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Continuous Washing Parameters and Their Effects on Pre-Treatment Results

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ABSTRACT

This paper presents some practical hints of an efficient washing in a continuous process for pre-treated fabrics. The work was performed in a well known Textile mill in Karachi, Pakistan. The study was done to determine effect of some important parameters to save on water and energy (steam and electricity) consumption. Important variable washing parameters such as temperature, water flow rate and speed (which are based on hydrodynamics & mass transfer principles) of the continuous washing range have been discussed & and their effects on TEGEWA, absorbency, pH & whiteness results have been reported with reference of standardize testing methods. Especially, this paper includes; the washing theory & principles & effective & efficient washing factors; which are explained in the simplest way with industrial standard calculations & experiments.

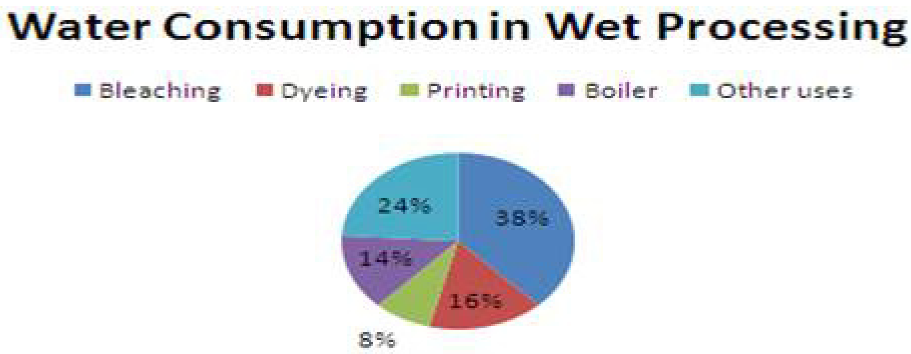
***Key Words*:** TEGEWA, Diffusion Washing, Water Flow rate, Absorbency, Cold Pad Batch, Turbulence (Mechanical Agitation).

1. INTRODUCTION

An old saying states that “with a good pretreatment, half of the dyeing or printing is made. For a good pretreatment, an efficient washing is half pretreatment. Washing of the pretreated textile substrate is an essential part of the preparation or pretreatment processes where all the impurities and non-cellulosic or greasy components of the material are removed by a continuous rinsing process.

Use of excessive quantities of water in textile wet processing is a common practice and this adds to the running cost of preparatory processes. Consumption of water in the wet processing of the cotton fabric is shown in Chart 1[1] and one can notice an excessive proportion of it is used at the pretreatment stage.

Chart I



Many research papers and reports have been reported on washing efficiency [5, 8, 11 & 13] with washing principles & theory in diversified aspects, in which complex calculations and equations are explained. However, the major gap in these research papers and reports is insufficiency of practical data & conditions in the washing process of Textiles. Therefore, in this paper, specifically washing principles & efficient washing factors are discussed by performing several experiments at industrial level.

The present study has been done to study effect of various washing parameters such as speed, water flow rate and temperature which are based on hydrodynamics & mass transfer principles; at a constant pressure of a padder on the washing efficiency in a Cold-Pad-Batch (CPB) bleaching process for some fabrics including polyester/cotton blend, CVC (Chief value cotton) and CVC denier. The washing efficiency was determined by parameters of absorbency, Tegewa rating and whiteness and effort has been made to determine the optimum conditions. It may however, be pointed out that the results of the findings are not confined to washing in the CPB process but are also applicable in general to all the washing off processes including desizing, scouring, bleaching, mercerizing, dyeing, printing and even some finishing processes.

Many world renowned companies BENNINGER, KUSTER & GOLLER have given high-tech & efficient washing machines to Textile industry, the major problem in the textile industry is lack of knowledge to use effectively the washing parameters and this leads high cost of the washing process and creates hurdles to get desired pretreatment results. In the washing process, complete removal of impurities after scouring and bleaching of the textile substrate is very important because their inadvertent presence is detrimental for subsequent processing. Even for the white fabrics, it affects absorbency, colour and handle of the fabric. Along with these considerations one has to keep in mind the quantity of water used for getting the optimum results because firstly it is not free of cost and more importantly the effluent has to be treated to achieve certain standards of purity at a considerable cost.

1.1 Background Theory

After a fabric has undergone several different treatments during pretreatment, desizing, scouring and bleaching, impurities and residual chemicals must be removed from it. The washing process after pretreatment discussed here is the one which is carried out in the open width washing machine.

The washing process is consist of three steps or phases [3]; (a) loosening of extraneous matter, (b) transfer of extraneous matter and (c) removal of extraneous matter. In first step, the dirt / impurity or oil/grease is swollen and loosen as much as possible, depending on the surrounding conditions. The second step is based on diffusion (this is important step & this is discussed in detail below). In this step, the impurity is transported onto the surface of textile substrate from the core of the substrate. In third step, the extraneous impurity is carried away by flow of the washing liquor and movement of goods.
In actual practice all the three phases are found to overlap. The optimum washing is characterized by maximum efficiency combined with significant savings in water, electricity, heat and chemicals. The efficiency of the washing action is promoted by mechanical movement (speed), water flow rate and counter-flow to the run goods.

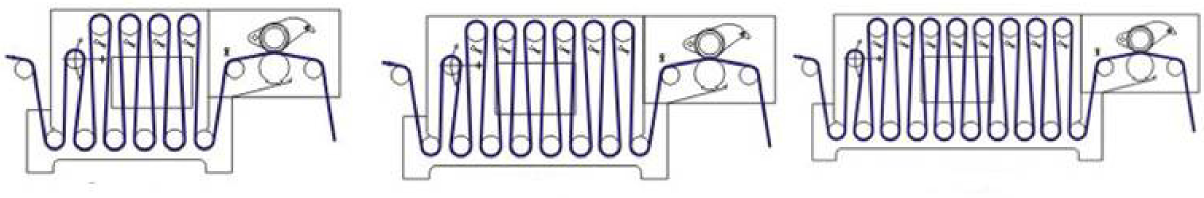


Fig. 1: Open-width Continuous Washing Compartments

Continuous Open Width Washing Machine: The classic open-width washing machine consist (Figure 1) of a series of top and bottom parallel rollers, the lower set being immersed in the liquor [8]. The fabric passes alternatively between top and bottom rollers, being subjected to a series of immersion in the liquor. The top rollers are driven usually by chains or V-belts in a bank of five or six, which make up a compartment or unit. The bottom rollers free-wheel and the bearings are sealed and self-lubricating. The bearing of the top rollers are usually mounted outside the wash box to permit ease of maintenance and lubrication. Both top and bottom rollers should be of the largest practicable diameter, say 12-13 cm, and the distance between top and bottom roller kept to a minimum to reduce the tendency for fabric creasing or edge curling [8].
The developments in continuous washing have given by many scientists which are [5];

1 Increase in number of washing units; for water saving & repeated impregnation in fresh water in each unit, (see Table I)

2 Improvement in fabric dewatering between units; to increase the liquor exchange

3 Universal use of counter-current liquor flow; for mechanical agitation

4 Matching of wash water flow rate to impurity exchange rate

Table I

It shows typical water savings obtained by counter-current washing [7]

Number of Washing Tank	Water Saving (%)
2	50
3	67
4	75
5	80
Source:(US EPA, 1995)	

1.2 Washing Efficiency

Washing process is characterized by its washing efficiency that is the amount of the impurities that are removed divided by the total amount that could have been removed. Parish has given the concept about performance of any washing machine; he concluded that effective washing is based on water flow rate and efficiency of each washing unit. For any given set of conditions an efficiency parameter, which is characteristic of the machine and independent of the flow of water, can be determined. The performance of a single unit C_1/C_0, i.e. the ratio of impurity concentrations in the fabric after and before the wash, is given by following Eqn 1 [5]:

$$\frac{C_1}{C_0} = \frac{1-K+KF}{1-K+F} \quad \text{...... (1)}$$

Where, K is the efficiency parameter (equal to C_1/C_0 for a wash in clean water) and F is the flow of wash water per unit mass of solution in the fabric that enters in unit time. The use of this relationship allows the calculation of water flow required for a machine of known K value or of the K value required when the water available is limited. The value of K can be varied by changing the temperature of the wash liquor, so that energy may be saved by using a temperature no higher than necessary. The washing performance of a series of units is given by multiplying together the values of each separate unit. If, for example, C1/C0 were 0.3 for each of four units, then the overall performance would be 0.34 = 0.0081, i.e. a 99.2% removal of impurity. The value of K is determined by time of contact, temperature, amount of interchange and properties of the impurity.

Diffusion Washing: This is second step of washing process, which has much important for efficient & effective washing process. Diffusion washing is a complex process. With reference to Figure 2 there may be up to 4 steps in sequence [11] :

I. Diffusion of impurity out of the substance of the fibre into the aqueous phase.

II. Interfilamentary diffusion in the aqueous phase within a yarn structure.

III. Interyarn diffusion bringing impurity to the macroscopic surface of the fabric.

IV. Diffusion through the hydrodynamic boundary layer into the water bulk. This boundary layer may be laminar or turbulent, depending on fabric

speed through the water and length of immersion.

In practical term, the washing efficiency depends on the following factors [13];

- Machine Design
- Nipping roll
- Roll configuration

- Numbers of roll
- Roll diameter
- Simulator height
- Water flow rate
- Fresh water addition techniques
- Water temperature
- Impurities & chemical concentration
- Counter-current flow
- Water flow pattern
- Water bath design
- Fabric speed
- Fabric GSM (Areal Density) /GLM (Linear Density)
- Fabric contamination
- Fabric tension
- Fibre content
- Yarn twist
- Last process efficiency

All parameters/factors mentioned above play very important role for efficient washing of textile substrate. All parameters can be control but some parameters would be out of control if not consider before choosing the washing equipment, for example Machine design, Roll configuration, water bath design etc.

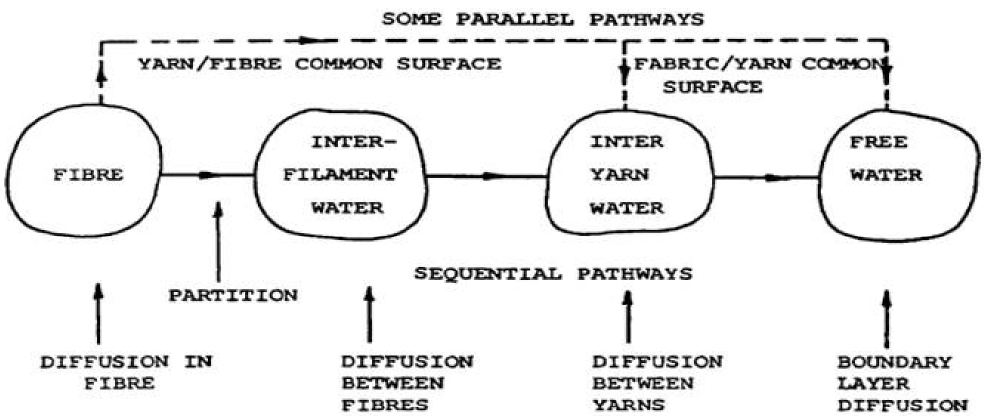


Fig: 2: Diffusion Washing Pathways in Textile Fabric [11]

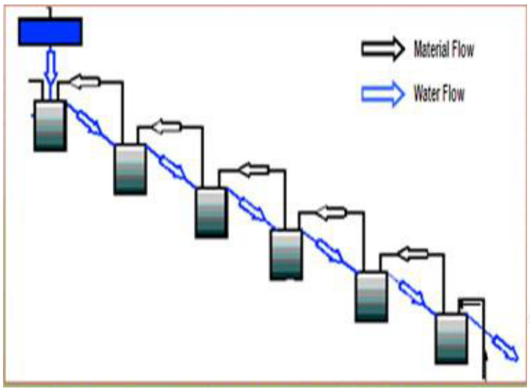
1.3 Counter-Current Flow Principle

The countercurrent washing principle is now common in textile washing process due to its efficient and economical factors. Basically, the least contaminated water from the final wash is reused for the next-to-last wash and so on until the water reaches the first wash stage [2], after which it is discharged. This technique is useful for washing after continuous bleaching, dyeing and printing, see *fig 3 & 4*. As purpose of washing is to reduce the amount of impurities in the substrate, as much water as possible must be remove between sequential washing steps in multistage washing operations. Water containing contaminants that are not removed are "carried over" into the next step, contributing to washing inefficiency. Proper draining in the batch drop/fill washing and proper extraction between steps in the continuous washing process are important. Often, 350 percent water on weight of goods is carried over in typical drop/fill procedures.

In further work it has been argued that the single most important feature of an efficient washer is that it has a very large number of effects in counter-flow. This makes it approach closely the ideal of a reversible thermodynamic system [11].

The operations of counter-current flow are;

- Counter-current washing is often practiced by introducing raw water into the last wash of the washing series.
- The wastewater is then circulated from the last step to the next preceding step and so on up the line.
- The cleanest product is washed with the cleanest water and the most contaminated product is washed with dirtiest water. The system leads to huge savings in water use.



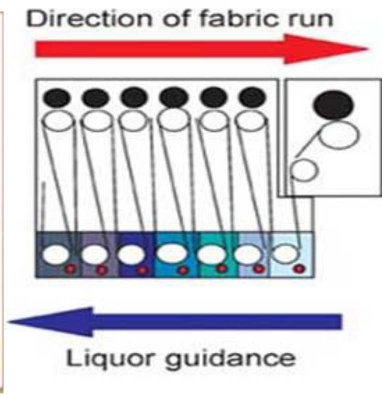


Fig. 3: Counter-Current Flow [6]

Fig. 4: Material & Water Flow Mechanism

2. EXPERIMENTAL

2.1 MATERIALS

Table II

Fabric	Construction (Warp/inch x Weft/inch / Warp Count x Weft Count	Blend Ratio (Polyester: Cotton)	Areal (g/m^2) / Linear (g/m) Density	Width
PC	76 x 52/30 x 30	65:35	106/230	85''
PC Denier	76 x 44/30 x150D*	80:20	94/180	75"
CVC Denier	114 x 62/75D x30	75:25	92/219	94''
**D = Denier Count*				

2.2 EQUIPMENT:

The Continuous washing range having 4 washing units (the schematic diagram of single washing unit can be seen in fig. 3) was used to perform this work. The capacity

of each unit was 3500 liters of water. Fabric Content was 20 meters/unit. Water Jet showering was installed in first unit. The Washing unit specs were;
-Stainless steel compartment with top cover and side large windows. Fabric entry and exit adopts water lock.
-Each row of rollers at top and at below and with central distance 950mm (Simulator height), single thread.
-All rollers covered with stainless steel and with mechanical sealing.
-Guide rollers with external bearings, bottom roller with slide ring seals and top rollers with special steam chamber seals.
-Water blocks plate inside compartment for liquor zig-zag counter flow
-1 indirectly steam heating system
- Clothing guiding rollers inside compartment are distributed as 5 at top and 6 at below. The diameter of roller was 180mm (Including compensator).
-One Pneumatic compensator
- Pneumatic drain valve for each washer
There were high ton (5.5 tons) bowl squeezers after each unit for dewatering purpose & one bowl squeezer after neutralizing bath (10 tons).

2.3 Method:

All experiments were carried out on Continuous washing machine by using counter-flow, up-and-down single threading, without soaping method. Water flow pattern was, drain at first unit and water inlet flow was from 4th unit. The range of machine speed was 30-80 meters/ min, and during experiments machine was run at different speed within given range. These experiments were repeated multiple times to take average and valid results. Each pretreated unwashed fabric via cold pad batch process was taken X length, length and weight of fabric (in Areal (GSM) & Linear (GLM) density) is mentioned in the table II, the counter-current water flow was set accordingly and water flow rate, speed and temperature were analyzed on the basis of results. The padder pressure in each washing unit was set according to standard (depend on the construction of fabric i.e. light padder pressure for light weight fabric), similarly the standard temperature was set according to quality of fabric, see Table III.

2.4 Test Methods:

The weight (GSM) of each fabric was tested by ISO 3801 (g/m2) method. The Tegewa rating was taken from Violet-blue scale. Absorbency was conducted by AATCC-79 method. The pH of each sample was conducted by pH Extraction method, (ISO 3071). The whiteness was measured by CIE @ Spectrophotometer.

- For GLM calculation;

$$GLM = \frac{GSM \times Fabric\ width}{39.37}$$

- The total amount of water (TW) required;

$$TW = \frac{FW \times Pick\text{-}up\%}{100}$$

- To calculate the fabric weight (FW) passing through the machine per minute;

$$FW = \frac{GLM \times Machine\ Speed}{1000}$$

- The Water flow rate is expressed in l/kg (liters per kg);

$$Water\ Flow\ Rate = \frac{Liters/min \times 1000}{GLM \times Speed}$$

Table III

Washing Unit #	Temperature	Padder Pressure
1st	95 °C	2 Bar
2nd	85 °C	3 Bar
3rd	75 °C	3 Bar
4th	65 °C	4 Bar

Table IV

The requirements of pretreatment results for pigment printing are,

Fabric	pH	Tegewa	Absorbency	CIE Whiteness
Cotton	6-7	>3	5mm-20mm	67-72
PC	6-7	>3	5mm-20mm	67-72
PC denier	6-7	>3	5mm-20mm	67-72
CVC	6-7	>3	5mm-20mm	67-72
CVC denier	6-7	-	5mm-20mm	67-72

3. RESULTS AND DISCUSSION

Table V

	Material # 01 CVC Denier Fabric						
Material Details	Fabric/Const.	Padder Pressure	GSM	GLM	Width	Total Meters	
	114 x 62/75D x 30	Std	92	219	94’’	5000	
Parameters & Results	Temp. 1,2,3,4	Whiteness	Flow Rate (l/kg)	Tegewa	Absorbency	pH	Speed (m/min)
Normal Operation	95,85,80,70	70-80	6-7	7-8	5 mm	6.5	70
Recommended Operation	80,75,70,60	70-80	3-4	7-8	5 mm	6.5	70
	Material # 02 PC Denier Fabric						
Material Details	Fabric Const.	Padder Pressure	GSM	GLM	Width	Total Meters	
	76 x 44/30 x 150D	Std	94	180	75”	5650	
Parameters & Results	Temp. 1,2,3,4	Whiteness	Flow Rate (l/kg	Tegewa	Absorbency	pH	Speed (m/min)

			)				
Normal Operation	95,85,80,70	65-72	8.5	2	15mm	6.5	65
Recommended Operation	95,90,85,70	65-72	6-7	3	15mm	6.5	50-55
	Material # 03 PC Fabric						
Material Details	**Fabric/Const.**	**Padder Pressure**	**GSM**	**GLM**	**Width**	**Total Meters**	
	76 x 52/30 x 30	Std	106	230	85”	6000	
Parameters & Results	**Temp. 1,2,3,4**	**Whiteness**	**Flow Rate (l/kg)**	**Tegewa**	**Absorbency**	**pH**	**Speed (m/min)**
Normal Operation	95,85,80,70	65-72	6-7	3-4	10mm	6.5	65
Recommended Operation	90,80,70,60	65-72	5-6	3-4	10mm	6.5	70-75

The three materials were taken under consideration to assess the desired pretreatment results such as tegewa, absorbency, pH & whiteness by keeping in the view saving on water and energy consumption. The normal operation was conventional operation at that mill; recommended operation was result of multiple experiments on continuous washing machine which were conducted at same Textile mill. Comparisons with respect to parameters & results have been reported. The required pretreatment results for subsequent processes are given above in Table IV.

3.1 Material 01:

In washing of this material, water and steam consumption were saved by reducing water flow rate and by lowering the temperature (as mentioned in recommended operation), because there is no concept of sizing material (so called Tegewa) in given material due to denier polyester is interlaced in warp direction. Secondly, this material was processed in low recipe during cold pad bleaching thus fewer amounts of chemicals were present within the fabric structure. As a result, there was no need to high water flow rate & high water temperature. As far as, concern with absorbency, because of very fine structure of the fabric & it did not create any problem during pigment printing & generally, in case of pigment printing very low absorbency rating is required in to avoid flushing problem. An important idea is here, the major advantage is that we can superimpose the CVC filament fabric in washing machine because fabric thickness is comparatively low but this is a little bit complicated and needs an extra winder for batching.

3.2 Material 02:

In the Normal operation of this material, the flow rate was high but one can see the Tegewa rating is not improved. It was observed that the same tegewa result on water flow rate at 6.5 l/kg; it shows that improvement is required to get desired Tegewa rating by;

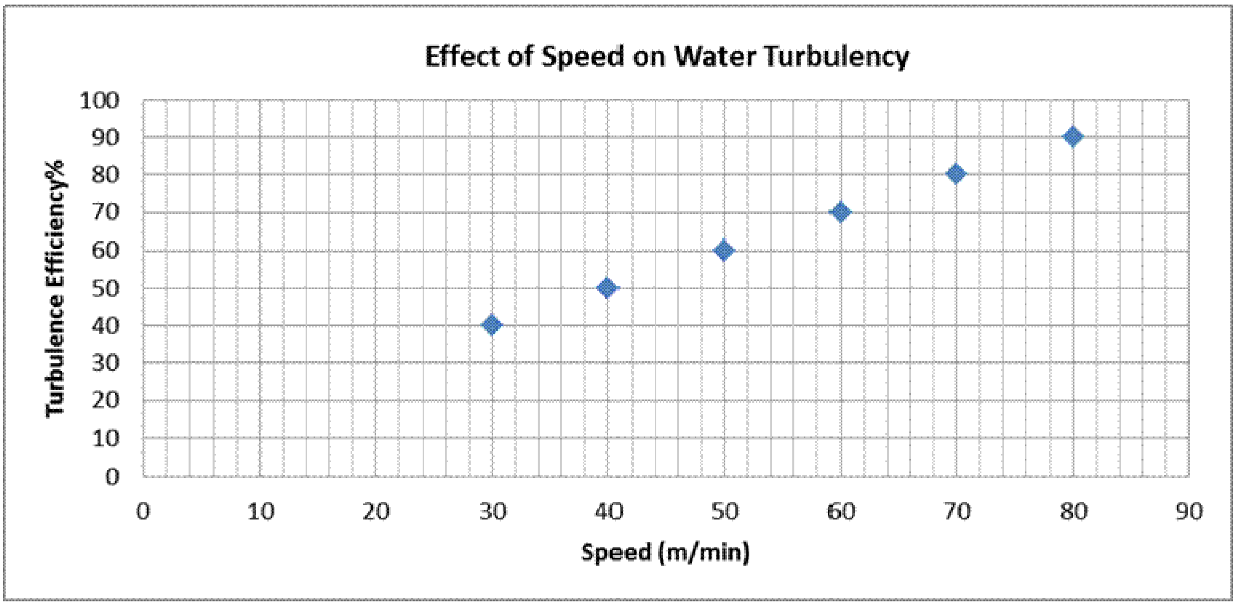
- Alteration in cold pad batch recipe
- To improve desizing results
- Increment in washing temperature

The quantity of sodium hydroxide in Cold Pad Batch bleaching should be increased to optimum level; to improve the desizing efficiency, so called alkaline desizing [12]. In addition, the desizing results can be improved by using of sodium/potassium per persulfate in cold pad batch bleaching, because it is mild oxidizing agent and increase the rate of oxidation combine with hydrogen peroxide [10]. After increased the caustic soda recipe & introducing the sodium persulfate in cold bleach process, as a result the Tegewa rating was increased from 3 to 4; in connection to this, the continuous water jet showering was operated in first washing tank & washing machine run at optimized speed (50-55 m/min) by keeping flow rate 6 or 6.5 l/kg (to increase interaction with hot water). The increment in temperature was set as given in table, because heating effect lower the viscosity of water thus increase the water diffusion in the core of yarn [16].

3.3 Material 03:

The desired results were taken by altering the parameters as mentioned in recommend operation. Water Flow rate could be set 4 l/kg or even at 3 l/kg but it was analyzed that the contamination, TDS remains in bath and hence in fabric which have adverse effect on subsequent processes & it gives low whiteness, therefore water flow rate 5-6 l/kg was effective. At the same time, it was also observed that efficiency of washing was increased by increasing the speed e.g. 70-75 m/min (more turbulence of water, the turbulence in the liquor produces a high liquor exchange [17], see also Graph I). At higher speed, the diffusion into the core of the fibers begins immediately and makes additional penetration time superfluous [11].

Graph I



Temperature of each washing tank was lowered as given in recommended operation, it saves energy, and lower temperature also increases life of the padder (pad mangle).

4. CONCLUSION

Our core focus was on water flow rate because the key factor of washing efficiency is **turbulence,** see the below graph II; how water flow rate affects washing efficiency*?* The flow rate was set on the basis of results, such as contamination in water and conductivity (less than 100µS/cm) parameters [4, 13], it was observed that water flow rate had shown very efficient results in between 5-6 liters/kg. Therefore, we recommend the following optimized water flow rate **(S. No. 2) in Table VI** which was found very efficient & effective water flow rate for cold bleached CVC, PC, PC denier Fabrics.

Graph II

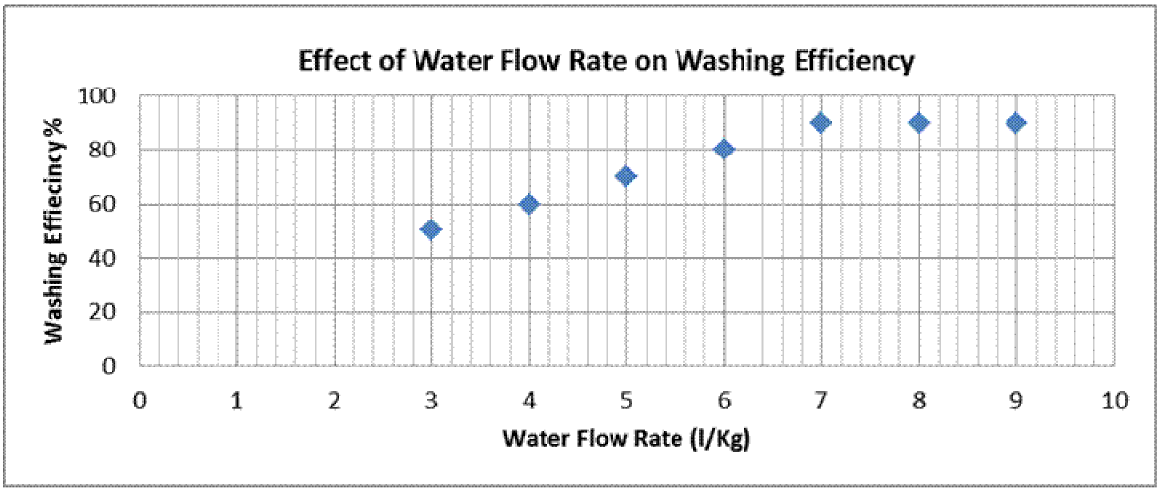


Table VI

S. No	Water Flow Rate (l/kg)	Efficiency	Tegewa	Absorbency	pH
1	3-4	Relatively low	2	5-10 mm	6.5
2	**5-6**	**Optimum**	**>3**	**10-15 mm**	**6.5**
3	6-7	Normal	>3	15-20 mm	6.5
4	>7.5	Normal	>3	15-20 mm	6.5

[***Note for Table VI****: Recommended water flow rate is only for cold pad bleached PC, CVC denier fabric not for the desized and 100% cotton fabric. For 100% cotton materials, water flow rate may be increased to 8-9 liters per kg*].

This recommended water flow rate is set by considering the water properties as well such as turbidity, conductivity, pH, TDS, TSS and colour, because these factors rigorously affect the pretreatments results [14].

In this work, it has been analyzed that washing process can be effective and efficient by considering & controlling the simple parameters such as water flow rate, water temperature and speed of the machine [15]. It is important to consider the fabric type, construction and level of impurities in the fabric.

Generally speaking, the parameters/factors which are given earlier in washing efficiency heading, we can use all parameters/factors for available washing system or choosing new washing equipment, in this way we can save on energy and water consumption by simply altering the discussed parameters.

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