AN APPROACH TO ESTIMATE DYE CONCENTRATION OF DOMESTIC WASHING MACHINE WASTEWATER

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Abstract:

This article focuses on developing a methodology which can be used to estimate the concentration of dyestuff released from textiles during domestic laundering, so that further studies involving decolorization of the wastewater from domestic washing machine can be conducted in an attempt to develop eco-friendly domestic washing processes. Due to the complexity of the problem, an approach was adopted so that, as an initial step, synthetic red and blue reactive dye solutions were prepared as representative wastewater solutions using Reactive Red 195 and Reactive Blue 19 dyestuffs for the estimation of dye concentration. This was followed by an experimental work consisting of washing tests involving the calculation of dye concentration in the wastewater obtained from domestic washing machine as well as tergotometer as a machine simulator. For this part of the work, dyed cotton plain jersey fabric samples were used to obtain wastewater solutions. All the dye solutions and the wastewater samples were measured with VIS spectrophotometer, and the maximum absorbance values were obtained at relevant wavelengths. Although the characteristics of absorbance spectra of synthetic and wastewater solutions were very different, the maximum absorbance values of both solutions overlapped at relevant wavelengths. The concentration of the dyestuff was calculated from the absorbance values measured at 540 and 592 nm for the red and blue, respectively. The statistical analysis of the data suggested that tergotometer can be used as a domestic washing machine simulator. Moreover, the regression analysis done for the dyestuff concentration under discussion revealed that the most significant factor was the washing step (main wash or rinsing) (89.5%) followed by color (red or blue) (3.4%) and washing device (washing machine or tergotometer) (1.5%).

Keywords:

Domestic wastewater, dyestuff concentration, colored textile effluent, azo dye, anthraquinone dye, tergotometer, VIS spectrophotometer

1. Introduction

There is a potential for gray water reuse in the developing regions of the world. Gray water is defined as wastewater generated from domestic activities, such as dish washing, laundry, and bathing. The advantage of recycling gray water is that it is a large source with low organic content; however, it contains significant concentrations of materials with potential negative environmental and health impacts, such as salts, surfactants, oils, synthetic chemicals, and microbial contaminants [1]. Therefore, reusable gray water should fulfill four criteria: hygienic safety, aesthetics, environmental tolerance, and technical and economic feasibility [2]. Different reuse applications require different water quality specifications, thus demanding different treatments varying from a simple coarse filtration to an advanced biological treatment [3]. It was also reported that, besides conventional techniques used to remove various pollutants, there are some advanced techniques which have been proven to be more eco-friendly, rapid, and cost- and time-effective in nature [4].

Within this context, domestic washing machines, which consume 50 L of water per cycle on average, require special attention because they provide significant source of recyclable water for nonpotable uses [5]. The wastewater obtained from such machines is defined by temperature (°C), pH-value, suspended substances (mg/L), sediment substances (mL/L), Cl_2 (mg/L), total nitrogen (mg/L), nitrogen ammonia (mg/L), total phosphorus (mg/L), chemical oxygen demand (COD, mg O_2/L), biological oxygen demand (BOD_5, mg O_2/L), mineral oil (mg/L), adsorbable organic halides (mg/L), and anionic surfactant (mg/L) [6]. Treatment of domestic laundry wastewater is particularly difficult because it contains different types of dyes, detergents, bleaches, perfumes, and so on, and it requires processes for the removal of the contaminants and decolorization.

Color substance in the laundry wastewater usually comes from dyed textiles. The concentration of the substance is dependent on washing conditions, dyestuff class, and degree of fixation. As there is a combination of several dye classes in the same washing medium, the decolorization process becomes quite challenging due to the reasons given by the presence of diversified functional groups in different classes of dyes [7] and of a wide variety of auxiliaries, such as salts, enzymes, surfactants, scouring agents, oils, and oxidizing and reducing agents [8]. Particularly in reactive dyeing processes, large concentrations of dyes and dye-assisting chemicals are used, and they end up in the exhausted dyebath forming a difficult-to-treat effluent [9]. Moreover, the color imparted to wastewater from the dyes must be removed before being discharged to water bodies because it affects water transparency and is regarded as being a pollutant [4].

Today, cotton is the most preferred textile fiber in the world for apparel and home furnishings [10]. Colored cotton fabrics are consumed in very high quantities due to their comfort and naturalness. In parallel, the use of reactive dyes has continually increased, and various kinds of reactive dyes have been developed for cellulosic textiles particularly to achieve various colors and high washing fastness values. It is known that reactive dyes form a covalent bond with cellulose. But, color fading and dye transfer caused by dye loss of colored fabrics during domestic washing are still common consumer problems, even though reactive dyes show excellent color fastness properties [11].

Reactive dyes are the best choice for dyeing of cellulosic fibers. These dyes are colored compounds that contain functional groups, such as azo, phthalocyanine, anthraquinone, formazane, and oxazine as chromophore [4, 12]. Azo dyes constitute about 60% of reactive dyes and play a significant role in dyestuff chemistry, followed by anthraquinone dyes [4, 13]. There are two key components in the azo dye molecules, namely the chromophores, and the auxochromes. The chromophores for azo dyes are azo groups (-N=N-) bound to an aromatic group, which are difficult to treat with conventional chemical and biological methods [14]. The auxochrome groups, which render the solubility of the molecules, give affinity to fibers [15]. On the other hand, anthraquinone dyes are more stable against biodegradation than azo dyes because of their complicated aromatic molecular structure [16]. During the dyeing process, under the influence of heat in alkaline conditions, the reactive sites of a dye react with the functional groups of a fiber. However, a large fraction of the applied reactive dye is wasted because reactive dye is hydrolyzed to some extent, and some of the reactive dyestuff are inactivated by this competing hydrolysis reaction. Consequently, the degree of dye fixation to cellulose fibers can be relatively low, and the release of reactive dyes into dyebath effluent is usually high [9].

Apart from color ingredient, detergent is another important parameter for domestic washing. Literature findings suggested that when fabrics are washed under alkali condition at high temperature, hydrolysis of the covalent bonds between dyes and fibers accelerates [11, 17], and that the presence of active oxidant species, like bleaching agents, during washing, leads to the oxidation of dye chromophores, which will cause color changes or color loss of the fabrics though dyes, may still be covalently bonded on the fabrics [18]. Besides chemicals and temperature, the other causes of dye loss are mechanical action resulting in friction of fabrics, wash liquor ratio, and washing time. Finally, overdosing washing products strongly increases the burden of wastewater by increasing BOD_5, COD, and suspended and sediment substances [19].

Literature survey showed that studies on decolorization largely focus on the wastewater from the industrial-scaled textile dyeing processes because a large section of industrial dyes are left over in wastewater due to low-removal efficiency of the conventional wastewater treatment plants. With this respect, treatment of textile effluent which is contaminated with synthetic dyes is deemed necessary before discharged into wastewater bodies [4]. Various physical, chemical, and biological methods, such as adsorption, photolysis, chemical precipitation, chemical oxidation and reduction, and electrochemical precipitation, have been used as textile effluent treatment methods [20]. On the other hand, environmentally friendly natural dyes to replace hazardous synthetic dyes in textile have become a significant topic for researchers [21–24]. The use of natural dyes can significantly minimize the volume of toxic effluents resulting from the conventional dyeing processes. Putting natural dyes aside, synthetic dyes still have the advantages including high color fastness, good reproducibility of shades, and brilliance of color and ease of use [23]. However, the studies on decolorization of most widely used synthetic dyes for the reuse of wastewater from domestic washing machines have been neglected. Furthermore, the majority of the studies [16, 20, 25–27] on decolorization employed synthetic dye solutions which were prepared to simulate industrial dye bath effluent, which may not be a good representative of the chaotic wastewater of domestic washing machines.

Bearing these characteristics in mind, the study under discussion was conducted to devise a methodology to estimate the dye concentration in the wastewater released from dyed fabrics (i.e., fabrics ready for clothing) through washing in a domestic washing machine. Such a methodology, which can be used for further work to develop a decolorization process namely ozonation for the washing machine wastewater, is essential since the initial and final dye concentrations of the wastewater can be known before; hence, color removal efficiency (%) of the process can be calculated after ozonation.

2. Experimental study

2.1. Materials

Since decolorization represents destruction of chromophore group of a dye molecule [20], the red (C.I. Reactive Red 195) and blue (C.I. Reactive Blue 19) dyes were chosen with respect to the commonly used chromophore groups within reactive dyes, namely azo and anthraquinone groups. Moreover, the most common color/generic class combinations are black/gray cotton (27%), blue cotton (20%), and red cotton (15.6%) [28]. Reactive Red 195 is an azoic anionic dye characterized by the presence of five sulfonic groups and one azoic group. Since it has good solubility in water, it causes difficulties in decolorization process [29]. The Reactive Blue 19 is, however, very resistant to chemical oxidation because its aromatic anthraquinone structure is highly stabilized by resonance [30].

The azo and anthraquinone reactive dyes purchased from a textile mill are given in Table 1.

The chemical structures of the red and blue dyestuffs are also presented in Figure 1.

For the experimental work, Reactive Red 195 and Reactive Blue 19 were dissolved in water, and "synthetic dye solutions" were prepared. Besides reactive dye solutions, the single jersey knitted fabrics dyed in the same textile mill with the very same dyestuffs were used as laundry load to obtain domestic washing wastewater. For simplicity, the colored water released from those fabrics through domestic washing was alluded to "wastewater solution" in the text.

The details of the dyed fabrics and dyeing recipe provided by the fabric supplier are given in Table 2. As may be seen from Table 2, Reaktoset Red RFT (4.20%) and Reaktoset Brilliant Blue R SPEC (4.41%), which are in the structure of Reactive Red 195 and Reactive Blue 19, respectively, are dominant ingredients in the commercial dyeing recipe which were referred as "Red" and "Blue" in the text.

2.2. Methods

Tergotometer offers a simple and rapid evaluation of washing performance by producing a certain level of soil removal which is sufficient to reflect reasonably small formulation differences for one wash [31–35]. Therefore, Copley Scientific tergotometer was used for preparing both synthetic dye and small-scaled wastewater solutions for the study. It comprises eight stainless steel vessels, each with a capacity of around 1,000 mL of water. The temperature within the stainless steel vessels of tergotometer is controlled by a water circulatory heating system up to 70°C. Each vessel is capable of being stirred varying from 50 to 200 rpm.

A frontloading domestic washing machine was used to obtain wastewater solutions from washing of the dyed fabrics. The domestic washing machine algorithm, which is a frequently used cotton program, sequentially consisted of washing (i.e., main wash with detergent), rinsing, (1. rinse, 2. rinse, and 3. rinse without detergent), and the final spinning steps. The wastewater solutions were collected through the drain pipe of the washing machine at the end of main wash and first rinsing steps, respectively.

The methodology devised for the preparation of the synthetic dye and wastewater solutions was summarized in Figure 2.

Both the colored synthetic and wastewater solutions were scanned by using VIS spectrophotometer (Hach Lange DR 3900) within the visible light region (400–700 nm). For the statistical analysis indicating the relationship between washing machine and tergotometer, Minitab 17 software was used.

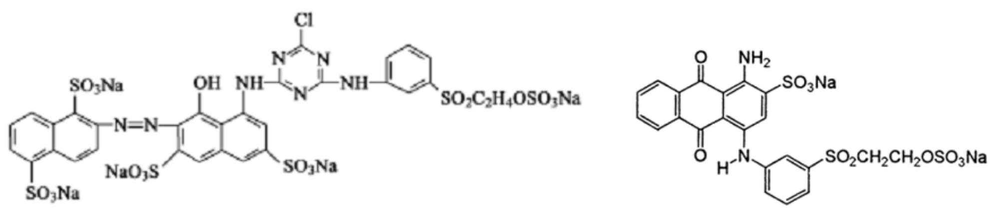
2.2.1. Synthetic dye solution preparation

For Step 1, the synthetic red and blue dye solutions at various concentrations (1 – 5 – 10 – 20 – 40 – 50 – 75 – 100 mg/L) were prepared as control samples by using Red and Blue, respectively, and the maximum absorbance value of each solution was measured at the relevant wavelength to formulate the calibration curve. In addition to the main dyestuff given in Table 2, the other dyestuffs (i.e., Reaktoset Yellow RFT and Sunfix Red s2b) were also scanned within the same range.

For Step 2, two different detergent doses were employed. This was mainly because of the fact that depending on temperature, the characteristics of main wash water and rinse water are different in terms of detergent and dyestuff concentration. Consequently, in accordance with EN60456, the detergent dose was set to 4.6 g/L for main wash and to 0.5 g/L (i.e., 1/10 of main wash) for rinsing by considering the spinning efficiency at the end of main wash. For this step, water was prepared according to EN60734 [36] (Water properties: hardness: 14–16°dH, pH: 7.3–7.7, conductivity: 750–850 µS, and water inlet

Table 1. Azo and anthraquinone reactive dyes

Color Index	CAS No	Linear Formula	Molecular Weight (g/mol)
Reactive Red 195	93050-79-4	$C_{31}H_{19}ClN_7Na_5O_{19}S_6$	1136,32
Reactive Blue 19	2580-78-1	$C_{22}H_{16}N_2Na_2O_{11}S_3$	626,55

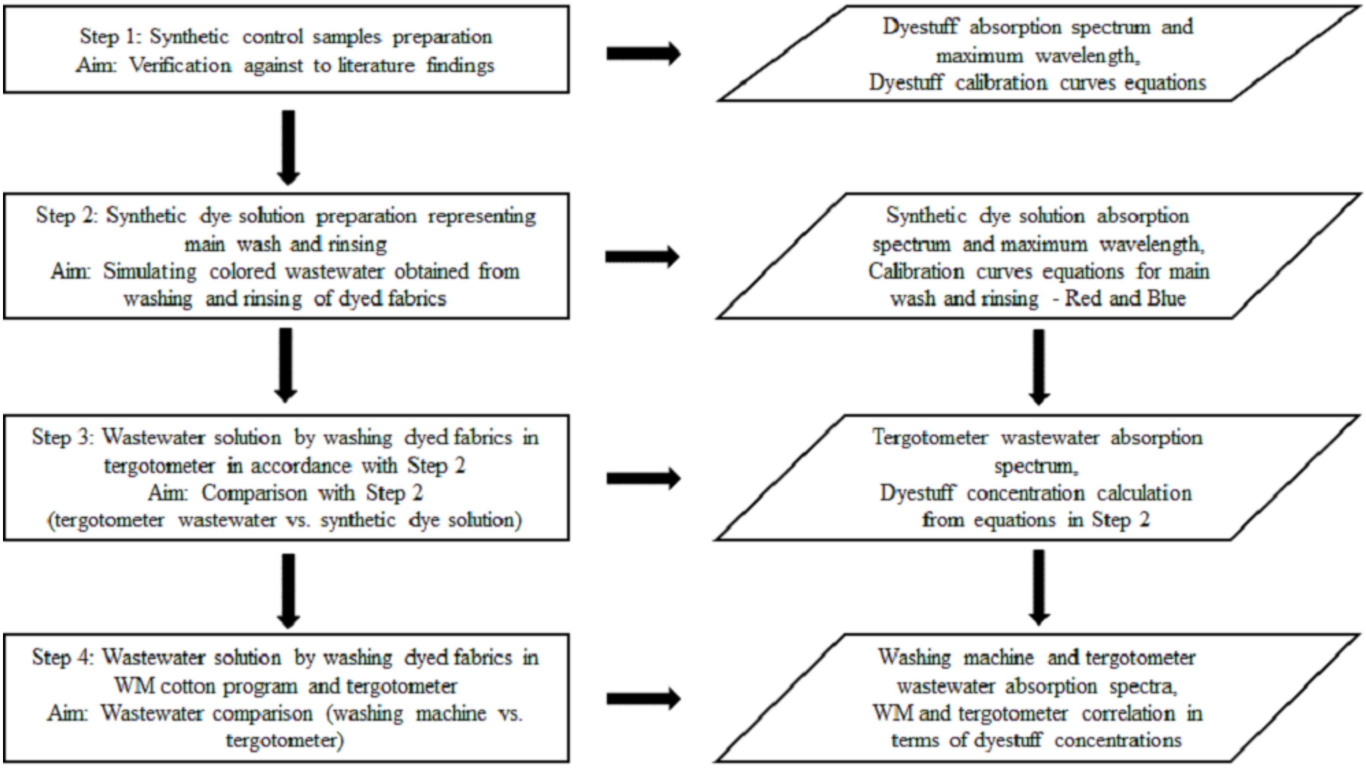


Reactive Red 195 C.I. Reactive Blue 19

Figure 1. Chemical structure of the studied dyes.

Table 2. Dyed fabrics

Fabric Construction	Color	Commercial Dyestuff	Dyestuff Percentage (%)
96% Cotton/ 4% Elastane, Single Jersey	Red	Reaktoset Red RFT	4,2
		Reaktoset Yellow RFT	3,78
		Sunfix Red s2b	2,99
96% Cotton/ 4% Elastane, Single Jersey	Blue	Reaktoset BRL Blue R SPEC	4,41
		Reaktoset Red RFT	0,157
		Reaktoset Yellow RFT	0,0315



WM refers to washing machine

Figure 2. The methodology for the experimental work.

temperature: 15 ± 2°C), and IEC reference detergent type A* was prepared according to EN60456 [37].

The preliminary work showed that the dye concentration of main washes in domestic laundering machines was approximately 3–4 times of that of the rinsing. Accordingly, the synthetic dye solutions representing main wash and rinsing cycles were prepared in the tergotometer using Red and Blue dyestuffs at two different sets of concentrations, namely 10 – 20 – 30 – 45 – 60 – 75 – 90 – 100 mg/L for main wash and 1 – 5 – 10 – 15 – 20 – 25 – 30 – 40 mg/L for rinsing. The set for the main wash (1 L) was mixed in the tergotometer at the speed of 52 rpm for 60 min. The solution temperature was 40°C. On the other hand, for the set of dye solutions (1 L) for rinsing, the tergotometer was run at 52 rpm for 5 min, and the solution temperature was 15°C.

To eliminate the noise caused by the detergent presence on the absorption spectra, a blank solution, which contained conditioned water and detergent except dyestuff (the one to be analyzed), was also prepared for Step 2. Then, the synthetic dye solutions including both dyestuff and detergent were scanned against a blank solution with detergent.

Finally, the maximum absorbance values of the two sets of the synthetic dye solutions were measured at the relevant wavelength with VIS Spectrophotometer.

2.2.2. Wastewater solution preparation in tergotometer

For Step 3, the wastewater solutions were prepared using the tergotometer. In doing so, 50 g of the dyed fabrics (Red and Blue in 10 x 10 cm pieces) were separately washed under the conditions given for Step 2 (i.e., main wash with 4.6 g/L IEC A* detergent at 40°C) followed by rinsing with fresh water at 15°C. The water amount was 1 L, and the stirring speed was 52 rpm for 60 min for the main wash and 5 min for the rinsing, respectively.

Table 3. Washing conditions of domestic washing machine and tergotometer as a simulator

Washing Device	Load Amount (g)	Water Amount (L)	Wash Liquor Ratio (fabric/water)	Temperature (°C)	Detergent Concentration (g/L)	Rotational Speed (rpm)	Duration (min)	Main Wash Duration (min)
WM - Cotton Program	500	10	1:20	20	4.6	52	160	100
				40				
				60				
Tergotometer	50	1		20				
				40				
				60				

2.2.3. Wastewater solution preparation in washing machine

For Step 4, the wastewater solutions were prepared by using a domestic laundering machine. In this part of the work, it was also investigated whether tergotometer could be used as a simulator of domestic washing machine for various washing conditions given in Table 3.

The spinning speed between the main wash and rinsing steps was 1,000 rpm, whereas in the case of tergotometer, the fabric samples were squeezed by hand to remove excess water just before rinsing. Fresh water (1 L) at 15°C was added to the vessel, so that the samples were rinsed for 10 min.

3. Results and discussion

For Step 1, the wavelength giving the maximum absorbance value from the absorption spectrum was found at 540 nm for the Red dye solution and 592 nm for the Blue dye solution, which complies with the literature survey [15, 16, 38–41]. In addition, the maximum absorbance values were measured at 420 nm for Reaktoset Yellow RFT and at 534 nm for Sunfix Red s2b.

Finally, the equations of the calibration curves obtained for Step 1 are given by:

$$A = 0.0192C - 0.0010\left(R^2 = 0.9997\right) \text{ for Red} \quad (1)$$

$$A = 0.0126C + 0.0109\left(R^2 = 0.9998\right) \text{ for Blue} \quad (2)$$

For Step 2, the solutions of 75 and 20 mg/L being the closest concentrations representing the main wash and rinsing cycles, respectively, were selected for demonstration and the absorption spectra for the Red and Blue dyestuff solutions simulating the main wash and the rinsing, which are shown in Figures 3 and 4.

As shown in Figures 3 and 4, the maximum absorbance value was recorded at 540 nm for the Red dye solution, whereas it was 594 nm for the Blue dye solution. Therefore, the equations

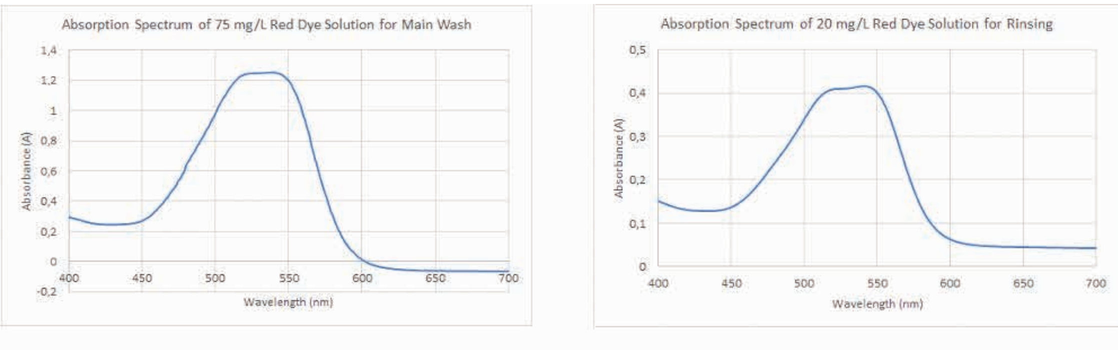


Figure 3. Absorption spectra of the Red dye solution for Step 2: (A) main wash and (B) rinsing.

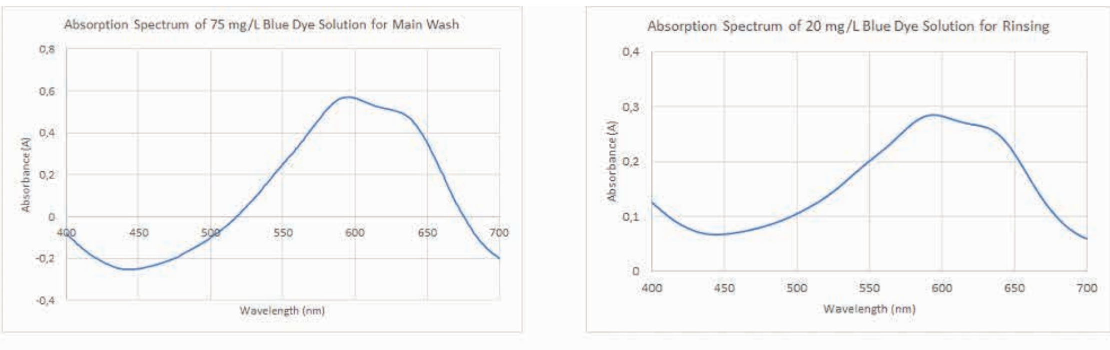


Figure 4. Absorption spectra of the Blue dye solution for Step 2: (A) main wash and (B) rinsing.

of the calibration curves obtained for the main wash and rinsing cycles are given as follows:

$$A = 0.0169C - 0.0942 \ (R^2 = 0.9959) \text{ for Red main wash} \quad (3)$$

$$A = 0.0107C - 0.0832 \ (R^2 = 0.9966) \text{ for Blue main wash} \quad (4)$$

$$A = 0.0186C + 0.0427 \ (R^2 = 0.9997) \text{ for Red rinsing} \quad (5)$$

$$A = 0.0115C + 0.0540 \ (R^2 = 0.9956) \text{ for Blue rinsing} \quad (6)$$

where A stands for absorbance and C refers to dyestuff concentration.

A comparative study of Figures 3 and 4 revealed that the Red dye solution gave higher absorbance value than the Blue one. This may partially be attributed to their chemical structure and properties, particularly the difference in size of the dye molecules (Table 1 and Figure 1) [42]. As was suggested in the literature [43], due to the steric hindrance associated with the size of the dyes, a higher adsorption capacity may have been achieved for small dye molecules. Also, Beer–Lambert Law, namely A = $\varepsilon\lambda \cdot b \cdot c$, states that measured absorbance (A) increases linearly with wavelength-dependent molar absorptivity coefficient $\varepsilon\lambda$, path length (b), and concentration (c). As given by Eqs (1) and (2), the molar absorptivity of Red (0,0192) was higher than Blue (0,0126), which supported why the red dye solution gave higher absorbance values than the blue one for the same concentration. Irrespective of the type of the dyestuff (i.e., Red or Blue), the absorbance value of the concentrated dye solution (i.e., main wash) was higher than that of the diluted dye solution (i.e., rinsing).

For Step 3, the absorbance values of the wastewater solutions obtained at 540 nm for the red and 592 nm for the blue were used to calculate dyestuff concentration by using Eqs (3)–(6) (Table 4).

Table 4. Dyestuff concentration of the wastewater solutions

Concentration (mg/L)	Main Wash (Eqs. 3, 4)	Rinsing (Eqs. 5, 6)
Red	61,7	25,7
Blue	73,1	34,3

In Figure 5A,B, the absorption spectra of the wastewater solutions (main wash and rinsing) are given versus that of the selected synthetic dye solutions from Step 2 (Table 4).

Figure 5A,B shows that the absorption spectra of the wastewater solutions were significantly different from that of the synthetic dye solutions. There were no strong peaks for the wastewater solutions. This was mainly because of the fact that unlike the synthetic solutions, they contained not only one dyestuff but also auxiliary chemicals as well as dyestuff combination (Table 2) causing more chaotic medium. On the other hand, in Figure 5, the absorbance value of main wash or rinse wastewater at the relevant wavelength was close to that of the synthetic dye solution whose concentration value was the nearest concentration value in Table 4.

For Step 4, the absorption spectra of the colored wastewater obtained from the main wash and rinsing of the fabric samples in domestic washing machine (WM) and tergotometer (T) are comparatively presented in Figure 6A,B.

As may be seen from Figure 6, the wavelength giving the maximum absorbance value was shifted to 518 nm for the wastewater solution released from red dyed fabric. This may be due to the fact that in addition to RR 195, the dyes Reaktoset Yellow RFT and Sunfix Red s2b, wavelengths of which were 420 and 534 nm, were also released from the fabric sample during washing. On the other hand, no change was observed for the relevant wavelength of the wastewater solution released from the blue dyed fabric sample because the blue mainly consisted of Reaktoset BRL Blue R SPEC (i.e., the Blue dyestuff), whereas the other compounds were present in trace amounts (Table 2). This is in agreement with Beer–Lambert Law, so that if multiple substances that absorb light at a given wavelength are present in a sample, the total absorbance of a solution at a given wavelength is equal to the sum of the absorption of absorbing substances in the solution [44]. As a final note, in the case of the tergotometer trials, the absorbance values seemed to be higher than those obtained for the domestic washing machine ones. This may be because of the fact that the samples had to be squeezed by hand in tergotometer, which in turn may have caused inefficient removal of the wastewater solution.

For the washing machine (WM) and tergotometer (T), the absorbance values of the red and blue wastewater solutions

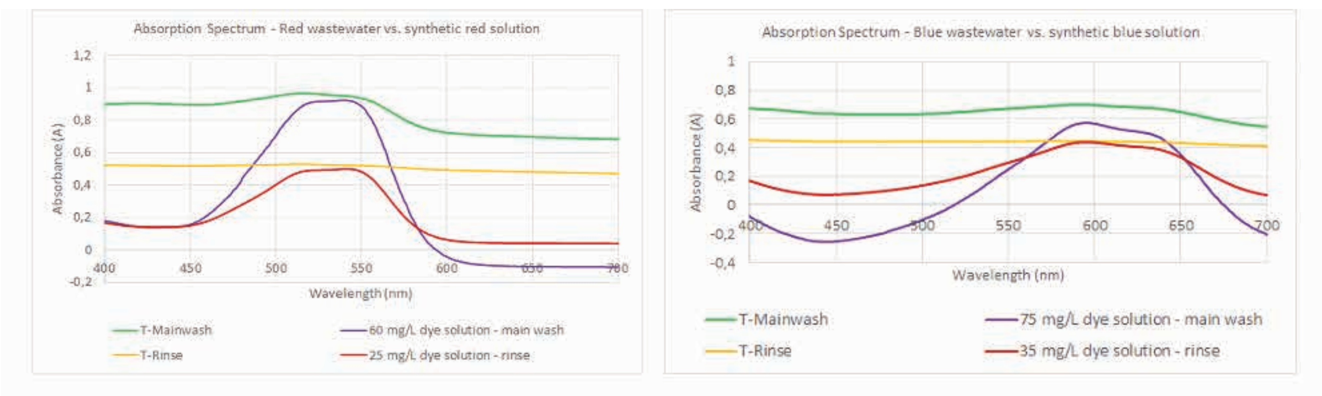


Figure 5. Absorption spectra of wastewater versus synthetic dye solutions (A) Red and (B) Blue.

from the main wash and the rinsing at the wavelength of 540 and 592 nm are shown in Figures 7 and 8.

The figures showed that the absorbance values slightly increased as the temperature increased. Moreover, the main difference in the absorbance values was significantly dependent on the washing steps (i.e., main wash or rinsing). So, as far as both washing devices (i.e. WM and tergotometer) were concerned, the absorbance values of the wastewater solutions from the main wash were higher than those of the ones from the rinsing. Furthermore, the tergotometer gave higher absorbance values especially for the rinsing compared to the main wash, which may be because of lack of efficient spinning process.

The correlation analysis between the washing machine and tergotometer absorbance data for the red and blue wastewater solutions is shown in Figure 9.

The Pearson correlation coefficients between the washing machine and tergotometer absorbance values were found to be 0.983 (*p*-value 0.000) and 0.948 (*p*-value 0.000) for the red and blue wastewater solutions, respectively, which referred to the presence of a strong relationship between these devices. By using Eqs (3)–(6), the wastewater concentrations were calculated from the absorbance values, which are shown in Figures 7 and 8. The average values of these concentrations are presented in Table 5.

The Pearson correlation coefficients calculated for the dyestuff concentrations were 0.993 (*p*-value 0.000) and 0.972 (*p*-value 0.001) for the red and blue wastewater solutions, respectively. Thus, it may be concluded that tergotometer can be used as a domestic washing machine simulator for the purpose.

As the literature suggests [45–47], color transfer is influenced by washing machine type (horizontal or vertical axis), water temperature, and detergent type. Reducing water usage increases the potential for color transfer [45]. Also, heat, moisture, alkali, and oxidizing bleach result in hydrolysis of the dye–fiber bond causing dye desorption during washing and rinsing. Domestic washing conditions (time, temperature, detergent, and detergent concentration) may influence the performance of dye during the life cycle of garment [46]. In reactive dye class for cellulose fiber, the estimated loss to effluent percentage is between 10 and 50%, which is the widest range of different dye/fiber combinations [47]. Regarding these literature findings, a regression analysis was performed to find out the factors affecting the dyestuff concentration both in domestic washing machine and tergotometer as a simulator (Table 5). Color/dyestuff type (Red, Blue), washing device (WM and tergotometer), washing step (main wash and rinse), and temperature (20, 40, 60°C for main wash and 15°C constant for rinsing) were the parameters influencing the dyestuff concentration. The model summary gave R^2 (adj) value of 93.54%. The most significant factor was the washing step with 89.5% (*p*-value 0.000), followed by the color/dyestuff type with

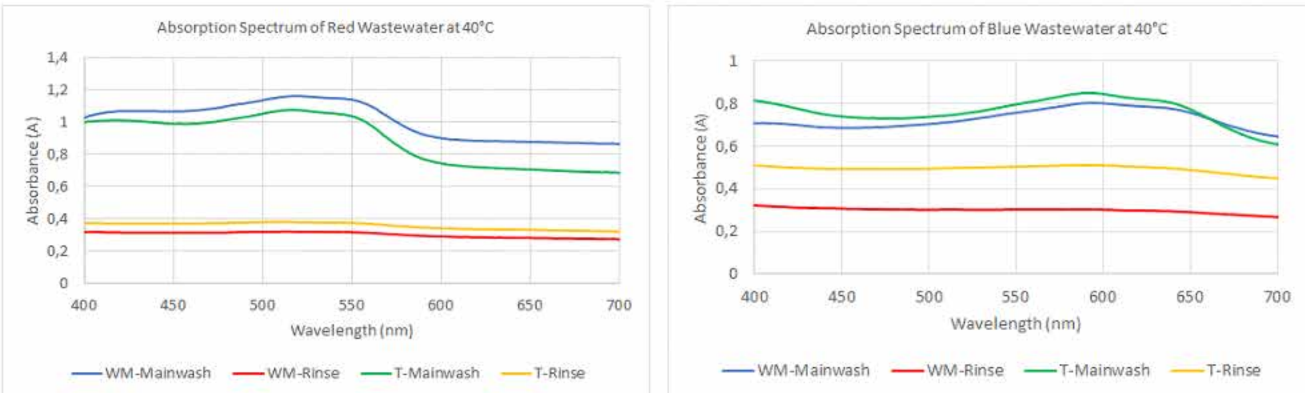


Figure 6. The absorption spectra of the wastewater solution from washing machine and tergotometer: (A) Red and (B) Blue.

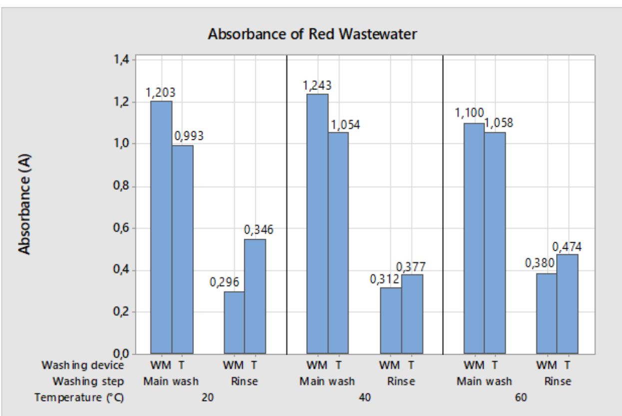


Figure 7. The absorbance values of the wastewater solutions released from the red fabrics.

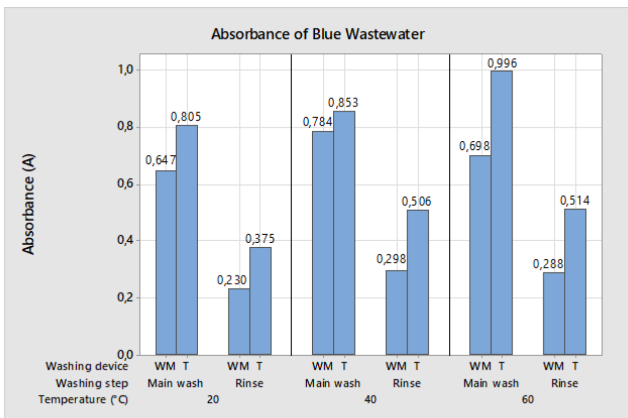


Figure 8. The absorbance values of the wastewater solutions released from the blue fabrics.

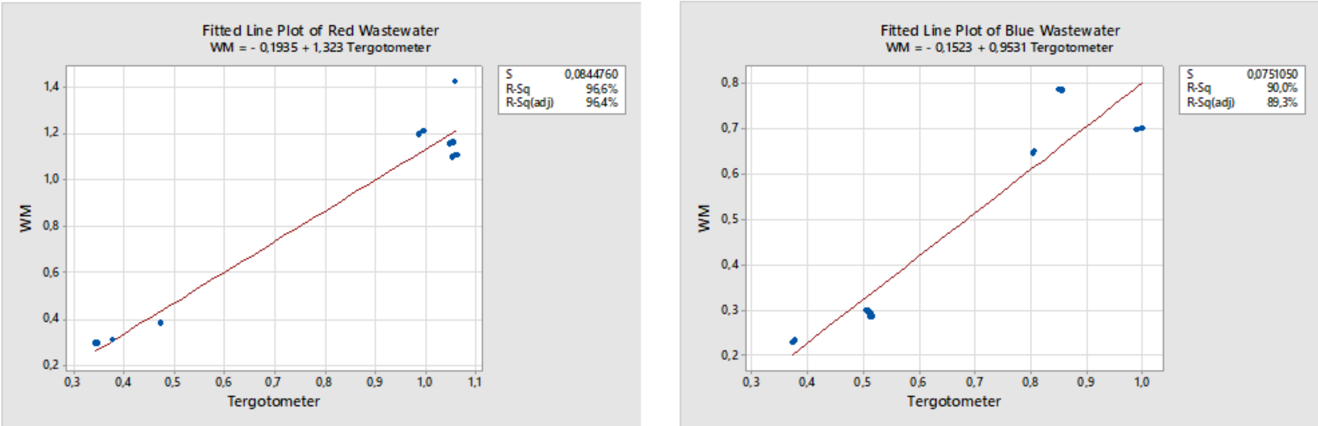


Figure 9. Correlation analysis between the washing machine and tergotometer for the red and blue wastewater solutions.

Table 5. Red and blue dyestuff concentrations of the wastewater solutions from domestic washing machine and tergotometer

Temperature (°C)	Washing Step	Red		Blue	
		C_{WM} (mg/L)	C_T (mg/L)	C_{WM} (mg/L)	C_T (mg/L)
20	Main wash	76,8	64,3	68,2	83
15	Rinse	13,6	16,3	15,3	27,9
40	Main wash	79,1	67,9	81	87,5
15	Rinse	14,5	18,0	21,2	39,3
60	Main wash	70,7	68,2	73	100,9
15	Rinse	18,1	23,2	20,3	40

*WM refers to washing machine, where T refers to tergotometer.

3.4% (*p*-value 0.002) and by the washing device with 1.5% (*p*-value 0.032) in 95% confidence level. There was only a very slight effect of washing device on the dyestuff concentration. The model implied that the temperature was ineffective on dye concentration, which may be because of the fact that it was only changed in the main wash and not in the rinsing cycle.

4. CONCLUSION

The study discussed in this article focused on developing a methodology to estimate the dye concentration in chaotic wastewater obtained from the domestic machine laundering of dyed textiles. For this purpose, an approach using synthetic red and blue reactive dye solutions for the estimation of the concentration was adopted. This was followed by washing trials of dyed fabrics involving the calculation of dye concentration in the wastewater obtained from domestic washing machine and from tergotometer as a simulator. The significant results of the work are as follows:

1. The maximum absorbance values for the red and blue synthetic dye solutions were recorded at 540 and 594 nm, respectively. Based on the representative synthetic dye solutions prepared for main wash and rinse, the relevant calibration curves of the red and blue dyestuff solutions were formulated for main wash and rinsing. Using calibration curves, it could be possible to estimate the dyestuff concentration of wastewater obtained from main wash and rinse.

2. When it comes to the characteristics of wastewater solutions obtained from the domestic washing machine and/or tergotometer trials, the maximum absorbance values were measured at the wavelength of 518 and 590 nm for the red and blue wastewater in turn, though the peaks observed within the scanned wavelength range were not as strong as the ones observed for the synthetic dye solutions.

3. Regarding the factors affecting dyestuff concentration, the washing step was found to be significantly effective followed by the color/dyestuff type, and washing device was found to be very slightly effective.

4. The statistical analysis regarding the red and blue dyestuff concentrations obtained from the washing machine and tergotometer suggested that tergotometer can be used as a domestic washing machine simulator.

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