning it is calculated and displayed for each measurement wavelength by using software. K/S grows to infinity as reflectance decreases to zero, so the software may not display a K/S value for a particular wavelength or wavelengths if the reflectance is very low. The reactive dyes is adopted widely for its wide chromatograph, gorgeous luster, lower cost, easy operation, good performance in the wet friction fastness, drying stuff after dyeing, and so on. The K/S value is one of the key values in reflecting the surface luster shade of the dyeing products. Researchers Jiang et al. estimate the K/S value of the dyed dyes is estimated by using the nerve network method. It shows the feasibility of the artificial nerve network applied to the reactive dyes dyeing [5]. Color value, used in calculating colorant strength, is a single numerical value related to the amount of light-absorbing material (colorant) contained in a sample and is usually based on spectral data. Color value may be calculated by any one of three acceptable methods. The color value which results from one method may not agree with any other method. The choice of method is usually dependent on the nature of the sample and the need to obtain a color value [4].

3.3 K/S values of fabric dyed with various types of water

Cotton fabric dyed with Reactive Red M8B using various types of water with different percentage shade as shown in following Table No.16 and Graph No. 2

Table No.16 Dye Category: COLD BRAND Type of Dye: REACTIVE RED M8B

Sr. No.	Percentage Shade	Fabric sample dyed with		
		Ground water	Tap water	Pilot Plant Water
1	0.5	10.5847	11.5326	11.1308
2	1.0	14.5782	15.4554	16.1548
3	1.5	20.2458	21.5648	22.6528
4	2.0	22.1145	23.5487	24.2358
5	2.5	27.4455	27.2568	28.2546
6	3.0	32.2244	32.4589	33.5568



Graph No.2 : K/S values of fabric dyed with various types of water

3.4 Anova: Two-Factor without Replication

From above table it is clear average k/s values of all dyed fabric samples using treated water from pilot treatment plant are greater than k/s values of other dyed fabric samples using municipal tap water and ground water. Improvement in k/s values found in all fabric samples which are processed with recycled wastewater. Three types of dye brands used in the experiment i.e. Cold brand dye, Hot brand dye and Remazol brand dye show same improvement in k/s values. Total dissolved solids (TDS) and hardness values are important for better dye fixing on fabric. Total dissolved solids and hardness of pilot plant water are found smaller than ground water and municipal tap water. K/s values increases with increase in percentage shade of dye. K/s values of cotton fabric dyed using pilot plant water are found higher than other two samples. Low TDS values and hardness values is the basic reason behind better k/s values of cotton fabric dyed using pilot plant water. This result shows that there is ample scope of using pilot plant water in textile wet processing. Here sample calculations for Dye Reactive red M8B have been shown in Table No.17. Similarly Anova is implemented on other parameters and results are discussed below.

Table No.17 Anova: Two-Factor without Replication for REACTIVE RED M8B

SUMMARY	Count	Sum	Average	Variance		
0.5	3	33.2481	11.0827	0.22636381		
1	3	46.1884	15.39613333	0.624051293		
1.5	3	64.4634	21.4878	1.452859		
2	3	69.899	23.29966667	1.171491623		
2.5	3	82.9569	27.6523	0.28097589		
3	3	98.2401	32.7467	0.50594407		
k/s value for Ground water	6	127.1931	**21.19885**	63.76465898		
k/s value for Tap water	6	131.8172	**21.96953333**	58.40061776		
k/s value for Pilot plant water	6	135.9856	**22.66426667**	65.55259347		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
% Dye Shade	936.5140861	5	187.3028172	**902.5489358**	**6.18164E-13**	3.325834529
Water samples	6.448106423	2	3.224053212	**15.53562215**	**0.000855679**	4.102821015
Error	2.07526495	10	0.207526495			
Total	945.0374574	17				

In Table No. 17 for Dye Reactive red M8B average k/s value for fabric dyed using pilot plant water is 22.66426667 which is greater than other k/s value of fabric dyed using Ground water and Tap water i.e. 21.19885 and 21.96953333. P-values

for % dye shade is 6.18164E-13 and P value for water samples is 0.000855679, which are less than 0.05 which is level of significance. Similarly F-values for % dye shade is 902.5489358 and F- value for water samples is 15.53562215 which are positive shows that there is significant change in k/s values with increase in dye percentage.

4. RESULTS AND DISCUSSION

4.1 Performance of pilot treatment plant

Pilot treatment plant was prepared for treating wastewater of WWTP at Ichalkaranji in Maharashtra. Experimentation conducted with Pilot treatment plant which provides following results shown in Table No18. Parameter discussed here i.e. Hardness values between 223 mg/l to 270 mg/l. Hardness values of treated water from Pilot treatment plant are ranging between 18 mg/l to 31 mg/l. Similarly following Table No.18 shows various ranges of values for other parameters before treatment of wastewater and after treatment by pilot treatment plant.

Table No.18: Performance of pilot treatment plant

Sr. No.	Parameters	Range of values of wastewater from WWTP	Range of Values after treated in pilot plant	Limits for Textile wet processing *(IS 201:1992)
1.	Total Dissolved Solids mg/l	845 to 930	402 to 457	< 500
2.	Total Hardness mg/l	223 to 270	18 to 31	< 50 *
3.	Oil and Grease mg/l	73 to 92	0	< 1
4.	P^H	6.90 to 7.14	6.76 to 7.09	6.0 to 8.5*
5.	Chlorides mg/l	55 to 78	41 to 59	< 100*
6.	Nitrates mg/l	0.0124 to 0.027	0.0111 to 0.0154	< 0.50
7.	Sulphates mg/l	73 to 91	49 to 62	< 100*
8.	Alkalinity mg/l	153 to 233	123 to 150	< 150*
9.	Suspended solids mg/l	56 to 123	0	< 5
10.	Electrical conductivity (µmhos/cm)	0.73 to 1.01	0.46 to 0.74	-
11.	Aluminium mg/l	0	0	0.1
12.	Iron mg/l	0	0	0.25*
13.	Manganese mg /l	0	0	0.1*
14.	Chlorine mg/l	Below 0.1	0.1 to 0.25	0.1 to 0.2
15.	Colour	Yellowish	Colourless	20 Hazen Units*
16.	Odour	Pungent	Odourless	-
17.	Most Probable Number (/100 ml.)	82 to 126	0	-
18.	Chemical Oxygen Demand mg/l	56 to 89	12 to 25	< 50

From pilot plant experimentation it is clear that, treated wastewater from pilot plant is suitable for cotton textile wet processing. The potential to use treated municipal wastewater as a water supply for industrial use is of interest as a way to conserve water resources while supporting economic development. Using treated municipal wastewater in industries will help to reduce ground water depletion by providing an alternative supply for non-potable water uses and to provide a reliable and potentially optimum cost water source for industries. Above Table No.18 gives values obtained in experimentation using pilot treatment plant and its comparison with I.S. Standards.

4.2 Anova: Two-Factor without Replication

Analysis of variance (ANOVA) allows testing for differences in the means of several different groups or populations. ANOVA tests the null hypothesis that the means for all of the groups are equal.

Table No.19 :average k/s values of all dyed fabric samples

Sr. No.	Name of the dye	Average k/s value for fabric sample dyed with		
		Ground water	Tap water	Pilot plant water
1.	Reactive red M8B	21.19885	21.96953333	22.66426667
2.	Procion brill yellow-M4G	4.187966667	4.2838	4.45155
3.	Procion blue MG MR	7.3076	7.3961	7.612083333
4.	Reactive red HE8B	46.32535	47.37371667	48.24786667
5.	Procion yellow HE4G	14.467	14.7235	15.15183333
6.	Reactive Navy blue HER	64.05796667	64.12683333	65.1386
7.	Remazol red RB	4.7141	4.712566667	4.846933333
8.	Remazol golden yellow RNL	8.673883333	8.775916667	8.929566667
9.	Remazol turquoise blue G	16.93271667	17.16413333	18.19216667

From above Table No.19 it is clear that average k/s values of all dyed fabric samples using treated water from pilot treatment plant are greater than k/s values of other dyed fabric samples using municipal tap water and ground water. Improvement in k/s values found in all fabric samples which are processed with pilot plant water. Three types of dye brands used in the experiment i.e. Cold brand dye, Hot brand dye and Remazol brand dye show same improvement in k/s values. Total dissolved solids (TDS) and hardness values are important for better dye fixing on fabric. Total dissolved solids and hardness of pilot plant water are found smaller than ground water and municipal tap water. K/s values increases with increase in percentage shade of dye. K/s values of cotton fabric dyed using pilot plant water are found higher than other two samples. Low TDS values and hardness values is the basic reason behind better k/s values of cotton fabric dyed using recycled wastewater. This result shows that there is ample scope of using pilot plant water in textile wet processing.

4.3 P-Values and F- values for various dyes and water samples

P-values of all dyed fabric samples using treated water from pilot treatment plant are smaller than 0.05 and F values for all samples indicate that there is significant change in k/s values when used different dyes and water samples. Following Table No.20 shows P value and F values for percentage dye shade and water sample.

Table No.20: P-values and F-values

Sr. No.	Name of the dye	P-Values < 0.05		F- values for	
		% dye shade	Water sample	% dye shade	Water sample
1.	Reactive red M8B	6.18164E-13	0.000855679	902.5489358	15.53562215
2.	Procion brill yellow-M4G	7.60222E-11	0.024074002	343.2029132	5.535626011
3.	Procion blue MG MR	5.8639E-13	0.008561007	912.1510617	7.955823756
4.	Reactive red HE8B	1.19935E-15	0.000852557	3153.25938	15.55063891
5.	Procion yellow HE4G	2.64377E-11	0.026435276	424.5188194	5.340302303
6.	Reactive Navy blue HER	5.23094E-18	0.006739833	9355.372978	8.590648389
7.	Remazol red RB	1.41396E-14	0.020309605	1924.162368	5.900080593
8.	Remazol golden yellow RNL	4.42238E-18	0.000821124	9674.969924	15.70561879
9.	Remazol Turquoise blue G	1.7051E-14	5.82725E-06	1853.351286	50.70282366

4.4 T-Test: Paired Two Sample for Means

A paired t-test compares two samples in cases where each value in one sample has a natural partner in the other. The concept of paired samples is covered in more detail in the pages on choosing a t-test. A paired t-test looks at the difference between paired values in two samples, takes into account the variation of values within each sample, and produces a single number known as a t-value. It can be found out how likely it is that two samples from the same population (i.e where there should be no difference) would produce a t-value as big, or bigger, than yours. This value is called a p-value. So, a t-test measures how different two samples are (the t-value) and tells how likely it is that such a difference would appear in two samples from the same population (the p-value). Using the Significant (2-tailed) value, it can be determined whether the Correlation is a significant one. The Null Hypothesis is that the Correlation Coefficient is zero (or close enough to be taken as zero), and we reject this at the 5% level if the significance is less than 0.05. Following Table No.21 t-stat value and P(T<=t) two-tail values for all parameters.

Table No.21 :t-stat value and P(T<=t) two-tail values

Sr. No.	Parameters	t- stat value	P(T<=t) two-tail < 0.05
1.	Total Dissolved Solids mg/l	19.93780705	1.9973E-07
2.	Total Hardness mg/l	33.01206861	6.05919E-09
3.	Oil and Grease mg/l	37.1421099	2.66606E-09
4.	P^H	3.375874223	0.011825088
5.	Chlorides mg/l	5.103142798	0.001394622
6.	Nitrates mg/l	2.829057826	0.025440541
7.	Sulphates mg/l	8.099118672	8.425E-05
8.	Alkalinity mg/l	4.334062738	0.003420807
9.	Suspended solids mg/l	11.95880685	6.50673E-06
10.	Electrical conductivity (µmhos/cm)	6.699390668	0.000277593
11.	Most Probable Number before disinfection (/100 ml.)	7.400607752	0.000149346
12.	Most Probable Number after disinfection (/100 ml	17.41951099	5.05477E-07
13.	Biological Oxygen Demand mg/l	23.13399702	7.15254E-08
14.	Chemical Oxygen Demand mg/l	13.9846855	2.26295E-06

In above Table No.21 all parameters P(T<=t) two-tail values are less than 0.05 and t- stat values also are positive. T values with positive sign denote that outlet values of all parameters have decreased significantly if compared with their inlet values. This shows that there is significant difference in outlet and inlet values of treated water from pilot treatment plant.

5. CONCLUSION

In case of Anova method P-values of all dyed fabric samples using treated water from pilot treatment plant are lesser than 0.05 and F values for all samples indicate that there is significant change in k/s values when used different dyes and water samples. Similarly in case of T-Test: Paired Two Sample for Means used for above all parameters, P(T<=t) two-tail values are less than 0.05 and t- stat values of all parameters are positive. T –stat values with positive sign denote that outlet values of all parameters have decreased significantly if compared with their inlet values. This shows that there is significant difference in outlet and inlet values of treated water from pilot treatment plant. Paired T-Test and Anova are statistical methods of analysis which are used for analysis shown satisfactory results. Similarly above all parameters were assessed for technical suitability also and found within expected range of values as per I.S. specification (I.S.201:1992**)**. Results and discussions carried out here conforms the technical and statistical suitability of treated municipal wastewater from pilot treatment plant for textile wet processing.

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