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Broadbent, PJ, Carr, CM, Rigout, M orcid.org/0000-0002-4894-7768 et al. (4 more authors) (2018) Investigation into the dyeing of wool with Lanasol and Remazol reactive dyes in seawater. Coloration Technology, 134 (2). pp. 156-161. ISSN 1472-3581

https://doi.org/10.1111/cote.12329

Investigation into the Dyeing of Wool with Lanasol and Remazol Reactive Dyes in Seawater

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Abstract

Freshwater is an increasingly scarce resource which is extensively used in textile wet processing. In seeking to identify alternative low freshwater usage colouration technology this study examined the potential use of seawater (SEAW) as the dyeing medium for wool colouration. Initially the dyeing behaviour in simulated seawater (SSW) was compared against conventional dyeing from distilled water (DW) in terms of dye exhaustion, dye fixation, colour yield, colour difference and levelness of the α-bromoacrylamide based Lanasol dyes and sulphatoethylsulphone based Remazol dyes. These encouraging SSW studies demonstrated that comparable colouration performance could be achieved in simulated seawater dyeing. Subsequent "real" seawater dyeing studies of wool with a range of reactive dyes again confirmed that comparable colouration performance could be achieved highlighting the potential for substituting freshwater with much more plentiful seawater as the dyeing medium.

Keywords: Seawater, wool, dyeing, reactive dyes.

Introduction

Water is the application medium for wet chemical processing of textiles, with textile mills typically located in areas where the freshwater supply is sufficiently clean and plentiful throughout the year [1]. However according to a United Nations report on water resources, by 2025 two thirds of the world will suffer from a lack of freshwater, with the main sector areas affected being agriculture, energy and domestic consumption [2]. High population growth, scarcity of natural water resources and lack of investment in infrastructure will all contribute to the future potential water shortage [3, 4].

The consumption of freshwater in textile processing varies considerably depending on the fibre type, the complexity of processing and the processing equipment used [5 - 10]. However in all these various approaches to wet processing of textiles water is a significant, increasing cost and is encouraging the industry to explore alternative processing media [11, 12].

Oceanic saltwater contributes 97.5% of the earth's water, with freshwater only providing the remaining 2.5%. Even then the majority of that freshwater is inaccessible, since it is present in the form of snow and ice in remote locations. Similarly groundwater, which contributes approximately 30% of the freshwater total, is again not always readily available. Therefore the most accessible and economic water sources are located in lakes, rivers and reservoirs but these sources only provide 0.26% of the total water resource [13]. In contrast the much more abundant seawater is little used except where freshwater is so scarce that desalination processing is necessary to remove the dissolved salts to provide freshwater. Dissolved in seawater are mainly chloride, sodium, sulphate, magnesium, calcium, potassium, bicarbonate, bromide, strontium, borate and fluoride ions with sodium chloride contributing over 86% by mass [14, 15, 16]. Traditionally in textile processing the quality of freshwater is regarded as vital to successful processing but over the years textile dye chemical manufacturers have developed more robust formulations which are able to function efficiently over a broader range of processing conditions in the dyehouse.

Reactive dyes are extensively used for wool colouration with their excellent fastness performance related primarily to the high levels of exhaustion, covalent fixation of the dye to the fibre and less to the molecular size and polarity necessary for alternative acid dyes [17, 18, 19]. The major reactive dye classes for wool are the Lanasol α-bromoacrylamide reactive dyes and the Remazol sulphatoethyl sulphone dyes, with the Lanasols currently the market leader in terms of usage. In delivering high wash fastness the Lanasol dyes react with wool by nucleophilic substitution and nucleophilic addition mechanisms while the Remazol dyes covalently bond through a nucleophilic addition mechanism. Following the after-soaping and rinsing processes when hydrolysed and unreacted dye are removed from the fibre the covalently bound reactive dyes offer excellent wash fastness and rub fastness. Therefore this study examines the potential of using seawater as a textile processing medium and assesses the applicability of the current "robust" freshwater-based commercial dyeing processes to the colouration of wool in simulated seawater and then actual seawater. The comparative quality of the wool dyeing with Reactive dyes in both distilled water (DW), simulated seawater

(SSW) and seawater (SEAW) have been evaluated in terms of dye bath exhaustion, fixation and colouration.

Experimental

Materials

A woven 100% wool botany serge (2/2 twill, scoured and set) fabric (295 g/m^2) was supplied by Whaley's (Bradford) Ltd and was used for the distilled water and simulated seawater dyeings in the UK. A hydrogen peroxide bleached 100% wool fabric (knitted single jersey, 195 g/m^2), Tropic Knits Ltd., Mauritius) was used for distilled water and seawater dyeing studies performed in Mauritius.

The Lanasol α-bromoacrylamide reactive dyes were kindly supplied by Huntsman and were used without further purification. The dyes evaluated were Lanasol Red 6G (C. I. Reactive Red 84), Lanasol Blue 3G (C. I. Reactive Blue 69), Lanasol Yellow 4G (C. I. Reactive Yellow 39) and Lanasol Deep Black CE-2B (proprietary mixture containing 60% C. I. Reactive Black 5). The Remazol sulphatoethyl sulphone dyes were supplied by Pharmacie Nouvelle, Mauritius and used without purification. The dyes evaluated were Remazol Brilliant Violet 5R (C. I. Reactive Violet 5), Remazol Brilliant Red 3BS (C. I. Reactive Red 239), Remazol Brilliant Blue R (C. I. Reactive Blue 19), Remazol Yellow 3RS (C. I. Reactive Yellow 176) and Remazol Black B (C. I. Reactive Black 5).

Simulated Seawater (SSW) Composition

SSW was prepared according to the literature [16] but with the omission of minor components such as KBr, H_3BO_3, NaF and $SrCl_2.H_2O$, Table 1. Laboratory grade salts were used throughout and distilled water was used as the diluent. The pH of SSW was 7.80 at 19.6°C.

Insert Table 1

Wool Dyeing

All Lanasol dyeings were performed using a Mathis IR lab dyeing machine, at a liquor to goods ratio of 10:1 and a pH of 5.5. The dye application levels were 0.5, 1.0 and 2.0% on mass of fibre (o.m.f.) for the Lanasol Red, Blue, Yellow and Black dyes. The dyeings followed recommended manufacturer's conditions and were commenced at 50ºC, then raised to 70ºC at 1ºC per minute over 20 minutes, then raised to 98°C at 1ºC per minute and the dyebath then maintained at 98ºC for 60 minutes. The dyebath was then cooled to 80ºC at 1ºC per minute and 1% o.m.f. ammonium hydroxide (0.88M) added. The dyebath was maintained at 80°C for 20 minutes and then cooled to 30°C. In addition to the dye, the aqueous bath contained a levelling agent, 2.0% o.m.f. Albegal B, and sufficient acetic acid to give a final pH of 5.5. The recommended 10% (o.m.f.) sodium sulphate was not added to seawater baths for the dyeings. The dyeings were performed in duplicate to confirm reproducibility. All wool fabrics were pre-wetted by soaking in 2 g/L Invadine O at 40°C for 30 minutes.

All Remazol dyeings on the hydrogen peroxide bleached wool fabric were performed using a Mathis IR lab dyeing machine at a liquor to goods ratio of 10:1 and a pH of 5.5. The dye application levels were 0.5, 1.0 and 2.0% on mass of fibre (o.m.f.) for the Remazol Red, Blue, Yellow and Black dyes. The dyeings were commenced at 50ºC, raised to 70ºC at 1ºC per minute and maintained at 70ºC for 20 minutes. The dyebath was then raised to 98ºC at 1ºC per minute and maintained at 98ºC for 60 minutes. The dyebath was then cooled to 80ºC at 1ºC per minute, 1% o.m.f. ammonium hydroxide (0.88M) was then added in order to adjust the bath pH to 8.5 and the dyebath maintained at 80ºC for 20 minutes. The dyebath was then cooled to 30ºC at 1ºC per minute. In addition to the dye, the aqueous bath contained a levelling agent, 2.0% o.m.f. Albegal B, and was adjusted to pH 5.5 using acetic acid. The recommended 4% sodium sulphate was not added to seawater dyeing baths. The dyeings were performed in duplicate to confirm reproducibility. All wool fabrics were pre-wetted by soaking in 2 g/L Invadine O at 40°C for 30 minutes.

The dyed Lanasol and Remazol fabric samples were rinsed using distilled water and given a washing-off procedure using Hostapal NIN at 1.0 g/L, for 20 minutes at 60ºC. The washing-off process was repeated until no further unfixed dye was removed from the dyed fabric. The wool fabrics were then given a final rinsing with distilled water, hand-squeezed and left to air-dry overnight.

Colour Analysis

Dye exhaustion (%E) from solution was determined using a UV-Visible spectrophotometer and calculated using Equation 1:

$$\text{Dye Exhaustion (\%E)} = \frac{(Abs_{t=0} - Abs_t)}{Abs_{t=0}} \times 100 \qquad \text{Equation 1}$$

$$\text{Total Efficiency (T)} = \frac{(Abs_{t=0} - Abs_t - Abs_{S1} - Abs_{S\,2} - Abs_{S3} - Abs_{S4})}{Abs_{t=0}} \times 100 \qquad \text{Equation 2}$$

Where $Abs_{t=0}$ is the optical density of the dyebath, at λ_{max}, prior to dyeing, Abs_t is the optical density of the exhausted dyebath and Abs_{S1}, Abs_{S2}, Abs_{S3} and Abs_{S4} are the optical densities of the soap-off baths.

Dye fixation (F) was calculated using Equation 3:

$$\text{Fixation (F)} = \frac{T}{E} \times 100 \qquad \text{Equation 3}$$

The colour strength (K/S) was calculated from reflectance measurements using the single constant Kubelka-Munk equation, Equation 4:

$$\left(\frac{K}{S}\right)_{\lambda} = \frac{(1 - R_{\lambda})^2}{2R_{\lambda}}$$ Equation 4

Where K is the coefficient of absorption, S is the coefficient of scatter, R is reflectance expressed as a proportional value and λ is the wavelength at maximum absorption.

The K/S and CIE L*a*b* values were calculated from the mean of four reflectance measurements obtained using a Datacolor Spectroflash 600 spectrophotometer. The CIE L*a*b* values of the twice folded fabrics were calculated under illuminant D65 using a 10° standard observer and the K/S values were calculated at the λ_{max} of the dyed fabric.

The colour difference, ΔE^*_{94}, of the fabrics was determined using a Datacolor Spectroflash 600 spectrophotometer according to the CIE L*a*b* 1994 colour difference equation using the D_{65} illuminant and a 10° standard observer angle (SAV/Spec. Excl., d/8). Each fabric was folded twice and the mean of four readings calculated.

Seawater Filtration

The seawater was obtained off the east coast of Mauritius at Belle Mare and prior to usage, was filtered using a Büchner suction filtration system with a Whatman filter paper, grade 3.

Results and Discussion

Over the last 60 years commercial dyes and dyeing methodologies have been developed to be more robust to variations away from the optimum application pH, temperature or the presence of dyebath contaminants and still be able to deliver commercially acceptable exhaustion, colour and fastness performance. In a preliminary assessment of the Lanasol and Remazol dyes the solubility and light absorption behaviour of the eight reactive dyes were evaluated and it was found there was little change in the λ_{max} of the dissolved dyes in DW, SSW and SEAW. The light absorption of the dyes increased linearly with dye concentration and followed the Beer-Lambert Law. For the SSW and SEAW dyeings the addition of sodium sulphate was omitted as it was expected the natural levels of electrolyte in the seawater would function adequately in supporting the dyeing process.

At depths of 0.5, 1.0% and 2.0% o.m.f. the Lanasol dyes were soluble in SSW and SEAW at room temperature and it was anticipated that as the temperature of the dyebath increased any non-solubilised colorant would dissolve at the higher temperatures. Exhaustion and fixation data are presented in Table 2 and the data demonstrates that all four dyes have high exhaustion values onto the wool fabric in both DW and SSW. In addition all the dyed fabrics showed level colouration suggesting the Albegal B was an effective levelling agent even in presence of hard water ions.

INSERT TABLE 2

Examination of Table 2 also indicates there was a consistent build-up of colour on the wool fabrics, both in the DW and SSW dyeings. It was evident that the red, blue and yellow dyeings in DS produced coloured wool fabrics with marginally lower colour strength values, K/S, than for the comparable SSW dyeings, while for the Lanasol Black colour strength was marginally lower for the SSW dyeings. Nevertheless the exhaustion, fixation and overall depth of shades obtained for the Lanasol dyeings in SSW were still commercially acceptable. Assessment of the associated wash fastness, dry and wet rub fastness, light fastness and perspiration fastness of the dyed fabrics produced through the two aqueous media indicated there was comparable fastness performance properties.

Examination of Tables 3 and 4 indicated that wool can be successfully dyed in filtered Mauritian seawater, SEAW, and that the levelness and colour strength obtained with Lanasol reactive dyes was comparable to that achieved dyeing in distilled water. Increasing the dye concentration in the seawater dyeings resulted in a progressive increase of colour depth on the wool fabric similar to that observed on the comparable distilled water dyeings. In this study the seawater was simply filtered through Whatman filter paper as the Mauritian seawater was particularly clean with little industrial or domestic pollution. However for seawater sourced off other parts of the world where levels of industrial and domestic effluent is more obvious, more rigorous filtration may be necessary to provide a suitable dyeing medium. Nevertheless these results are encouraging in terms that commercial levels of colour depth and levelness could be achieved in seawater.

INSERT TABLE 3 AND TABLE 4

The second major class of reactive dyes for wool are the Remazol dyes which have a vinyl sulphone-based reactive functionality. Examination of the colour profile and colour strength of the comparable DS and SSW Remazol dyeings indicated in this reactive colorant system the DW dyeings were marginally deeper in shade. Nevertheless the exhaustion, fixation and overall depth of shades obtained in SSW were still acceptable, Table 5, and it is again reassuring that the Remazol dyeings on wool mirrored the behaviour of the Lanasols in the comparative distilled and simulated seawater trials.

INSERT TABLE 5

Examination of Tables 6 and 7 indicated that wool can be successfully dyed in filtered Mauritian seawater and that the levelness and colour strength obtained with Remazol reactive dyes was comparable to that achieved dyeing in distilled water. Increasing the dye concentration application in the seawater dyeings resulted in a progressive increase of colour depth on the wool fabric similar to that observed on the comparable distilled water dyeings. The colorimetric properties of the wool fabrics dyed in distilled water and seawater were similar and were encouraging in terms that commercial colour depths could be achieved. Further the wash and rub fastness of the wool fabrics dyed in distilled water and seawater were found to be comparable.

INSERT TABLE 6 AND TABLE 7

Conclusions

A major challenge for textile wet processors is to address the increasing cost and competitive demand associated with the usage of freshwater in industrialised countries. Traditionally textile dyers have been located away from the coast in to areas with ready access to freshwater which can support commercial dyeing activities. However in recent years there have been significant water shortages in traditional textile dyeing areas and alternative colouration technologies based on low liquor processing, waterless dyeing and SCF dyeing have been developed as solutions to this logistical challenge. In this paper the potential for dyeing wool with commercial reactive dyes in seawater has been investigated. The results indicate that it is possible to achieve level dyeings on the wool fabric using seawater as the dyeing medium and that by increasing the Lanasol or Remazol reactive dye applications progressively deeper depths of shade can be obtained similar to that observed with distilled water dyeings. In addition the levels of dye exhaustion and fixation obtained using seawater were comparable to that achieved in distilled water and comparable fastness performance was found on the seawater dyed fabrics.

In conclusion while the initial results with reactive dyes on wool are encouraging further work using other dye classes and textile fibres are underway to establish the wider commercial feasibility of this wet processing approach.

Acknowledgements

The authors are grateful to the Association of Commonwealth Universities (ACU) for supporting the researcher, MAU, with a Commonwealth scholarship.

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Salt	Concentration, g/L	Molarity, M
NaCl	24.72	0.425
KCl	0.67	0.009
$CaCl_2$	1.03	0.0093
$MgSO_4.7H_2O$	6.29	0.0255
$MgCl_2.6H_2O$	4.66	0.023
$NaHCO_3$	0.18	0.002

Table 1. Composition of simulated seawater (SSW) used in this study [16].

Dye (% o.m.f)	E (%)	T (%)	F (%)	K/S	E (%)[1]	T (%)[1]	F (%)[1]	K/S[1]
0.5% Lanasol Red GN	93.8	90.5	96.5	5.3	98.1	91.5	92.9	5.8
1.0% Lanasol Red GN	91.3	88.9	97.4	10.1	97.4	91.5	93.9	10.2
2.0% Lanasol Red GN	91.0	89.1	98.0	17.4	96.5	90.2	93.5	18.4
0.5% Lanasol Blue 3G	96.4	90.2	93.6	4.6	98.0	87.0	88.8	4.9
1.0% Lanasol Blue 3G	95.7	88.9	92.9	9.5	98.1	89.4	91.1	10.3
2.0% Lanasol Blue 3G	96.3	87.8	93.2	18.0	97.8	90.5	92.6	20.9
0.5% Lanasol Yellow 4G	90.2	82.3	91.2	6.6	91.6	67.9	74.1	6.5
1.0% Lanasol Yellow 4G	87.4	81.1	92.8	12.5	92.7	75.2	81.2	13.6
2.0% Lanasol Yellow 4G	85.8	79.4	92.6	21.8	91.1	73.6	80.8	23.4
0.5% Lanasol Deep Black CE-2B	95.6	93.4	97.8	8.6	98.7	92.0	93.2	7.2
1.0% Lanasol Deep Black CE-2B	92.0	90.2	98.0	13.5	97.7	93.7	95.8	13.5
2.0% Lanasol Deep Black CE-2B	84.9	83.4	98.3	21.8	98.5	89.7	91.1	21.0

Table 2. Dye exhaustion, % E, Total efficiency, %T, and Dye Fixation, % F, for wool fabric dyed with Lanasol Reactive dyes in distilled water and simulated seawater.

[1] Dyeings in simulated seawater.

Dye (% o.m.f.)	L*	a*	b*	K/S	ΔE+
0.5% Lanasol Red GN (DW)	51.5	52.0	3.3	5.6	1.6
1.0% Lanasol Red GN (DW)	45.0	56.1	6.6	11.3	0.2
2.0% Lanasol Red GN (DW)	39.8	57.7	11.6	20.9	0.4
0.5% Lanasol Red GN (SEAW)	52.1	50.7	2.3	5.2	
1.0% Lanasol Red GN (SEAW)	45.1	55.9	6.4	11.1	
2.0% Lanasol Red GN (SEAW)	39.0	57.4	12.0	22.2	
0.5% Lanasol Blue 3G (DW)	44.6	-12.9	-23.4	6.1	1.7
1.0% Lanasol Blue 3G (DW)	37.2	-11.9	-25.7	11.3	0.5
2.0% Lanasol Blue 3G (DW)	29.5	-9.4	-26.7	21.1	1.5
0.5% Lanasol Blue 3G (SEAW)	43.4	-12.8	-24.5	6.9	
1.0% Lanasol Blue 3G (SEAW)	37.0	-11.7	-26.1	11.6	
2.0% Lanasol Blue 3G (SEAW)	30.8	-9.9	-26.2	18.8	

+ ΔE value between comparable dyeings in distilled water and seawater.

Table 3. Colour properties of bleached wool fabric dyed with Lanasol Reactive dyes in Mauritian seawater (SEAW).

Dye (% o.m.f.)	L*	a*	b*	K/S	ΔE+
0.5% Lanasol Yellow 4G (DW)	82.2	-3.0	65.5	6.7	1.8
1.0% Lanasol Yellow 4G (DW)	81.1	-0.4	77.5	13.1	2.2
2.0% Lanasol Yellow 4G (DW)	78.4	2.9	85.9	23.7	0.1
0.5% Lanasol Yellow 4G (SEAW)	81.1	-1.6	65.4	7.3	
1.0% Lanasol Yellow 4G (SEAW)	79.9	0.6	76.0	13.2	
2.0% Lanasol Yellow 4G (SEAW)	78.4	2.8	85.9	23.7	
0.5% Lanasol Deep Black CE-2B (DW)	29.9	-4.4	-3.0	9.9	0.4
1.0% Lanasol Deep Black CE-2B (DW)	21.0	-3.2	-2.9	19.7	0.4
2.0% Lanasol Deep Black CE-2B (DW)	15.2	-1.2	-1.7	29.7	0.3
0.5% Lanasol Deep Black CE-2B (SEAW)	30.0	-4.1	-2.9	9.7	
1.0% Lanasol Deep Black CE-2B (SEAW)	21.3	-3.1	-2.7	19.0	
2.0% Lanasol Deep Black CE-2B (SEAW)	15.5	-1.1	-1.8	28.8	

+ ΔE value between comparable dyeings in distilled water and seawater.

Table 4. Colour properties of bleached wool fabric dyed with Lanasol Reactive dyes in Mauritian seawater (SEAW).

Dye (% o.m.f)	E (%)	T (%)	F (%)	K/S	E (%)[1]	T (%)[1]	F (%)[1]	K/S[1]
0.5% Remazol Brilliant Red 3BS	98.7	93.8	95.0	6.9	94.8	90.1	95.0	6.5
1.0% Remazol Brilliant Red 3BS	97.3	93.5	96.1	13.2	94.3	89.1	94.5	11.4
2.0% Remazol Brilliant Red 3BS	95.9	90.9	94.8	22.4	92.3	87.5	94.8	21.4
0.5% Remazol Brilliant Blue R	98.3	91.2	92.8	5.6	99.6	94.1	94.5	5.0
1.0% Remazol Brilliant Blue R	98.7	92.9	94.1	10.8	99.7	96.2	96.5	9.8
2.0% Remazol Brilliant Blue R	98.8	92.7	93.8	20.4	99.7	95.7	96.0	19.7
0.5% Remazol Yellow 3RS	78.7	72.7	92.4	4.8	91.6	85.3	93.1	5.3
1.0% Remazol Yellow 3RS	78.6	75.3	95.8	8.3	91.2	88.1	96.6	9.4
2.0% Remazol Yellow 3RS	74.2	72.1	97.2	12.5	87.4	84.6	96.8	14.4
0.5% Remazol Black B	99.3	97.6	98.3	9.3	98.3	95.0	96.6	6.8
1.0% Remazol Black B	99.2	97.2	98.1	16.3	96.6	93.3	96.6	14.5
2.0% Remazol Black B	99.1	96.9	97.7	26.0	95.1	91.6	96.3	24.0

Table 5. Dye exhaustion, % E, Total efficiency, %T, and Dye Fixation, % F, for wool fabric dyed with Remazol Reactive dyes in distilled water and simulated seawater.

[1] Dyeings in simulated seawater.

Dye (% o.m.f.)	L*	a*	b*	K/S	ΔE+
0.5% Remazol Violet 5R (DW)	46.1	17.1	-16.5	3.8	1.5
1.0% Remazol Violet 5R (DW)	36.6	19.9	-20.0	7.7	0.8
2.0% Remazol Violet 5R (DW)	26.6	22.1	-21.6	17.7	0.7
0.5% Remazol Violet 5R (SEAW)	43.4	18.2	-17.3	4.6	
1.0% Remazol Violet 5R (SEAW)	36.1	21.0	-21.0	8.2	
2.0% Remazol Violet 5R (SEAW)	27.5	22.7	-22.1	16.5	
0.5% Remazol Brilliant Blue R (DW)	44.5	-3.2	-29.9	5.3	1.3
1.0% Remazol Brilliant Blue R (DW)	34.3	1.7	-35.1	11.9	0.7
2.0% Remazol Brilliant Blue R (DW)	27.4	5.6	-36.1	20.2	0.4
0.5% Remazol Brilliant Blue R (SEAW)	42.5	-2.4	-30.7	6.1	
1.0% Remazol Brilliant Blue R (SEAW)	33.1	2.0	-34.9	13.0	
2.0% Remazol Brilliant Blue R (SEAW)	27.7	5.2	-35.8	19.7	

+ ΔE value between comparable dyeings in distilled water and seawater.

Table 6. Colour properties of bleached wool fabric dyed with Remazol Reactive dyes in distilled and Mauritian seawater.

Dye (% o.m.f.)	L*	a*	b*	K/S	ΔE^{+}
0.5% Remazol Yellow 3RS (DW)	70.1	22.2	56.8	4.9	1.8
1.0% Remazol Yellow 3RS (DW)	66.3	31.8	67.5	10.3	0.9
2.0% Remazol Yellow 3RS (DW)	62.3	37.3	72.3	18.2	0.3
0.5% Remazol Yellow 3RS (SEAW)	70.1	24.8	60.5	5.8	
1.0% Remazol Yellow 3RS (SEAW)	67.0	30.4	67.0	9.6	
2.0% Remazol Yellow 3RS (SEAW)	62.1	36.8	71.9	18.1	
0.5% Remazol Black B (DW)	32.5	-5.7	-13.0	9.9	0.9
1.0% Remazol Black B (DW)	22.4	-3.7	-12.1	21.6	0.3
2.0% Remazol Black B (DW)	15.9	-1.2	-9.1	32.4	0.4
0.5% Remazol Black B (SEAW)	31.1	-5.5	-13.1	11.1	
1.0% Remazol Black B (SEAW)	22.2	-3.6	-12.3	22.1	
2.0% Remazol Black B (SEAW)	15.8	-1.0	-8.8	32.2	

Table 7. Colour properties of bleached wool fabric dyed with Remazol Reactive dyes in distilled and Mauritian seawater.

$^{+}$ ΔE value between comparable dyeings in distilled water and seawater.