IOSR Journal of Polymer and Textile Engineering (IOSR-JPTE)
e-ISSN: 2348-019X, p-ISSN: 2348-0181, Volume 5, Issue 1 (Jan. - Feb. 2018), PP 22-31
www.iosrjournals.org

Investigation of Different Effects of Water Repellent Finishes on Different Knit Dyed Fabrics

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Abstract: *The purpose of this study was to investigate the effects of high performance water repellent finishes on different knit dyed fabrics. The water repellency evaluation tests and the effects of water repellent treatment towards the physical testing systems like GSM test, bursting strength test and hydrostatic head test were been studied. The experiments were done in two parts: the first was to apply different water repellent chemicals on different knit dyed fabrics. The research work includes different chemical concentrations such as 70g/L, 90g/L and 100g/L, pick up ratio 80%, drying temperature 120°C, curing temperature 160°C and curing time 1 minute. The second part was to evaluate the water repellency by drop test and spray test. The physical properties of the fabric were determined through bursting strength test and hydrostatic head test according to the standard testing procedures. Besides these, ISO 105-C06 and ISO 105-X12 methods were used for wash and rubbing fastness respectively. Moreover, the effects of different water repellent treated fabrics and their comparisons with different concentrations were also been studied.*

Keywords: *Water repellent finish; Knit fabric; Chemical; Drop test; Spray test; Physical test; Fastness test.*

Date of Submission: 02-03-2018 Date of acceptance: 17-03-2018

I. Introduction

Water repellent finishing is a treatment applied to textile substrates which prevents penetration of water droplets through the fabric but allows the passage of water vapor and air. It is an important finishing process for cotton and blended fabrics which can be provided without destroying comfort of the fabric. Fabrics that are been treated to resist wetting shed water by causing the water to bead on the surface. It does not close the pores of the fabric as waterproof treatments do, so the fabrics are comfortable to wear. It will offer protection in light shower but not in case of heavy rain [1-3]. Water repellency may be added by treating the fabric withaluminum (Al) andzirconium (Zr) compounds, paraffin emulsions, fluorocarbon based chemicals, silicon compounds, N-methylol compounds, stearic acid-melamine compounds or metal complexes [4]. Water repellent fabrics are used in rain-wear, sportswear, medical bandages, upholstery fabrics for automobiles, headliners, cover tapes for adhesive plasters and outdoor activities.

In the early 1930's there was an increased interest in achieving durable water repellency and it has played an important role in the apparel industry ever since. The existence of inter-molecular attractive forces of polarity and hydrogen bonding imperatively providing strength, heat resistance and dry-cleaning resistance to textile fabric. However, these forces enhance easy wetting of fiber by water offering little resistance to snow and rain for outerwear garments. These problems could be overcome by adding various water repellent chemicals to the fabric either chemically or with mechanical coating. The water repellent compounds cover the outer surface of the fabric with hydrophobic groups. These hydrophobic groups repel water molecules forming a low energy surface and thus resist water absorption.

The formation of permanent covalent bonds between fibers and water repellent chemicals are necessary to produce durable water repellency. The chemical nature of the bond between fiber and water repellent chemicals prevents removal of the water repellent chemical during laundering or dry-cleaning. Pyridinium$[C_5H_5NH]^+$compounds, chromium (Cr) based metal complexes and N-methylol based products accomplish the durable chemical bond formation. These products provide durable water repellent performance. Unfortunately, these compounds are hazardous and toxic to the environment limiting their production. Polysiloxanes can also be applied to textile fabrics based on the hydrogen bonding and mechanical interactions between the fabric and the –Si-O-Si- bonds of the silicone compound along with the network cross link formation within the polysiloxane compound itself [5]. This finish provides semi-durable water repellency.

Fluorocarbon-based repellents provide the best performance of water repellency among all other repellents. They provide the lowest surface energies to fiber surface, which even can improve textiles with oil repellent ability. The polymers of fluorocarbon will form a dense structure of CF_3 when being applied to textile fibers, giving maximal repellency. Fluorochemical repellents have much lower surface energies than hydrophobic and silicon repellents imparting both water repellency and oil repellency together. Due to its hazardous chemical attitudes [6], the use of fluorocarbon based repellents has become limited to textile applications.

II. Experimental

2.1 Materials and Methods

Materials, chemicals and the experimental methods used in this thesis work were available in most of the textile industries. Since availability and cost were major concerns, we tried to use such type of raw materials, chemicals and experimental techniques which were easily available, safe and economical. All the knitted fabrics used in our experiments were made of cotton.

Table 1: Types of knit fabrics used in the experiment with their characteristics

Types of Knit Fabrics Used	Characteristics
Single Jersey	Simplest knit structure, back and face side appearance different, curling tendency prominent, plain can be unroved from the course knitted last or from the course knitted first [7].
Rib	Vertical cord appearance much more prominent, no curling tendency, same appearance on both sides like technical face of plain, thicker and extensibility and elasticity are higher.
Interlock	Appearance like technical face of plain, no curling tendency, horizontal and vertical stripes can be produced, can be unroved from end point.
Polo Pique	A single jersey derivative, a knit-tuck single jersey structure, design repeat consists of four courses of which the first two courses are same, popular structure to produce cut and sew knit wear, prominence of the design appears on the back side of the fabric.

Reactive dye was been used thoroughly as the coloring agent. Reactive dye is a class of highly colored organic substance which chemically reacts with cellulosic or protein fibers in an alkaline dye bath to form covalent bond and becomes a part of fiber. General structure of reactive dye is:S ⟷D ⟷B ⟷RG ⟷X
Where, S = Solubilizing group; D = Dye chromophore; B = Bridging group;RG = Reactive group; X = Leaving group.

Table 2: Water repellent chemicals used

Chemicals Used	Manufacturer	Composition	Application Recipe
Nuva TTC	Archroma	Dispersion of a fluorine compound.	Nuva TTC: 70g/L, 90g/L, 100g/L Acetic acid: 1ml/L as required for p^H 4-5
Rucostar EEE6	Rudolf	Fluorocarbon resin with polymeric, hyper branched dendrimers in a hydrocarbon.	Rucostar EEE6: 70g/L, 90g/L, 100g/L Acetic acid: 1ml/L as required for p^H 4-5
Zelan R3	Huntsman	Alkyl urethane, non-fluorinated material.	Zelan R3: 70g/L, 90g/L, 100g/L Acetic acid: 1ml/L as required for p^H 4-5 Phobol XAN: 10g/L Invadine PBN: 5g/L

The method of application for the whole experiment lies on the following technique:
Pad ⟶ Dry ⟶ Cure
Padding is the method of applying finishing chemicals to the fabric. Padding was done at pick up of 80% allowing through pad roller pressure. Drying is the process to remove moisture from the treated fabric. Drying was done at 120°C. Curing is the process of placing the fabric at high temperature for allowing the chemical to carry out the reaction process. Curing was done at 160°C for 1 minute. Padding pressure was 1 bar. Machines used for impregnation were Horizontal Pad-Mangle as padding machine of which fabric speed was 2 meter per minute and padding pressure was 1 bar, Fine Oven as drying machine and Mathis Steamer (*Switzerland*) as curing machine.

2.2 Testing and Analysis of Treated Fabrics

Two types of water repellency evaluation tests were been used for the treated samples. One was Drop Test and the other one was Spray Rating Test. Drop test was the first and foremost test of the treated samples in which the fabric was tested with water droplets to retain its spherical structure on the fabric surface. Spray rating test was done according to the AATCC test method 22-2005 [8] in which samples were conditioned for 24 hours at a relative humidity of 65±2% prior to testing. The specimens were stretched on a hoop, which was held at an angle of 45° and 250ml of water was been poured through a spray nozzle on the fabric surface. Any wetting or spotted pattern observed was compared with the photographic rating chart.

Table 3: British Spray Rating

Rating	Description
1	Complete wetting of the whole of the sprayed surface.
2	Wetting of more than half of the sprayed surface.
3	Wetting of the sprayed surface only at small discrete areas.
4	No wetting, but adherence of small drops to the sprayed surface.
5	No wetting and no adherence of small drops to the sprayed surface.

Physical testing is imperative to check either the physical properties of the treated fabrics having changed or not. Three physical testing methods were used during the inspection procedure such as GSM test, Bursting Strength test and Hydrostatic Head test. GSM stands for 'gram per square meter' which means the weight of fabric in gram per square meter. By this we can compare the fabrics in unit area which is heavier and which is lighter.

Gram per square meter (GSM) = Weight of fabric cut by GSM cutter (in cm^2) × 100 (1)

Bursting strength test is a method of measuring strength in which the material is stressed in all directions at the same time and is therefore more suitable for knitted materials, laces or nonwovens. ASTM test method D3786 [9] was used to evaluate the treated knit fabric bursting strength. The specimens to be tested (30mm and 113mm) were clamped over a rubber diaphragm by means of an annular clamping ring and an increasing fluid pressure was applied to the underside of the diaphragm until the specimen burst (within 20±3 seconds). The same process was carried out without a specimen. The operating fluid was a liquid.

Bursting Strength = Pressure required to burst the specimen at a certain height of the diaphragm (in kpa) (P_1) - Pressure required to lift the diaphragm to the same height without the specimen (in kpa) (P_2) (2)

If the extension percentage [10] be calculated due to fluid pressure then,

Extension = $\left[\left(\frac{c^2+h^2}{h}\right) tan^{-1}\left(\frac{h}{c}\right) - c\right]\frac{100}{c}$ percent (3)

Where, h= height and c= radius of the specimen.

Hydrostatic head test means water permeability test which exhibits how much the pressure required to penetrate the water into the fabric. According to the British Standard ISO 811 test method [11] the test specimen was cut at 6cm diameter and the test cell was rinsed thoroughly with distilled water and filled to approximately 0.3cm of the top. The specimen was clamped between the gaskets and orifice. Air was supplied by the manometer and the pressure under the surface of the specimen was allowed to increase until water appeared at three places. The dial showed the result in cm of water.

Hydrostatic pressure in a liquid can be calculated using the following equation,

$p = \rho\ g\ h$(4)

Where, p= pressure in liquid, ρ= density of liquid, g= acceleration due to gravity, h= height of fluid column. Here, in case of hydrostatic head test the head was derived as the height of the fluid column in centimeters.

Color fastness to wash was measured with ISO 105-C06 method [12] using 10cm × 4cm dyed fabric samples with the washing recipe: ECE (Detergent): 3g/L, Soda ash (p^H 11): 2g/L, Sodium per borate ($NaBO_3.10H_2O$): 1g/L, M:L=1:10, Washing temperature: 60°C, Washing time: 30minutes, 10 stainless balls were used to provide mechanical action each had diameter of 0.6cm and weight of 1gm.

The resistance of color of dyed treated samples to the action of rubbing (dry and wet) was evaluated with ISO 105-X12 method [13] using 14cm × 5cm sample by rubbing at 1 turn per second (10 × 10 seconds).

III. Results And Discussion

3.1 Water Repellency of Fabrics

Drop test was the visual test and the first test to evaluate the water repellency of the fabrics. All the treated fabrics showed better results on visual examination in Fig. 1. The pictures of the treated samples before and after are given below:

Figure 1: Drop test on treated fabrics and their visual appearance

The water repellency of the treated fabrics was actually evaluated using the spray test method whose obtained results and graphical analysis are given below in Fig.2. The water repellent chemicals were used at three different concentrations of 70g/L, 90g/L and 100g/L on four different types of knit dyed fabrics. All the fabrics were rated under 160°C curing temperature at 1 minute.

Table 4: Water repellency ratings- Spray test

Concentration (g/L)	Fabric Types	Nuva TTC	Zelan R3	Rucostar EEE6
70	Rib	3-4	4	4-5
	Polo Pique	3-4	3-4	4-5
	Interlock	3-4	3-4	4
	Single Jersey	3-4	3-4	4
90	Rib	4-5	4-5	4-5
	Polo Pique	4	4-5	4-5
	Interlock	4	4	4
	Single Jersey	4	4	4
100	Rib	4-5	4-5	4-5
	Polo Pique	4-5	4-5	4-5
	Interlock	4-5	4	4
	Single Jersey	4	4	4

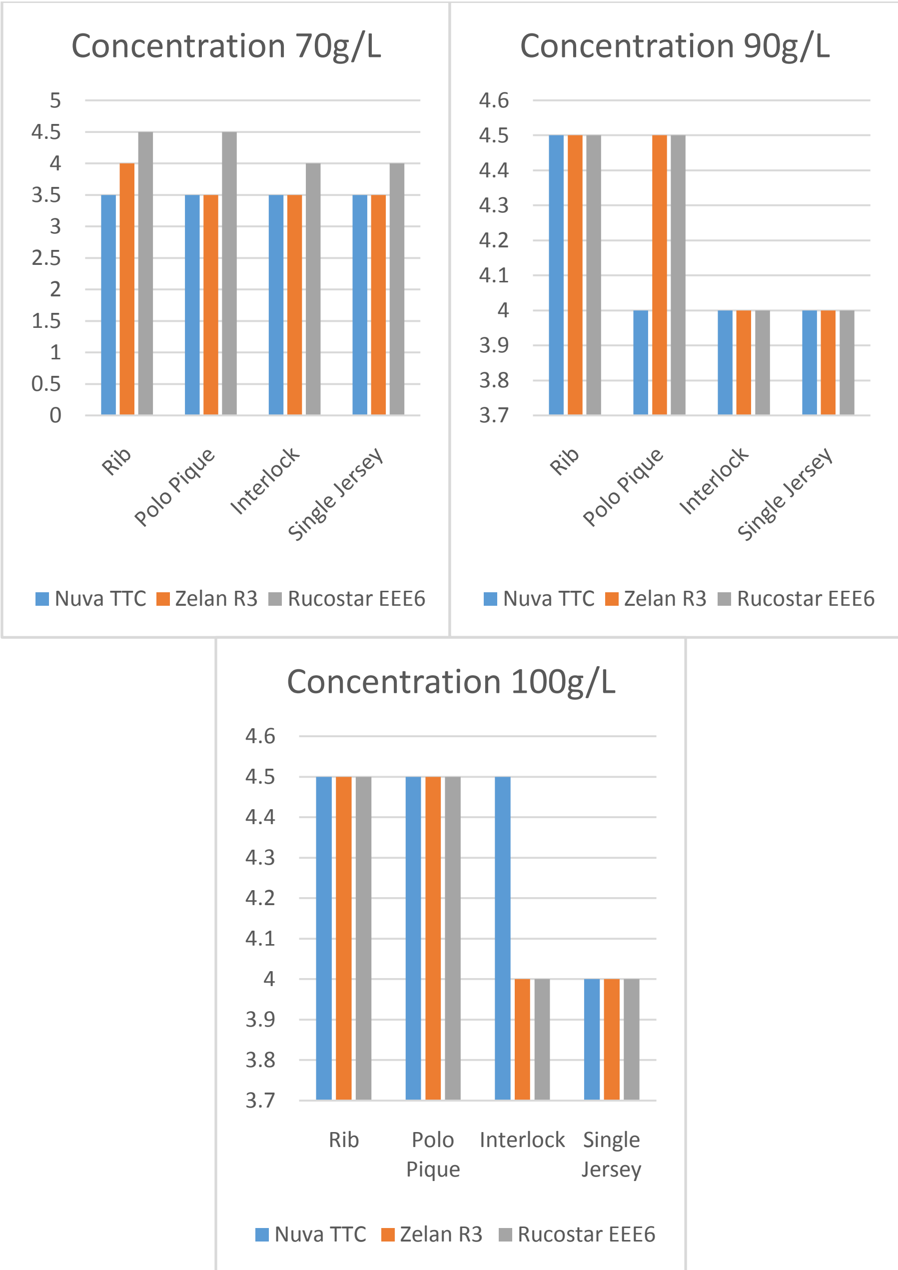

Figure 2: Water repellency of treated fabrics at different concentrations

At 70g/L concentration, water repellency found varied with different knit fabrics that we got comparatively better results for Rucostar EEE6 and rib fabric combination which showed the efficiency of the chemical and also the fabric because of its compactness and heavy GSM. At 90g/L concentration, Zelan R3 showed similar results like Rucostar EE6 and in this case also rib showed the best results for all three chemicals. At 100g/L concentration, particularly Nuva TTC provided the best results among others and rib and polo pique both fabrics showed similar activation.

3.2 Fabric GSM

Table 5: Changes in GSM due to chemical treatment

Fabric Types	GSM Before	Concentration (g/L)	Nuva TTC	Zelan R3	Rucostar EEE6
Rib	315	70	325	323	322
Polo Pique	200		210	213	211
Interlock	150		160	159	157
Single Jersey	160		172	173	172
Rib	315	90	328	327	326
Polo Pique	200		215	217	216

Interlock	150		167	168	169
Single Jersey	160		175	173	172
Rib	315	100	330	332	334
Polo Pique	200		218	215	214
Interlock	150		170	173	171
Single Jersey	160		178	180	179

The GSM tests were done under GSM cutter for all fabrics with all concentrations in Fig. 3. After chemical implementation, GSM of the treated fabrics increased thoroughly because chemical covered up all the pores of the fabric and a chemical coating was created on the fabric. That was the reason behind the weight of the fabric increased. Also because of the coating water was not allowed to penetrate into the fabric.

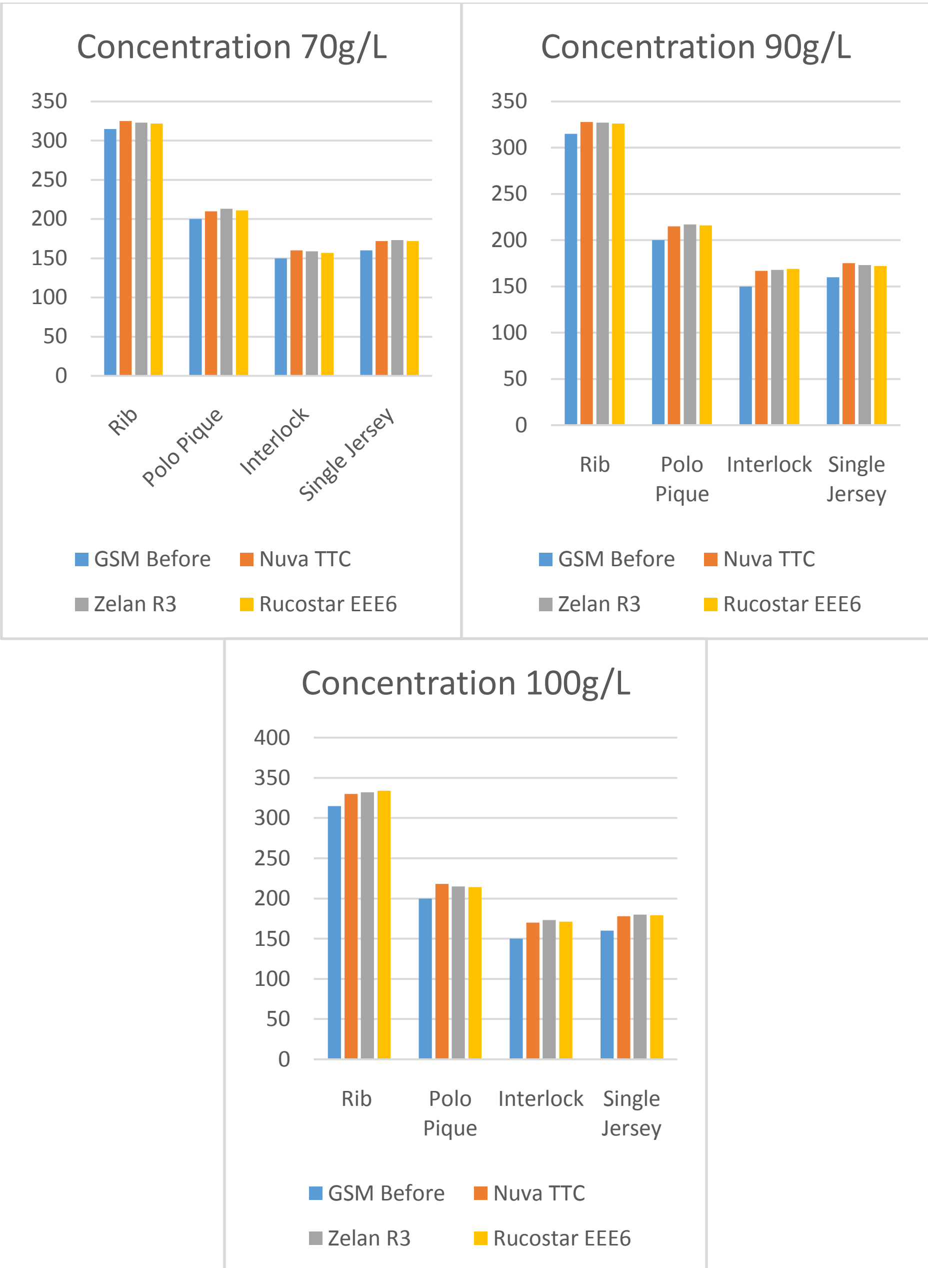

Figure 3: Fabric GSM at different concentrations of chemical implementation

3.3 Bursting Strength of Fabrics

ASTM test method D3786 was used to evaluate the treated knit fabric strength. Bursting strength of the cotton knit fabric showed slight deterioration and it was taken into account. Though the change was marginal but it was important for the treated fabric to go for the next proceedings.

Table 6: Bursting strength of treated fabrics

Fabric Types	Bursting Strength Before (kpa)	Concentration (g/L)	Nuva TTC	Zelan R3	Rucostar EEE6
Rib	538.1	70	522.0	526.3	523.7
Polo Pique	428.3		416.2	417.7	420.5
Interlock	341.7		328.8	329.0	327.1
Single Jersey	304.7		298.0	300.6	297.6
Rib	538.1	90	516.5	516.3	513.8
Polo Pique	428.3		408.3	407.5	410.9
Interlock	341.7		320.5	322.4	321.0
Single Jersey	304.7		289.9	291.7	288.2
Rib	538.1	100	513.4	511.2	510.7
Polo Pique	428.3		401.1	403.3	405.4
Interlock	341.7		314.3	316.5	316.0
Single Jersey	304.7		286.0	286.3	285.9

Figure 4. Bursting Strength of treated fabrics at different chemical concentrations

According to the derived results in Fig.4, it is clear that after water repellent finish the fabric strength decreases slightly and reasonably. The fabric strength fall phenomena increases with increasing concentration.

The cause behind this trend may be fluorocarbon affects the crystalline region of cellulosic fiber during cross linking. When the water repellent chemicals form cross link with the free O-H group of cotton in the amorphous region, it stiffs the fabric and that is why the fabric bursting strength decreases.

3.4 Fabric Water Permeability

The Hydrostatic Head was tested to find out the water permeability of the treated fabrics. It is a major parameter to evaluate since it is directly connected with the efficiency of the water repellency treatment.

Table 7: Water permeability of the treated fabrics

Fabric Types	Hydrostatic Head Before (cm of H_2O)	Concentration (g/L)	Nuva TTC	Zelan R3	Rucostar EEE6
Rib	19	70	21	21	22
Polo Pique	16		18	18	20
Interlock	14		15	15	17
Single Jersey	13		15	15	16
Rib	19	90	22	23	23
Polo Pique	16		19	20	20
Interlock	14		16	17	17
Single Jersey	13		15	16	16
Rib	19	100	24	23	23
Polo Pique	16		21	20	20
Interlock	14		17	17	17
Single Jersey	13		17	16	16

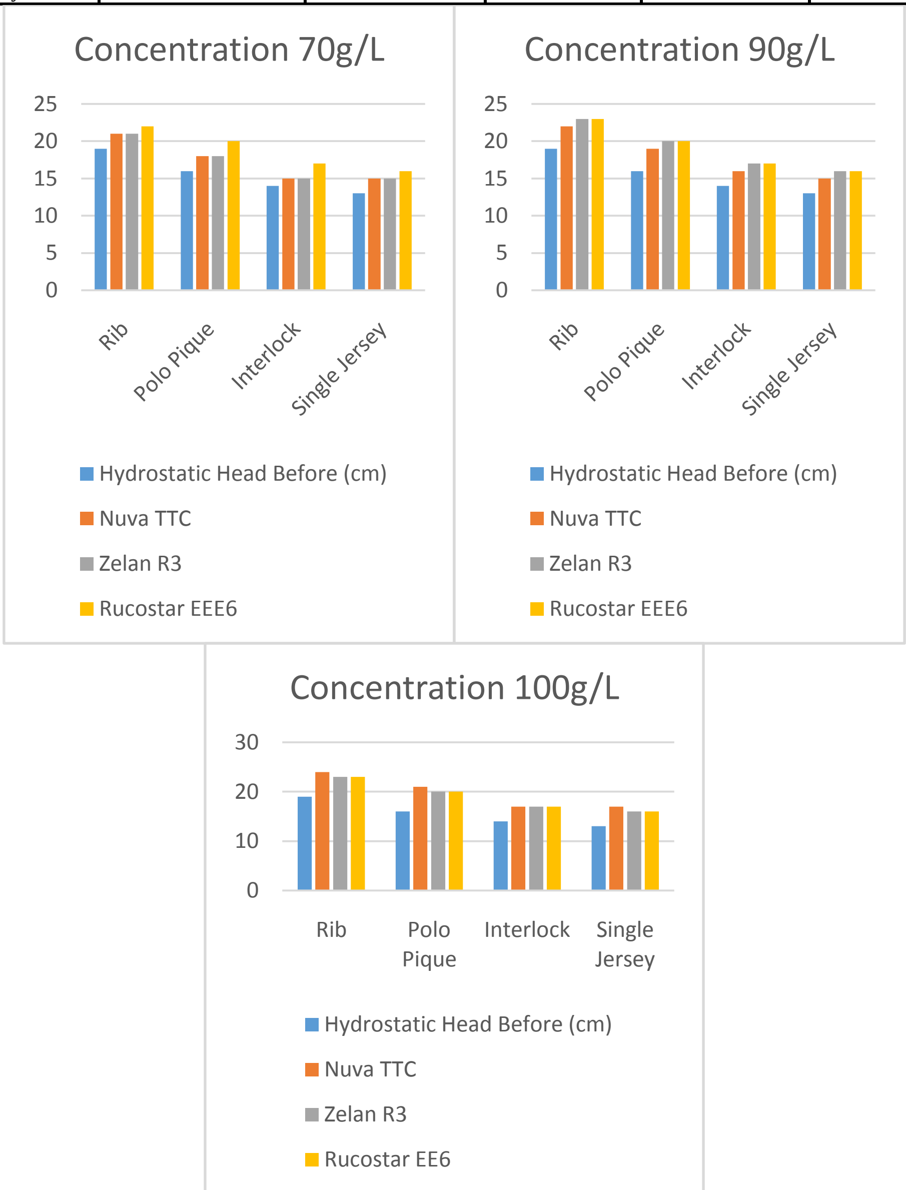

Figure 5: Water permeability of treated fabrics at different chemical concentrations

According to the results obtained in Fig.5, as the concentrations of the water repellent chemicals increased gradually from 70g/L to 100g/L, the pressure required to force water through the fabric also increased. The reason behind this phenomena is that the water repellent chemical forms a coating on the fabric surface and the more the concentration is the higher will be the density of coating and also the pressure required.

3.5 Fabric Wash Fastness

The wash fastness of water repellent fabrics with different concentrations were rated under grey scale for two types of measurements, one for color change and another for color staining. Color change was measured with the standard sample which was washed and compared with the washed sample according to the standard recipe.

Table 8: Color fastness to washing of the treated fabrics using all chemicals (Color Change)

Concentration (g/L)	Fabric Types	Grey scale value (Color Change)		
		Nuva TTC	Zelan R3	Rucostar EEE6
70	Rib	3-4	3-4	3-4
	Polo Pique	3-4	3-4	3-4
	Interlock	3	3-4	3-4
	Single Jersey	3	3-4	3-4
90	Rib	3-4	3-4	4
	Polo Pique	3-4	3-4	4
	Interlock	3	3-4	3-4
	Single Jersey	3	3-4	3-4
100	Rib	4	4	4
	Polo Pique	4	4	4
	Interlock	3-4	3-4	3-4
	Single Jersey	3-4	3-4	3-4

Color staining of the treated fabrics was also measured at grey scale with the help of washing with the Multi-fibers Fabric. The fabric comprises six different types of fibers such as acetate, cotton, nylon, polyester, acrylic and wool. Staining on these fibers was observed.

Table 9: Color fastness to washing of the treated fabrics using all chemicals (Color Staining)

Concentration (g/L)	Fabric Types	Grey scale value (Color Staining)					
		Nuva TTC (N), Zelan R3 (Z), Rucostar EEE6 (R)					
		Acetate	Cotton	Nylon	Polyester	Acrylic	Wool
70	Rib	4(N)4(Z) 4(R)	3(N) 3-4(Z)4(R)	3-4(N) 3-4(Z) 3-4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)
	Polo Pique	4(N)4(Z) 4(R)	3(N) 3-4(Z)4(R)	3-4(N) 3-4(Z) 3-4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)
	Interlock	4(N)4(Z) 4(R)	3(N)3(Z) 3-4(R)	3(N)3(Z) 3(R)	3-4(N) 3-4(Z) 3-4(R)	3-4(N) 3-4(Z) 3-4(R)	4(N)4(Z) 4(R)
	Single Jersey	3-4(N) 3-4(Z) 3-4(R)	3(N)3(Z) 3-4(R)	3(N)3(Z) 3(R)	3-4(N) 3-4(Z) 3-4(R)	3-4(N) 3-4(Z) 3-4(R)	3-4(N) 3-4(Z) 3-4(R)
90	Rib	4(N)4(Z) 4(R)	3(N)4(Z) 4(R)	3-4(N) 3-4(Z) 3-4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)
	Polo Pique	4(N)4(Z) 4(R)	3(N)4(Z) 4(R)	3-4(N) 3-4(Z) 3-4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)
	Interlock	4(N)4(Z) 4(R)	3-4(N) 3-4(Z) 3-4(R)	3-4(N) 3-4(Z) 3-4(R)	3-4(N) 3-4(Z) 3-4(R)	3-4(N) 3-4(Z) 3-4(R)	4(N)4(Z) 4(R)
	Single Jersey	3-4(N) 3-4(Z) 3-4(R)	3-4(N) 3-4(Z) 3-4(R)	3-4(N) 3-4(Z) 3-4(R)	3-4(N) 3-4(Z) 3-4(R)	3-4(N) 3-4(Z) 3-4(R)	3-4(N) 3-4(Z) 3-4(R)
100	Rib	4(N)4(Z) 4(R)	3-4(N) 3-4(Z)4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)
	Polo Pique	4(N)4(Z) 4(R)	3-4(N) 3-4(Z)4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)
	Interlock	4(N)4(Z) 4(R)	3-4(N) 3-4(Z) 3-4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)	4(N)4(Z)4(R)
	Single Jersey	4(N)4(Z) 4(R)	3-4(N) 3-4(Z) 3-4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)	4(N)4(Z) 4(R)

3.6 Fabric Rubbing Fastness

The rubbing fastness of water repellent fabrics with different concentrations were rated under grey scale for the measurement of color staining. According to the data obtained, for all three different chemicals the treated fabrics showed average rubbing (dry and wet) fastness and as the chemical concentration increased, the rating of rubbing fastness got better.

Table 10: Color fastness to rubbing of the treated fabrics using all chemicals

Concentration (g/L)	Fabric Types	Grey scale value					
		Nuva TTC		Zelan R3		Rucostar EEE6	
		Dry	Wet	Dry	Wet	Dry	Wet
70	Rib	3-4	3	4	3	4	3-4
	Polo Pique	3-4	3	4	3	4	3-4
	Interlock	3-4	3	3-4	3-4	3-4	3-4
	Single Jersey	3-4	3	3-4	3-4	3-4	3-4
90	Rib	4	3-4	4	3-4	4	4
	Polo Pique	4	3-4	4	3-4	4	4
	Interlock	3-4	3	3-4	3-4	3-4	3-4
	Single Jersey	3-4	3	3-4	3-4	3-4	3-4
100	Rib	4	4	4	4	4	4
	Polo Pique	4	4	4	4	4	4
	Interlock	3-4	3-4	3-4	3-4	3-4	3-4
	Single Jersey	3-4	3-4	3-4	3-4	3-4	3-4

IV. Conclusion

In this research we tried to establish an optimum condition for achieving a good durable water repellent finish by using three popular easily available water repellent chemicals such as Nuva TTC, Zelan R3 and Rucostar EEE6. For implementation of these chemicals we chose the mostly used knit fabric structures such as Rib, Polo Pique, Interlock and Single Jersey all of which were dyed with Reactive Dye before chemical treatment. We used the three chemicals in three different concentrations to find out the optimum chemical concentration for compatibility, efficiency and cost minimization. To evaluate the water repellency, Spray test and Drop test were performed whereas many more physical tests like GSM test, Bursting Strength test and Hydrostatic Head test were taken places for the evaluation of the performance of the treated fabrics. We used AATCC, ASTM and ISO test methods for performing these tests. Besides these, Color Fastness to Washing and Rubbing were also checked according to the ISO methods. The depth of this research is huge and we tried our level best to find out the superior outcomes within our limitations.

Acknowledgement

We, the authors would like to express our gratitude to our thesis supervisor KawserParveen Chowdhury (Assistant Professor, Department of Wet Process Engineering), Dr. Md. Forhad Hossain (Head, Department of Dyes and Chemicals Engineering) and Professor Dr. Md. Zulhash Uddin (Dean, Faculty of Textile Chemical Engineering), Bangladesh University of Textiles for their overall support and guidance. We would also like to thank deeply Archroma (Bangladesh) Ltd and Micro Fibre Group for providing us the lab facilities essentially during the thesis work. We would also like to thank Swiss Color (BD) Ltd for providing us required chemicals and Texeurop (BD) Ltd for providing us sample fabrics. Finally, we would like to mention the cordial support from Wet Process Lab and TTQC Lab of Bangladesh University of Textiles.

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Sk Nasimul Alahi. "Investigation of Different Effects of Water Repellent Finishes on Different Knit Dyed Fabrics." IOSR Journal of Polymer and Textile Engineering (IOSR-JPTE), vol. 5, no. 1, 2018, pp. 22–31.