

# Fabrication of C6-Fluorocarbon-dendrimer based superhydrophobic cotton fabrics for multifunctional aspects

Md. Ibrahim H. Mondal (✉ [mihmondal@gmail.com](mailto:mihmondal@gmail.com))

Rajshahi University

Joykrishna Saha

University of Rajshahi

---

## Research Article

**Keywords:** FC-dendrimer, cotton fabric, self-cleaning, superhydrophobic, protective textiles

**Posted Date:** February 4th, 2022

**DOI:** <https://doi.org/10.21203/rs.3.rs-490421/v2>

**License:**  This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

---

# Abstract

C6-Fluorocarbon-dendrimer has been applied to the cotton knit fabric to develop oil-water repellent, oil-water separation, acid-resistant, self-cleaning, flame retardant, UV resistant, and antibacterial properties. The C6-Fluorocarbon (FC)-dendrimer-coated 100% cotton single jersey knitted fabric samples were prepared using the “pad-dry-cure” method. The 90 g/L and 100 g/L FC-dendrimer-treated cotton fabrics showed excellent water repellency and oil-water separation as well as good self-cleaning performance. However, air permeability and heat conductivity were reduced by 13%, 15%, and 40%, 54%, for 90 g/L and 100 g/L FC-dendrimer-treated cotton fabrics compared to untreated fabrics. The presence of FC-dendrimer in the treated fabric was confirmed by FTIR, SEM, EDS, and XRD analyses. SEM analysis was employed to study the morphology of deposited FC-dendrimer particles on the fabric surface. TGA and DTA evaluated thermal performance. The FC-dendrimer-treated fabric also showed acid resistance, self-cleaning performance, and UV resistant attribute. In addition, Bacterial population growth appears to be less on the FC-dendrimer-treated sample than on the untreated sample. Overall, the result suggests that FC-dendrimer can be a valuable ingredient in the manufacture of multifunctional products.

## Introduction

The rapid growth in protective textiles and their services has created a severe need to apply functional finishes. Recent market surveys have shown that apparel consumers worldwide are demanding functionality in their purchased products. According to recent research, the global market of functional textiles is expected to reach USD 4.72 billion by 2020, growing at a CAGR (Compound annual growth rate) of 33.58 percent between 2015 and 2020 (Majumdar et al. 2019). “Protective” textiles are garments or fabrics which protect the wearer from environmental hazards (Gupta 2000).

Protective properties of clothing can be assured by many types of finishes, including paraffin (Abo-Shosha et al. 2008), silicone (Sun et al. 2017), stearic acid-melamine-based compound (Dashairya et al. 2019) fluoropolymer (Jain et al. 2018) and so on. However, paraffin repellents do not repel oil and are generally not durable for laundering and dry cleaning. Additionally, fabrics treated with paraffin-based finishes are less permeable by air and vapor, resulting in poor wearer comfort (Schindler and Hauser 2004). Silicone repellents offer moderate durability to laundering and dry cleaning and no oil or soil repellency. Wastewater, particularly from residual baths of the finish application processes, is toxic to fish (Dong et al. 2015). Silicone compounds like tetraethoxysilane (TEOS) modified cotton fabric showed good water repellent properties (Wang et al. 2007). However, TEOS exhibited toxicity and may cause potent respiratory hazards (Omae et al. 1998). In addition, stearic acid-melamine repellent finishes release of formaldehyde is a problem for human health and the environment (Schindler and Hauser 2004).

C6 Fluorocarbon (FC) polymer is primarily effective for liquid repellent and soil release finishes. Fluorocarbon finished product showed good resistance to water absorption, excellent adhesion properties and better transmission of water. Transmission of water vapor through a piece of fabric is the essential component of thermal comfort (Shekar et al. 2001). The efficiency of FC compounds is due to the bond

structure between the F and C atoms. The C-F (1.35 Å) bond length is shorter than the C-C (1.54 Å) bond. As a result, the C-F bond is more substantial than the C-C bond (Atav and Bariş 2016). FC compounds have a low boundary surface tension of 10-20 mN/m (Schindler and Hauser 2004). C6 Fluorocarbon (FC) polymer is also environment friendly. C6 fluorocarbon polymers degrade more quickly in the environment than C8 fluorocarbon polymers (Danish Environmental Protection Agency 2005). Fig. 1 shows the chemical structure of a fluorocarbon polymer on a fibre surface (Schindler and Hauser 2004).

On the other hand, dendrimers are highly branched molecules having a well-defined size, shape, molecular weight, and monodispersity compared to the linear polymer. Dendrimers have a tree-like form consisting of a central core, branches and terminal group, having diameters in the 2 to 10 nm range. Dendrimer has very low polydispersity and high functionality (Tomalia et al. 1985). There are different types of dendrimers like polypropylene imine (PPI) dendrimers, poly amido amine (PAMAM) dendrimers, tecto dendrimers, chiral dendrimers, hybrid dendrimers, micellar dendrimers, multiple antigen peptide dendrimers, amine-terminated hyperbranched dendritic polymers. Dendrimers terminated with amine end-groups are named amino-terminated dendrimers. End groups are generally called the surface group of the dendrimer or terminal group. The novel characteristics of amine-terminated dendritic polymers have many reactive end groups, globular shapes, and multi-valency, making them suitable for a wide range of applications; particularly, in textile engineering (Akbari and Kozłowski 2019). In this research, amine-terminated hyperbranched dendritic polymers are used.

Dendrimers are used along with FC to enhance water repellence by changing the nanostructure of the cloth's surface. Dendrimer's core molecules exhibited a large number of branched organic atoms (Windisch et al. 2000). Fabric treated with FC-dendrimer had higher oil and water repellency ratings than fabric treated with fluorocarbon polymer (Atav and Bariş 2016). Namligoz et al. (2009) also found that polymeric dendrimer containing FC had better results for water, oil, and stain repellency than conventional FC in performance and washing resistance. It is assumed that FC-dendrimer provides more functional groups on the surface of the textiles than one. On the other hand, the dendrimer has a well-known regular structure, built up over several generations, starting from a core and containing a surface with a high density of end groups (functional groups). The number of end groups increases exponentially with the number of generations building up the dendrimer.

Fluorocarbon polymers are applied together with dendrimers, causing self-organization where the fluorocarbon chains are enriched on the surface and co-crystallize with the dendrimers. Dendrimers are highly branched oligomers with non-polar chains forming a star brush structure. The resulting polar and non-polar sandwich arrangements are high-ordered, causing equal or better repellency effects, with lower fluorocarbon amounts than dendrimer-free FC finishes. Other advantages include low condensation temperature (80–130°C), high abrasion resistance, good wash permanence, and a soft feel (Duschek 2001). A hypothetical structure of a dendrimer is shown in Fig. 2 (Schindler and Hauser 2004). In addition, the hydrocarbon dendrimer is more environmentally friendly and economical than the FC polymer (Atav and Bariş 2016). Hydrocarbon dendrimer-treated fabric could withstand more water

hydrostatic pressure than FC-treated fabric. The breathability of hydrocarbon dendrimer-treated fabric was more than that of FC polymer-treated fabric (Chowdhury 2018a).

Generally, water-proof fabrics have lamination, high-density tight weaving, and solid coating, all of which block air and water vapor movement. As a result, the wearer feels discomfort due to the condensation of sweat inside the clothing. FC-dendrimer repellent finishes overcome these problems by developing a permeable layer that allows water vapor, heat, and air to pass through the dress due to the dendrimer macromolecule's ability to build up crystal structures in the nano range on the fabric surface. Water-repellent fabrics can use for various types of protective garments against rain, snow, cold and active sportswear (Krishnan 1991; Roey 1992; Chinta and Satish 2014; Colleoni et al. 2011).

Several research articles on fluorocarbon polymer have previously been published. However, there hasn't been enough research done on FC-dendrimer. Both compounds are solely used on textiles to make the oil and water-resistant (De et al. 2005; Midha et al. 2014; Crews and Clark 1990; Lee et al. 1999; Khoddami et al. 2012; Sayed and Dabhi 2014; Shekar et al. 2001; Behera and Hari 2010; Wang et al. 2011; Zhou et al. 2013; Shekar et al. 1999; Cerne and Simoncic 2004; Lidija and Simoncic 2008; Chowdhury 2018b). To the best of our knowledge, the oil-water separation, acid-resistance, self-cleaning, flame retardant, UV protection properties and antibacterial activity of FC-dendrimer treated fabric have not been evaluated. Using only one major chemical, FC-dendrimer, this study aimed to produce several functional qualities. Water-repellent chemicals have traditionally been applied to woven cloth. However, woven cloth has significant comfort constraints, such as limited moisture absorption, low air permeability, and reduced suppleness compared to the knitted fabric (Ajgaonkar 1998). Therefore, cellulosic knitted fabrics are used in this investigation.

In light of this information, the current research aims to investigate the various functional properties of 100% cotton-knitted fabric treated with C6-fluorocarbon resin with dendrimers, including oil-water separation, acid resistance, self-cleaning, flame retardant, UV protection factor, antimicrobial activity, and thermal comfort properties, as well as the water-oil repellent property. The contact angle, spray rating test, hydrostatic pressure, and vapor permeability were used to determine the water-resistance qualities. In addition, the morphology and surface composition of treated fabrics were studied using scanning electron microscopy (SEM) and energy-dispersive X-ray (EDX) analysis. In this research, the optimum concentration of fluorocarbon dendrimers suitable for particular end usage was studied. Statistical analysis was also used to determine the acceptable thermal comfort properties for different concentrated-fluorocarbon-dendrimer-treated fabrics at a 5% level of significance.

## Experimental

### Materials

100% cotton single jersey knitted fabric (Yarn count: 24 Ne carded yarn; Stitch length; 2.92 mm; GSM; 180) was used, which was collected from Fakhrudin Textile Mill Ltd., Sreepur, Gazipur, Bangladesh.

“RUCOSTAR EEE6” was used as a water- and oil-repellent chemical, which was C<sub>6</sub>-FC-dendrimer resin with polymeric hyperbranched dendrimers in a hydrocarbon matrix. In addition, Non-ionic polysiloxane (“RUCOFIN HSF”) was used as a softening agent, and blocked polyisocyanate (“RUCO LINK-RCX”) was used as a cross-linking agent. All chemicals were purchased from Spectra Dry-Chem (PVT.) Ltd., Germany.

### Sample preparation

Five samples of 60, 70, 80, 90, and 100 g/L FC-dendrimer resin plus 15g/L blocked polyisocyanate, and 10 g/L polysiloxane compound were prepared. At first, cut the 100% cotton single jersey knitted fabrics with a shape of 12 inches  $\times$  12 inches. The solution was prepared according to the recipe, and a material-to-liquor ratio of 1:30 was used. Next, the samples were immersed in the solution. After that, the samples passed through two nip rollers on a padding machine to squeeze out any excess solution at two bar pressures, leaving the fabric with a more limited amount of the chemical remaining. Then the samples were dried at 100° C. Finally, the samples were cured at 150°C, for two minutes, with the help of a mini-stenter machine. 100% cotton-bleached single jersey knitted fabrics used in this study and defined untreated. The sample preparation process is shown in Fig. 3.

## Methods

### Fourier transform infrared spectroscopy (FTIR)

Fourier-transform infrared (FT-IR) spectra of treated and untreated samples were obtained by an FTIR spectrophotometer (Spectrum-100, Perkin Elmer, USA), with a scanning range of 400-4000 cm<sup>-1</sup> was used to carry out the test.

### X-ray diffraction (XRD) analysis

The crystallinity of the treated and untreated samples was evaluated by X-Ray diffraction (XRD) analysis using X' Pert PRO diffractometer (PAN Analytical, Auckland, New Zealand). The XRD was carried out using Cu-K $\alpha$  radiation, of wavelength 0.15406 nm, as the X-ray source. The operating voltage and current were 40kV and 30mA, respectively, at room temperature. The sample holder was placed in the X-ray goniometer and a  $2\theta$  scanning range over 5°–50°, was used.

The ‘d’ spacing was evaluated according to Bragg’s law:

$$2d \sin \theta = \lambda \quad (1)$$

where,  $\lambda$  is the X-ray wavelength and d is the inter plane spacing.

The full width of the peak at half-maximum (FWHM) value of the XRD pattern was used to estimate the crystal diameter, using the Deby-Scherrer formula (Jenkins and Snyder 1996):

$$D = \frac{K\lambda}{\beta \cos\theta} \text{----- (2)}$$

In this equation, K (= 0.9) is the Scherrer constant, 0.15406 nm,  $\theta$  is the Braggs diffraction angle, and  $\beta$  is the full width of the peak in the X-ray pattern line at half peak-height in radians.

The crystalline percentage (Cr %) of treated and untreated samples was calculated from the XRD pattern, using the following equation (Ye and Farriol 2005):

$$\text{Cr \%} = \frac{I_{002} - I_{\text{am}}}{I_{\text{am}}} \times 100 \text{----- (3)}$$

Where:

$I_{002}$  represents the crystalline region of the material, and  $I_{\text{am}}$  represents the amorphous region of the material in cellulose fibers.

#### Energy-dispersive X-ray spectroscopy

The energy dispersive X-ray (EDX) represents the different elements composing the materials of the sample. The contents of carbon (C), nitrogen (N), oxygen (O), fluorine (F) of the treated cotton were measured by EDS (JEOL-6300F, Germany).

#### Scanning electron microscopy (SEM)

A scanning electron microscope was used to study the surface morphology of the cotton fabric both before and after modification. SEM (Model-Phenom G2 pro, Netherland) was performed to investigate the surface morphology at  $\times 3000$  magnifications.

#### Thermogravimetric analysis (TGA)

A simultaneous TGA and DTA thermal analyzer (Jupiter, Germany) studied both the FC-dendrimer-treated and untreated samples. The samples were heated to 20°C to 800°C with a heating rate of 10°C per minute in a nitrogen atmosphere. The mass of the sample and its temperature were recorded continuously, to determine the mass lost.

#### Water repellence test

A spray rating tester (Model no: 333A, Mesdan Lab, Italy) helped assess the fabric's water repellence. AATCC Test Method TM 22-2005 (2009) was followed in such assessment. For testing, a piece of cloth of 180 mm in diameter was stretched tightly in embroidery hoops. They were held at a 45° angle. Then 250 mL of water was sprayed on it from 150 mm height. The fabrics were rated between 0 and 100 based on photographic pattern, with the stages of 100, 90, 80, 70, 50, and 0. Zero ("0") rating revealed complete wetting, whereas 100 ratings pointed out the upper and lower surfaces were completely dry.

### Wash durability test

A wash durability test was carried out to check the water repellency after washing several times. Industrial washing machines washed treated fabrics according to AATCC 124-2018 (2018) standard. In the current job, washing was done just five times.

### Water contact angle measurement

The finished cotton sample was assessed for contact angle measurement with water using the goniometer (DSA 100, Kruss, Germany) sessile drop technique.  $5\mu\text{L}$  of water, by volume, was dropped at points on the sample in five places, at room temperature (Siddiqui et al. 2017). The average value of contact angles was used. The drops were photographed.

### Drop test

A drop test was also carried out, to observe the repellent properties of the treated fabric against aqueous dye solution and paraffin oil (Singh and Singh 2016).

### Hydrostatic pressure test

A hydrostatic pressure test was evaluated according to the AATCC Test Method 127-2008 (2009). The lower surface of the tested fabric was subjected to a hydrostatic pressure head, increasing the pressure at a constant rate, until leakage appeared in three points on the upper surface of the test specimen. A reservoir with a circular test area of  $100 \pm 5\text{ cm}^2$ , containing distilled or deionized water, supplied the water applied to the fabric surface. Results were obtained from water pressure by a millibar (mb).

### Oil repellence test

The ability of the treated fabric to repel oil was tested by the 3M Oil Repellency Test (Khoddami et al. 2015). In this test, a drop of oil was dropped onto the sample while lying flat on a smooth, horizontal surface. The droplets were observed for 30 seconds from a  $45^\circ$  angle. Standard test liquids for this test are shown in Table 1.

Table 1  
Standard test liquids for 3M oil repellency test method.

Composition of test liquid	3M oil repellency rating number	Surface <sup>a</sup> tension (mN/m)	Density <sup>a</sup> ((Kg/dm <sup>3</sup> ))
Paraffin oil	1	31.5	0.86
65/35 paraffin/n-hexadecane	2	29.6	0.82
n-hexadecane	3	27.3	0.77
n-tetradecane	4	26.4	0.76
n-dodecane	5	24.7	0.75
n-decane	6	23.5	0.73
n-octane	7	21.4	0.70
n-heptane	8	19.8	0.69
<sup>a</sup> Data are cited from Handbook of Chemistry and Physics (Haynes, 2017).			

#### Oil-water separation test

FC-dendrimer coated fabric was used to perform an oil-water separation test, according to the Yang et al., (Yang et al. 2019) method, with some amendments. For this purpose, a mixture of oil and water, 50 mL hexane, and 50 mL red-dyed was poured on FC-dendrimer coated fabric contained in a funnel placed on a conical flask. The filtrate mixed solution was collected in the flask and the FC-dendrimer coated fabric separated them. The following formula was used to measure the efficiency of separation:

$$\text{Efficiency} = \frac{V_a}{V_b} \times 100 \text{--- (4)}$$

where,  $V_b$  is the volume of oil before separation and  $V_a$  is the volume after separation.

#### Acid resistance test

An acid drop test tested acid-resistance. 20 $\mu$ L of 98% sulfuric acid was dropped on the fabric with a micropipette. A digital camera then recorded the ensuing damage (Wang et al. 2018).

#### Self-cleaning (Anti-fouling) tests

Self-cleaning tests, for both untreated cotton and FC-dendrimer-polymer-coated cotton, were carried out according to Yang et al.'s (Yang et al. 2019) method, with some modification. Very fine Methylene Blue (MB) dye powder was used as a surrogate for soil. The Methylene Blue powder was placed on untreated

cotton, and FC-dendrimer-polymer-coated cotton was dissolved in water and flowed with a water stream. After cleaning with water, the sample was dried, and an image of the samples was taken.

#### Flame retardant test

The flammability of treated and untreated fabric was evaluated by a 45° flammability tester (Govmark, Model No. TC-45, USA) according to the ASTM D 1230-94 standard (1994). On the other hand, a limiting oxygen index was carried out according to ASTM D2863.

#### Measurement of UV protection factor (UPF)

A UV spectrophotometer (Shimadzu 1650, Japan) was used to measure the ultraviolet protection factor, and the factor was calculated according to the AATCC Test Method: TM 183-2004 (2010) by the following equation:

$$UPF = \frac{\sum_{280}^{400} E_{\lambda} \cdot S_{\lambda} \cdot \Delta_{\lambda}}{\sum_{280}^{400} E_{\lambda} \cdot S_{\lambda} \cdot \Delta_{\lambda} \cdot T_{\lambda}} \dots\dots\dots (5)$$

In this equation:  $E_{\lambda}$  is erythermal spectral effectiveness,  $S_{\lambda}$  is solar spectral irradiancies,  $\lambda$  is the wavelength in nm,  $T_{\lambda}$  is spectral transmission and  $\Delta_{\lambda}$  is wavelength intervals (in nm).

#### Antibacterial activity test

Disc diffusion process was employed to test for an inhibition zone for both treated and untreated samples. The AATCC Test Method: TM 147-2004 (2010) was used.

#### Fabric weight

Fabric weight per unit area was measured according to the Standard ASTM-D 3776-96 (2002).

#### Fabric thickness

The thickness of the fabric was measured using James Heal's thickness gauge followed B.S. 2544:1954 (1954).

#### Bursting strength

A Trust Burst tester, ASTM D 3786-87 (1987) applied a force to the fabric plane at 90°, under specified conditions, until it ruptured the cloth.

#### Abrasion Resistance

The abrasion resistance was tested according to ASTM D 4966-98 (1989) using a Martindale Abrasion Tester.

#### Thermal conductivity

A Lee disc apparatus was used to measure the ability of the samples to conduct heat by the following formula (Vigneswaran et al. 2009):

$$\text{Thermal conductivity, } K = \frac{msd \times \frac{d\theta}{dt}}{a(t_1 - t_2)} \dots\dots\dots (6)$$

where, K is the ability of the sample to conduct heat, m is the brass disc mass, s is the specific heat of the disc material, d is the specimen thickness (in mm),  $\frac{d\theta}{dt}$  is the cooling rate, a is the area of the specimen cross-section,  $t_1$  is the highest temperature persisting over time, and  $t_2$  is the lowest temperature persisting over time.

#### Air permeability

The air permeability of the fabric was tested by the airflow method (BS 5636, 1990).

#### Water vapor permeability

The BS 7209 test (1990) was used to measure the water vapor permeability of the sample using the following formula:

$$\text{Water vapor permeability} = \frac{24 M}{At} \text{ gm/m}^2/\text{day} \dots\dots\dots (7)$$

In the above equation, M is mass loss (in grams), A is the sample's exposed area in  $\text{m}^2$ , and t is the time elapsed between weighing's of the assembly (in hours)

## Statistical analysis

Statistical analysis was used to investigate the acceptable level of thermal comfort properties. For this purpose, the Chi-square distribution Test Method was carried out at a 5% level of significance (Gupta 2002).

## Results And Discussion

The manuscript has been organized so that the confirmation tests, such as FTIR, XRD, EDX, SEM, and TGA, are discussed. Second, functional properties such as water and oil repellent, oil-water separation, acid resistance self-cleaning, flame retardant, UV protection and antibacterial have been addressed. Physical and mechanical properties have been addressed in the third section. Fourth, thermal

conductivity, air permeability, and water vapor permeability have all been explored as comfort properties. Finally, the comfort data were analyzed statistically. Each result will be analyzed and discussed below.

### FTIR spectra

In Fig. 4a, FTIR spectra of scoured bleached cotton show a broad peak at  $3331\text{ cm}^{-1}$  signifying the OH stretching vibration of cellulose hydroxyl groups in the region of  $3100\text{-}3600\text{ cm}^{-1}$ . The scoured bleached cotton fabric spectra also showed typical characteristic peaks at  $1428\text{ cm}^{-1}$  and  $2900\text{ cm}^{-1}$ , which may be C-H bending and stretching bands, respectively. (Chung et al. 2004). Wavenumber  $3331\text{ cm}^{-1}$  of bleached cotton fabric has been converted into little high wave numbers of FC-dendrimer treated cotton fabrics as shown in Fig. 4 (b, c, d, e, f), which indicated intermolecular hydrogen bond formation. The peak at  $2900\text{ cm}^{-1}$  of bleached cotton fabric has been shifted to a little lower wavenumber of the FC-dendrimer-treated fabrics except for 60 g/L. A peak at  $1427\text{ cm}^{-1}$  has also changed after FC-dendrimer treatment. These changes prove that FC-dendrimer was successfully attached to the cotton fabric.

### XRD Analysis

Table 2  
Measurement of crystallinity percentage (Cr %) of untreated and FC-dendrimer treated fabrics.

Observation	2 theta (°) in the CR	Intensity in counts	2 theta (°) in the AR	Intensity in counts	Cr%
60 g/L FC-dendrimer	22.56	2333	18	433	81.44
70 g/L FC-dendrimer	22.60	2413	18	483	79.98
80 g/L FC-dendrimer	22.43	2246	18	432	80.76
90 g/L FC-dendrimer	22.46	2028	18	409	79.83
100 g/L FC-dendrimer	22.44	2166	18	478	77.93
Untreated fabric	22.51	2519	18	448	82.21
N.B: Crystalline Region (CR), Amorphous Region (AR)					

Table 3

Measurement of crystal diameter and inter plane spacing (d) of untreated and FC-dendrimer treated fabrics.

Observation	2 theta (°) in the CR	Inter plane spacing 'd' in nm	FWHM (°)	Crystal diameter (nm)
60 g/L FC-dendrimer treated	22.56	0.393806	1.406	5.77
70 g/L FC-dendrimer treated	22.60	0.393118	1.497	5.44
80 g/L FC-dendrimer treated	22.43	0.396059	1.616	5.04
90 g/L FC-dendrimer treated	22.46	0.395536	1.561	5.17
100 g/L FC-dendrimer treated	22.44	0.395884	1.688	4.89
Untreated fabric	22.51	0.394669	1.375	5.84
* FWHM- Full width at half maximum				

The untreated and FC-dendrimer-treated fabrics both showed three distinctive peaks, at the crystal planes of (101), (002) and (040) as shown in Fig. 5. This result agrees with the result found by Altınışık et al., (Altınışık et al. 2013) for cellulosic fibre. The crystallinity percentages of 60g/L, 70g/L, 80g/L, 90g/L, and 100g/L FC-dendrimer-treated samples were 81.44, 79.98, 80.76, 79.83, and 77.93%, respectively (Table 2). The crystallinity percentage of the treated samples slightly decreased compared to those of the untreated samples (82.21%), the peak intensity of the treated fabric also decreased when  $2\theta$  value at the crystal plane was (002). The crystallinity percentage of the FC-dendrimer-treated samples gradually decreased as the FC concentration increased. As a result, the FC-dendrimer-treated fabric exhibited a slightly lower level of crystallinity. On the other hand, the full width at half maximum (FWHM) value of the FC-dendrimer-treated sample was greater than that of the untreated sample.

The full width at half maximum (FWHM) value is inversely proportional to the crystal diameter. Full length at half maximum value increases, the crystal diameter of the sample decreases according to Deby-Scherrer formula (Eq. no. 2). Thus, the crystal diameter of all FC-dendrimer-treated cotton fabrics was lower than that of the untreated fabrics. A positive correlation was clear between crystallite diameter and crystallinity percentage.

No major difference is seen in the inter-plane spacing of untreated and FC-dendrimer-treated fabric, as shown in Table 3. The X-ray diffraction shows that the characteristic peaks of untreated and FC-dendrimer-treated fabric are almost the same. Thus, the cotton fibre cellulose did not produce any remarkable changes after FC-dendrimer incorporation.

Energy-dispersive X-ray spectroscopy (EDX) Analysis

Table 4  
Weight % of untreated and treated samples of EDX spectra.

Elements	Untreated fabric	60 g/L treated fabric (Wt.%)	70 g/L treated fabric (Wt.%)	80 g/L treated fabric (Wt.%)	90 g/L treated fabric (Wt.%)	100 g/L treated fabric (Wt.%)
C	49.85	52.15	53.17	53.53	55.23	56.08
N	00	0.20	0.27	0.38	0.57	1.63
O	50.15	47.53	45.97	45.14	43.09	41.97
F	00	0.12	0.33	0.60	0.82	1.43

The EDX photograph of untreated fabric and that of FC-dendrimer treated fabrics is shown in Fig. 6. The weight percentages of carbon atoms were 49.85, 52.15, 53.44, 53.91, 55.80, 56.08% in untreated cotton for 60 g/L, 70 g/L, 80 g/L, 90 g/L and 100 g/L FC-dendrimer-treated cotton fabrics, respectively, are listed in Table 4. The weight percentages of oxygen atoms were 50.15, 47.53, 45.97, 45.14, 43.09, and 41.97% in untreated cotton, for 60 g/L, 70 g/L, 80 g/L, 90 g/L and 100g/L in FC-treated cotton fabrics, respectively. The weight percentages of oxygen atoms in FC-dendrimer-treated fabric were less than that in untreated fabric. Fewer oxygen peaks in FC-dendrimer-treated fabric indicate that few hydroxyl groups (OH), which attract water molecules, were present. But the weight percentages of carbon atoms were greater in the treated fabric. The greater weight for carbon peaks in FC-dendrimer-treated fabric implies that the number of hydrocarbon groups has increased. Hydrophobicity increases with the increased concentration of fluorocarbon polymer.

#### Scanning electron microscopy (SEM) study

The surfaces of both the treated and untreated fabrics were studied using a scanning electron microscope. The untreated fabric has a smooth surface, as shown in Fig. 7(a). The treated fabrics had rough and uneven surfaces, as shown in Fig. 7 (b, c, d, e, f) compared to untreated fabric. Granular material was visible in Fig. 7e. That gave the treated fabric its uneven surface and provided evidence that the water repellent agent was successfully attached to the untreated fabric surface. After FC-dendrimer treatment, the surface texture of the cotton fabric became similar to that of non-wettable fabrics. Among the samples, the uneven appearance of the surface of those treated with 90 g/L and 100g/L concentrations of FC-dendrimer treatment was most prominent. This result is similar to the outcome of Jeyasubramanian et al. (Jeyasubramanian et al. 2016).

#### Thermal analysis

Table 5  
TGA and DTA thermograph data of treated and untreated fabrics.

Observation	Weight loss % at 100°C	Nature of DTA peak	DTA 1st Peak Temp. (°C)	Weight loss % at DTA 1st Peak Temp. (°C)	DTA 2nd Peak Temp. (°C)	Char residue at 600 °C, %
Untreated fabric	6	Exothermic	377	82.4	478	2.6
60 g/L FC-dendrimer	5	Exothermic	379	89.5	504	2.3
70 g/L FC-dendrimer	5	Exothermic	376	82.7	506	1.5
80 g/L FC-dendrimer	3	Exothermic	380	82.6	503	1.9
90 g/L FC-dendrimer	4	Exothermic	382	83.2	497	2.6
100 g/L FC-dendrimer	6	Exothermic	382	75.1	495	3.2

Thermal behaviour of untreated fabric and FC-dendrimer-treated fabric were evaluated by the study of TGA and DTA thermograms. The weight loss percentage, DTA peak temperature and char residue percentage are shown in Table 5. The TGA thermogram represents the weight loss percentage of the specimen and shows three stages of thermal degradation. In the first stage, weight loss occurred, in the untreated 60, 70, 80, 90 and 100 g/L FC-dendrimer treated fabrics, of 6, 5, 5, 3, 4 and 6%, respectively, at 100°C due to loss of moisture, low molecular weight solvent and expulsion of gas. Major weight losses were observed. In the second stage, at DTA 1st peak temperature, as shown in Table 5. The DTA 1st peak temperatures of the untreated fabric, 60, 70, 80, 90 and 100 g/L FC-dendrimer-treated fabrics were 377, 379, 376, 380, 382, 382°C, respectively. A more-pronounced degradation occurred at this temperature due to the breakdown of glycosidic linkages and hydrogen bonds, leading to the formation of organic compounds. The final-stage residual char is obtained at DTA 2nd peak temperature (Table 5). From Table 5, the DTA peak temperature or decomposition temperature of FC-dendrimer treated fabrics was greater than in untreated fabrics. As a result, the thermal stability of FC-dendrimer treated fabric has been improved. The char residue of 100 g/l FC-dendrimer-treated cloth was higher than that of untreated fabric. In contrast, the char residue of 90 g/l FC-dendrimer treated fabric is similar to that of untreated fabric. On the other hand, char residue rates of 60, 70, and 80 g/L FC-dendrimer-treated fabrics are slightly lower than untreated cotton fabric. The use of polysiloxane, which might have catalyzed cellulose decomposition and resulted in decreased residue after degradation (Flynn 2002). As the add-on

percentage was higher with the increase of concentration of FC-dendrimer, this might be the cause of increased residual char % at 100 g/L FC-dendrimer.

### Spray test results

Table 6  
Standard Spray test rating chart according to AATCC-22 method (Khoddami et al. 2015).

<b>AATCC-22 Standard rating</b>	<b>Note</b>
AATCC 100	100: No sticking or wetting of upper surface
AATCC 90	90: Slight random sticking or wetting of upper surface
AATCC 80	80: Wetting of upper surface at spray points
AATCC 70	70: Partial wetting of whole of upper surface
AATCC 50	50: Complete wetting of whole surface
00	0: Complete wetting of whole upper and lower surface

Table 7  
Spray test readings of FC-dendrimer resin treated fabric.

<b>Observation</b>	<b>Spray Test Readings (AATCC-22)</b>	<b>After five times laundering (AATCC-22)</b>
60 g/L FC-dendrimer treated	80	80
70 g/L FC-dendrimer treated	90	90
80 g/L FC-dendrimer treated	90	90
90 g/L FC-dendrimer treated	100	100
100 g/L FC-dendrimer treated	100	100

Table 7 shows spray-test results for FC-dendrimer-treated fabric. The spray test readings, according to AATCC-22, of 60, 70, 80, 90 and 100 g/L FC-dendrimer-treated samples were 80, 90, 90, 100 and 100, respectively. Standard spray test ratings, according to the AATCC -22 method, are shown in Table 6. According to the rating chart, 90 g/L and 100g/L show the highest rating. This rating implies that there was “No sticking or wetting of the upper surface”. When the concentrations of FC-dendrimer were 90 g/L and 100 g/L, the weight gain percentage was maximized. As a result, the thickness of the treated fabric also increased. So, the treated fabric showed excellent water resistance performance.

Again, at 70 g/L and 80 g/L, the treated sample had a rating of “90” meaning “Slight random sticking or wetting”. After five launderings, the spray rating value for all five samples remained unchanged. Repellent finishes achieve repellence because they reduce the free energy on the fibres’ surface. A drop of liquid will spread if the adhesive interactions, between the fibres and the liquid droplets, are greater than the cohesive internal interactions within the liquid. A drop of liquid will not spread, if the adhesive interactions between the fibres and the liquid droplets, are lower than the internal cohesive internal interactions within the liquid. Surfaces that exhibit low interaction with liquids “low-surface energy” surfaces (Schindler and Hauser 2004).

#### Wash durability

After five launderings, the spray rating value for all five samples remained unchanged.

#### Water contact angle of the samples

Contact angle measurement is the best method to use to evaluate the water repellence of a hydrophobic surface. The static contact angle is the angle between a liquid and the surface created when the liquid contacts the surface. If the water contact angle is  $0 \leq \theta \leq 90^\circ$ , the surface is defined as “hydrophilic”. If the water contact angle is  $90 \leq \theta \leq 180^\circ$ , the surface is defined as “hydrophobic”. Water repellency increases when cotton fabric with low surface energy is used.

Water contact angle indicates whether a surface is hydrophilic or hydrophobic because it measures how much spread a drop of liquid will achieve on the surface. The surface will become more hydrophilic if oxidizing agents or ion-able groups are introduced on the cotton surface. As a result, a water droplet will spread across the surface more easily, and the water contact angle will become smaller. On the other hand, if hydrocarbons are introduced on the surface, the surface will become more hydrophobic, and the water contact angle will increase. Therefore, to measure the water contact angle, a droplet of water is placed on the surface. The height and width of the water’s spread are then recorded to calculate the angle.

The 100 g/L and 90 g/L FC-dendrimer treated cotton fabric provided excellent water repellence: its water contact angle measured between  $154^\circ$  and  $144^\circ$ , as shown in Fig. 8 (e, f). 60 g/L, 70 g/L and 80 g/L FC-

dendrimer-treated cotton fabrics exhibited water contact angles of 124 °, 122 ° and 136 °, respectively, as shown in Fig. 8 (b, c, d).

#### Drop test results

This study used 100 g/L FC-dendrimer resin plus 15 g/L blocked polyisocyanate and 10 g/L polysiloxane compound to prepare the sample. A coloured water droplet and paraffin oil spread easily on an untreated fabric surface, as shown in Figs. 9(a) & 5(b), respectively. On the other hand, coloured water droplets and paraffin oil did not spread on the FC-dendrimer treated fabric surface in Fig. 9(c). The spherical shape of the water and oil droplets is shown in Fig. 9(c). Thus, FC dendrimer-treated cotton fabrics are water and oil-repellent.

#### Hydrostatic pressure test result

Table 8  
hydrostatic pressure test result.

Observation	Hydrostatic Pressure (mbar)
Untreated fabric	140±1.22
60 g/L FC treated fabric	158±2.83
70 g/L FC treated fabric	162±2.00
80 g/L FC treated fabric	168±2.55
90 g/L FC treated fabric	175±1.22
100 g/L FC treated fabric	180±1.87

Hydrostatic pressure means the pressure needed for water to penetrate a fabric. Hydrostatic pressure increased after FC-dendrimer coating, compared to that of untreated fabric.

Table 8 shows this increase. Hydrostatic pressure increases gradually with the increase of coating because the FC-dendrimer polymer coating on the fabric becomes denser as the chemicals concentration increases. A denser coating makes the fibre more water-repellent. The highest hydrostatic pressure (180 mbar) and lowest hydrostatic pressure (158 mbar) were reached with coatings of 100 g/L, and 60 g/L treated fabrics, respectively. Hydrostatic pressure is directly proportional to the water repellency property. High hydrostatic pressure indicates a high repellent property. So, it can say that 100 g/L FC-dendrimer finished fabric exhibits the highest water repellence.

#### Oil repellence

The surface tension and density of paraffin oil are 31.5 mN/m and 0.86 kg/dm<sup>3</sup>, respectively, as shown in Table 1. Kasturiya & Bhargava (Kasturiya and Bhargava 2003) found that the critical surface tension for FC-dendrimer polymer-coated surfaces is 6 mN/m - 28 mN/m. Yet, for bleached cotton, this critical surface tension is 44 mN/m. When FC-dendrimer polymer is applied to bleached cotton fabric, the surface tension is reduced to 6 mN/m - 28 mN/m. Paraffin oil did not penetrate the FC-dendrimer-treated fabric, as the surface tension of paraffin oil is greater than that of the FC-dendrimer-treated fabric. On the other hand, paraffin oil easily penetrates the bleached cotton fabric since the surface tension of paraffin oil is less than that of the bleached cotton fabric. So, it can say that the 60 g/L, 70 g/L, 80 g/L, 90 g/L and 100 g/L FC-dendrimer treated fabric showed paraffin oil repellence.

The surface tension and density of n-heptane are 19.8 mN/m and 0.69 kg/dm<sup>3</sup>, respectively. The surface tension of n-heptane is less than that of the other organic oils used in the oil repellence test, as shown in Table 1. N-heptane organic oil can easily wet 60 g/L, 70 g/L, and 80 g/L FC-dendrimer-treated fabric, but not 90 g/L and 100 g/L FC-dendrimer-treated fabric. Therefore, according to the oil repellence test chart, 90 g/L and 100 g/L FC-dendrimer-treated fabric showed an oil repellence rating of 8 (eight) as shown in Table 1. A high value of water contact angle also indicated a high degree of oleophobicity. The water contact angle of 90 and 100g/L FC- dendrimer-treated fabrics are 154° and 144° as in Fig. 8 (e, f).

The surface tension and density of n-octane are 21.4 mN/m and 0.70 kg/dm<sup>3</sup>, respectively. N-octane organic oil can easily wet 60g/L and 70 g/L FC-dendrimer-treated fabric but not 80 g/L FC-dendrimer-treated fabric. So, 80 g/L FC-dendrimer-treated fabric achieved an oil repellence rating of 7 (seven), according to Table 1.

N-decane organic oil cannot wet the 60 g/L and 70 g/L FC-dendrimer-treated fabric, as the surface tension of n-decane is higher than that of n-octane. So, 60 g/L and 70 g/L FC-dendrimer-treated fabric achieved an oil repellence rating of 6 (six) according to Table 1. The oil repellence ratings of all the FC-dendrimer-treated samples are illustrated in Fig. 10.

### Oil-water separation

Oil-water separation becomes a crucial issue due to considerable oily wastewater from agricultural and industrial activities. On the other hand, improper disposal of used motor oil, oil spills, or leaks from ships or tankers have considerably contaminated watercourses and our food chain. (Wang et al. 2016; Cao and Cheng 2018; Yuan et al. 2018; Baig et al. 2019).

All concentrated FC-dendrimer-treated fabrics exhibited hydrophobic characteristics because the surface tension of water is fixed. On the other hand, FC-dendrimer-treated fabric showed oleophobic and oleophilic characteristics determined by the different surface tensions of the different organic oils tested. For example, n-decane cannot penetrate the 60g/L and 70 g/L FC-dendrimer-treated fabric, but n-octane can do so easily. As a result, a mixture of n-octane and water can be separated by 60 g/L and 70 g/L FC-dendrimer-treated fabric. Similarly, a mixture of n-heptane and water has been separated by 60, 70 and 80 g/L FC-dendrimer-treated fabric. In addition, It may also separate the n-hexane and water mixture using

any FC-dendrimer-treated fabric as the surface tension (18.43 mN/m) of n-hexane organic oil is less than that of all the FC-dendrimer-treated fabric.

50 mL water and 50 mL n-hexane were mixed, and used 100 g/L FC-dendrimer-treated fabric for separation. After separation, the collected water remaining was still about 50 mL. The collected oil decreased a little in volume due to the absorbency of cotton and volatilization. The coated cotton would let the oil permeate until saturation in the parts which make contact with it. The FC-dendrimer-treated cotton, however, showed excellent oil-water separation.

The separation efficiency of FC-dendrimer-treated cotton was 97-99%, as calculated according to **equation (4)**. A schematic diagram of oil-water separation is shown in Fig. 11. Materials which can repel water even amidst oily pollutants are very useful in seawater. Thus, as described here, coated fabric with dual functionality, is a promising material for anti-wetting, self-cleaning, support for aquatic floating devices and as a filtration material for rapid, continuous oil-water separation.

### Acid resistance

Among the possible applications of acid-resistant fabric are petroleum, chemistry, metallurgy, and electroplating. Workers in these industries need clothing made of such fabric to protect them from the dangerous acids they work with. In the past, clothing was made acid-resistant by coating it with rubber or hydrocarbon resins. These resins created a continuous film on the textile, which closed its empty spaces, stopping the intrusion of acid (Forsberg et al. 2014). **Gal'braikh (2005)** proved that fluoropolymers effectively resist corrosive solutions, including acid. Wang et al. (2011) and Zhou et al. (2013) used fluorinated polymers, which resisted acid most effectively.

The acid resistance performance of the untreated fabric and 100 g/L FC-dendrimer treated fabrics is shown in Fig. 12. Initially, 100 g/L FC-dendrimer was not affected by an acid droplet Fig. 12a. But the untreated fabric was affected by acid droplets to some extent Fig. 12b. After 30 minutes, the treated fabric washes with water. Colour change had taken place where the acid droplet had landed Fig. 12c. A large area of untreated fabric was burnt Fig. 12d by the acid droplet after 30 minutes.

### Self-cleaning`

Water-resistant finishes are chemical additions to clothing that enhance the hydrophobic nature of a fabric's surface. Completely hydrophobic surfaces also must be self-cleaning. Hydrophobic and self-cleaning attributes are exhibited in many surfaces of nature, such as the wings of butterflies, the leaves of cabbage and lotus, the elephant's ears and Indian cress. The surface of lotus leaves has protruding nubs, as proven by Scanning Electron Microscopy. Epicuticle wax crystalloid encloses each nub. Due to these crystalloids, lotus leaves clean themselves and have a water contact angle (WCA) of 160. From this model, researchers have created artificial surfaces with water contact angles greater than 90° (Guo et al. 2011; Lin et al. 2011; Li et al. 2014; Xu et al. 2010).

Self-cleaning coatings include: (Yoshida et al. 2006)

1. photocatalysis-induced superhydrophilic coatings and
2. superhydrophobic coatings.

In super-hydrophilic coatings, the surface is cleaned by the sheeting effect of water. Complex organic substances on the surface are broken down into carbon dioxide and water. Superhydrophobic coatings have air pockets that get trapped between the nano-structured substrate and water droplets. The formation of a composite solid/air/liquid interface leads to an increase in the contact angle (CA) of liquid droplets. Increased contact angle leads to de-wetting of the surface. Then the droplet rolls off easily, taking away dirt and pollutants with it.

Figure 13(a) shows that methylene blue dye powder spread widely on the untreated fabric surface due to the capillary effects of cotton fibers. The coated cotton surface has extremely little adhesion to methylene blue dye powder. However, water droplets quickly and easily removed dirt-like methylene blue dye powder on the superhydrophobic cotton surface. Thus, the surface in Figure 13(b-f) is clean and dry. Among the treated samples, 80 g/L, 90 g/L and 100 g/L FC-treated samples showed better self-cleaning performance than the 60 g/L and 70 g/L FC-treated samples.

#### Flame retardant property

Figure 14 illustrates that burning times for untreated, 60, 70, 80, 90, and 100 g/L treated fabrics were 10.5, 10.94, 11.44, 13.73, 14.3 and 14.6 seconds, respectively. Burning times of all the FC-dendrimer-treated samples were greater than that of the untreated samples. Burning time increased with an increase in the FC-dendrimer concentration. Burning time mainly depends on the amount of polymer loading on the sample and the amount of oxygen. Less oxygen in the sample increases the burning time. EDS results show that oxygen in untreated, 60, 70, 80, 90, and 100 g/L treated fabrics were 50.15, 47.53, 45.97, 45.14, 43.09, 41.97, respectively, as shown in Table 4. EDX results indicate that the oxygen level of untreated fabric was greater than that of the treated fabric. These results also revealed that the weight percentage of oxygen decreased with increasing concentrations of FC-dendrimer polymer solution as shown in Table 4.

The limiting oxygen index (LOI) is the minimum oxygen concentration needed to support the flaming combustion in a mixture of oxygen and nitrogen. The limiting oxygen index (LOI) of untreated cotton fabric was 17.8, and the treated fabric was 18. Thus, the flame retardant property of FC-dendrimer-treated fabric remains almost unchanged.

#### UV Protection Factor (UPF)

The United States Environmental Protection Agency has stated that 80% of the sun's UV rays reach the Earth, damaging human skin (The United States Environmental Protection Agency 2004), even in cold climates (Skin Cancer Foundation 2015). For this reason, it is essential to wear UV protective garments on

cloudy or rainy days and sunny days. Therefore, there is a strong demand for UV-resistant garments all over the world. There are three kinds of UV light:

1. UV-A (315-400 nm),
2. UV-B (280-315 nm) and
3. UV-C (100-290nm).

The ozone layer absorbs UV-C radiation. UV-A and UV-B radiation reach the earth's surface. These are the ones that can cause serious health problems. Ultraviolet radiation (UV-R) on earth is comprised of UV-A and UV-B rays. Its wavelength range is 280-400 nm.

Clothing serves as a link window between the outside environment and the human body. It can reflect, absorb, or scatter solar waves. Thus, ordinary clothing is usually not enough to protect the human body from the harmful effects of UV radiation. For this reason, UV-resistant finishing on textiles is necessary.

Table 9  
Ultra-violet Protection Factor (UPF) of untreated and FC-dendrimer treated fabrics.

Observation	Mean UV-A transmission	UPF rating of UV-A	Mean UV-B transmission	UPF rating of UV-B	Mean UV-R transmission	UPF rating of UV-R
60 g/L	0.657	2.16	0.113	4.00	0.476	2.84
70 g/L	0.426	3.16	0.111	4.11	0.315	3.25
80 g/L	0.415	3.21	0.109	4.23	0.314	3.49
90 g/L	0.278	4.22	0.089	4.95	0.221	3.66
100 g/L	0.275	4.58	0.081	5.42	0.213	4.42
# Mean UV-R transmission value of untreated sample was 2.792; and UPF value of untreated sample was 0.25.						

Table 9 illustrates that UPF value gradually increased with increasing FC-dendrimer concentration. The relationship between UPF rating and transmittance value is inversely proportional. The UPF value of the 100 g/L FC-dendrimer-treated samples was 4.42 for UV-R, nine times greater than that of the untreated sample. Pande and Crooks (Pande and Crooks 2011) identified the absorbance peak at 280 to 285 nm which is caused by the dendrimer structure. A dendrimer is a key component for maximizing the ultra-violet protection capacity of FC-dendrimer-treated clothing.

Antimicrobial activity

Clothing that fights germs is better for human health. Sometimes, as in a medical environment, it is essential. If clothing is water-, oil- and dirt-repellant and UV-protective and antimicrobial, this is almost ideal in many applications (Attia et al. 2017).

Antimicrobial clothing materials can be active or passive. Passive materials do not contain bioactive substances. Only the surface structure of the passive material can resist microbial contamination. Examples include “the lotus effect” and the micro-domain-structured surface. The key is to make it impossible for microbial cells to adhere to the fibre’s surfaces. Active antimicrobial clothing contains bioactive substances which kill microbes (Russell and Chopra 1996; Beumer et al. 2000).

Recently, modified dendrimers have been proposed to develop antimicrobial properties for applications to textiles. Ghosh et al. (2010) observed effective antimicrobial activities of the modified-dendrimer treated-fabric against *Staphylococcus aureus* (*S. aureus*).

Clear microbial inhibition zones were not found for treated fabrics in Fig. 15 (b-f). However, bacterial population growth seems to be less on the FC-dendrimer-treated samples in Fig. 15(b-f) than on the untreated sample in Fig. 15(a). Among the treated samples, 100 g/L FC-dendrimer treated fabric (Fig. 15(f)) showed the lowest bacterial population growth. The bacterial population was assessed by visual inspection. Around the untreated sample, the area is more ambiguous than the treated fabric. More ambiguity indicates a higher bacterial population.

FC-dendrimer polymer has no active antimicrobial properties. But it can act as a passive antimicrobial agent, due to converting fabric surfaces to super-hydrophobic surfaces. Hydrophobic and super-hydrophobic fabrics resist bacterial adherence by making it a slippery surface like that of lotus leaves.

In this study, RUCO STAR EEE 6 was used, containing dendrimers and FC resin. It is assumed that the amino group ( $\text{NH}_2$ ) in dendrimer is the functional group responsible for its antibacterial activity. After FC-dendrimer treatment, 100 g/L FC-dendrimer-treated samples exhibited the highest nitrogen level (1.63%), as found by EDS analysis.

GSM and thickness measurement

Table 10  
Thickness and GSM of treated and untreated fabric.

Observation	Thickness (mm)	Thickness Increase (%)	GSM (g/m <sup>2</sup> )	GSM Increase (%)
Untreated	0.480±.024	-	180±3.39	-
60 g/L FC-dendrimer treated	0.502±.012	4.58	185±3.42	2.70
70 g/L FC-dendrimer treated	0.506±.007	5.83	187±2.92	3.74
80 g/L FC-dendrimer treated	0.508±.008	7.50	188±2.92	4.25
90 g/L FC-dendrimer treated	0.522±.009	8.75	190±2.83	5.26
100 g/L FC-dendrimer treated	0.524±.006	9.16	191±2.59	5.75

After FC-dendrimer treatment, GSM and thickness of the treated fabrics increased markedly compared to that of the untreated fabric (Table 10). The FC-dendrimer resin closed all the pores in the fabric, creating a chemical coating. That was the reason behind the thickness and weight increases of the fabric. Both GSM and thickness gradually increased with increased FC-dendrimer resin concentration.

#### Bursting strength measurement

Table 11  
Bursting strength test result.

Observation	Bursting strength (Kpa)
Untreated fabric	176 ± 2.39
60 g/L FC treated fabric	180 ± 1.92
70 g/L FC treated fabric	183 ± 1.92
80 g/L FC treated fabric	186 ± 2.07
90 g/L FC treated fabric	189 ± 1.64
100 g/L FC treated fabric	188 ± 1.58

Bursting strength is the amount of pressure that ruptures the fabric. The increase or decrease in bursting strength is mainly a function of the smoothness or roughness of the treated fabric's surface. Generally, a smooth surface increases bursting strength and vice-versa. The SEM image revealed that micro-roughness was developed on fluorocarbon-treated cotton (Fig. 15**(b-f)**) in comparison to the untreated cotton fabric. Micro-surface roughness increases with the increased water contact angle of the treated fabric. But, visually, FC-dendrimer-treated cotton fabric showed a smooth surface. It is assumed that softening agents, like non-ionic polysiloxane, were the main contributor factors for the treated fabric's

visual smoothness and smooth feel. In the present study, Table 11 shows that the bursting strength of treated fabric increases as the FC-dendrimer concentration increases.

Additionally, the SEM result did not support the present outcome. The true explanation for this is still unclear.

#### Abrasion resistance measurement

The study aimed to see if the treated fabrics could withstand abrasion. The spray rating remained unchanged after 5,000 rub cycles, according to the results (Table 12). On the other hand, water repellency decreased a little after 10,000 rub cycles. Water spray rating of 60 g/L FC-dendrimer treated fabric was maintained at 4 using the ASTM D4966-98 (1989) standard. After 10,000 rub cycles, 70 g/L FC-dendrimer treated fabric maintains a 4-5 spray rating. 80, 90, 100 g/L FC-dendrimer treated fabrics showed the best abrasion resistance.

Table 12  
Spray rating result after abrasion.

Observation	Martindale rub cycle	Spray rating after abrasion	Martindale rub cycle	Spray rating after abrasion
60 g/l FC-D treated fabric	5000	5	10,000	4
70 g/l FC-D treated fabric	5000	5	10,000	4-5
80 g/l FC-D treated fabric	5000	5	10,000	5
90 g/l FC-D treated fabric	5000	5	10,000	5
100 g/l FC-D treated fabric	5000	5	10,000	5

#### Thermal conductivity

Thermal conductivity is heat flow through a material. Table 13 illustrates that the least conductivity existed in 100 g/L FC-dendrimer-treated fabric, and maximum conductivity was observed in 60 g/L concentration. The thermal conductivity value decreased as the thickness and GSM of the treated sample gradually increased. As FC-dendrimer concentration increased, the rate of heat transfer decreased. The thermal conductivity rate of 90 g/L and 100 g/L FC-dendrimer-treated fabric was decreased to 40% and 54%, respectively, due to their greater thickness. Moreover, it is assumed that changing the surface morphology of the treated fabric also created barriers to thermal conductivity. SEM study revealed that the FC-dendrimer polymer filled the pores of the untreated fabrics and deposited small amounts of

granular material on the surface of the treated fabric, which would reduce thermal conductivity in the treated sample.

Table 13

Thermal conductivity test results and their Chi-Square ( $\chi^2$ ) hypothesis test observation (Degree of freedom: (3-1) =2; Level of significance; 5%).

Observation	Thermal conductivity (Cal/cm/s/°C) $\times 10^{-3}$	Calculated value	Tabulated value	Comments
60 g/L FC-dendrimer treated	17.8±0.18	2.73	5.99	Null hypothesis test is accepted
70 g/L FC-dendrimer treated	16.53±0.34	4.46		Null hypothesis test is accepted
80 g/L FC-dendrimer treated	15.63±0.29	5.98		Null hypothesis test is accepted
90 g/L FC-dendrimer treated	13.43±0.29	10.81		Null hypothesis test is rejected
100 g/L FC-dendrimer treated	10.26±0.21	19.46		Null hypothesis test is rejected
*Thermal conductivity of untreated fabric: 22.3 (Cal/cm/s/°c) $\times 10^{-3}$				

The calculated values for thermal conductivity of 60 g/L, 70 g/L and 80 g/L FC-dendrimer-treated fabric are less than the tabulated values as shown in Table 13, so the null hypothesis is accepted. On the other hand, the calculated values of 90 g/L and 100 g/L FC-dendrimer-treated fabrics are greater than the tabulated values: as a result, the null hypothesis is rejected.

Therefore, thermal conductivity will not be hampered by 60 g/L, 70 g/L and 80 g/L FC-dendrimer treatment. But the comfort properties of the fabric will be significantly and negatively affected by 90 g/L and 100 g/L FC-dendrimer treatment.

#### Air permeability

Comfort and breathability are closely related to air permeability. The air permeability rate of 60 g/L, 70 g/L, 80 g/L, 90 g/L and 100 g/L FC-dendrimer treated fabric was 829, 818, 790, 750 and 733  $m^3/m^2/h$ , respectively, as shown in Table 14. The highest air permeability value existed in 60 g/L fabric, and the air permeability of 90 g/L and 100 g/L treated fabrics were 13% and 15% lower, respectively, than that of untreated fabric. As the concentration of FC-dendrimer coating materials increased, the pickup percentage gradually increased and, as a direct result, the air permeability value declined.

Cross-linking networks may form on the water-repellent finish. The FC-dendrimer treatment results in blocking some pores, which may be responsible for less air permeability. These are some of the factors that may create less air permeability.

Table 14

Air permeability test results and their Chi-Square ( $\chi^2$ ) hypothesis test observation (Degree of freedom: 3-1 = 2; and Level of significance; 5%).

Observation	Mean value of Air Permeability rate in ( $\text{m}^3/\text{m}^2/\text{hour}$ )	Chi-square calculated value	Chi-square Tabulated value	Comments
60 g/L FC-dendrimer treated fabric	829±1.92	3.29	5.99	Null hypothesis test is accepted
70 g/L FC-dendrimer treated fabric	818±2.07	5.97		Null hypothesis test is accepted
80 g/L FC-dendrimer treated fabric	818±2.07	16.78		Null hypothesis test is rejected
90 g/L FC-dendrimer treated fabric	749±1.58	42.46		Null hypothesis test is rejected
100 g/L FC-dendrimer treated fabric	790±2.59	56.56		Null hypothesis test is rejected
Air permeability of untreated fabric: 860 ( $\text{m}^3/\text{m}^2/\text{hour}$ )				

The critical chi-square value is evaluated at a 5% level of significance with two degrees of freedom. For each sample, we took three observations. The calculated values for 60 g/L and 70 g/L FC-dendrimer-treated fabrics are less than the tabulated values as shown in Table 14, so the null hypothesis is accepted. On the other hand, the calculated value for 80 g/L, 90 g/L and 100 g/L is greater than the tabulated value, as shown in Table 14, **so** the null hypothesis is rejected. The 80 g/L, 90 g/L and 100 g/L FC-dendrimer-treated fabric observation did not achieve a sufficient value for accepting the null hypothesis, but the 60 g/L and 70 g/L FC-dendrimer-treated fabric observation did.

Thus, we conclude that 60 g/L and 70 g/L FC-dendrimer treatment will not hamper the air permeability or comfort of the fabric. But this will not hold at higher levels of FC-dendrimer concentration.

### Water vapour permeability

Clothing should be able to let water vapour pass through it. Otherwise, heat accumulates in the body as humid water vapour is impacted between clothing and the body. Similarly, perspiration should pass through clothing. Lighter fabrics (less mass per square meter and thickness) permit the easy passage of water vapour through the fabrics.

The water vapour permeability rate decreased with the increased concentration of FC-dendrimer, as shown in Table 15. The water vapour permeability of 60 g/L, 70 g/L, 80 g/L, 90 g/L, and 100 g/L FC-dendrimer-treated fabrics were 1249, 1240, 1231, 1221 and 1212 gm/m<sup>2</sup>/day, respectively.

Table 15  
The results of water vapour permeability readings with variation of C6-FC-dendrimers.

Observation	After 01 hour in gm/m <sup>2</sup>	After 02 hour in gm/m <sup>2</sup>	After 03 hour in gm/m <sup>2</sup>	After 04 hour in gm/m <sup>2</sup>	After 24 hour gm/m <sup>2</sup>
60 g/L FC-dendrimer treated fabric	41	85	142	222	1249
70 g/L FC-dendrimer treated fabric	38	83	139	219	1240
80 g/L FC-dendrimer treated fabric	37	80	137	217	1231
90 g/L FC-dendrimer treated fabric	35	78	135	213	1221
100 g/L FC- dendrimer treated fabric	32	75	133	207	1212
*Water vapour permeability of untreated fabric - 1288 gm/ m <sup>2</sup> /day					

Table 16

Chi-Square ( $\chi^2$ ) hypothesis test observation in terms of water vapour permeability value of treated fabric (Degree of freedom:  $(3-1) = 2$ ; Level of significance, 5%).

Observation	Calculated value	Tabulated value	Comments
60 g/L FC-dendrimer treated fabric	3.6	<b>5.99</b>	Null hypothesis test is accepted
70 g/L FC-dendrimer treated fabric	5.51		Null hypothesis test is accepted
80 g/L FC-dendrimer treated fabric	7.65		Null hypothesis test is rejected
90 g/L FC-dendrimer treated fabric	10.56		Null hypothesis test is rejected
100 g/L FC-dendrimer treated fabric	13.69		Null hypothesis test is rejected
Water vapour permeability of untreated fabric: 1288 gm/ m <sup>2</sup> /day			

The calculated values of 60 g/L and 70 g/L FC-dendrimer-treated fabrics are less than the tabulated value, as shown in Table 16, so the null hypothesis is accepted. On the other hand, the calculated values of 80 g/L, 90 g/L and 100 g/L FC-dendrimer-treated fabrics are greater than the tabulated values: as a result, the null hypothesis is rejected.

It may determine that FC-dendrimer treatment at 60 g/L and 70 g/L does not affect on water vapour permeability or comfort qualities. However, treatment with 80, 90, and 100 g/L FC-dendrimer significantly reduces comfort qualities.

## Conclusion

The purpose of this experiment was to test whether FC-dendrimer treatment could improve the characteristics of cotton fabric to make it more functional and protective. In that sense, this experiment was a success. FC-dendrimer and crosslinking agents produce a fabric that is water-, oil- and dirt-repellent, as well as UV-protective. As the amount of FC-dendrimer concentration increases, these properties of the treated fabric intensify. An increase in the surface hydrophobicity, reduction of surface energy and lowering the number of hydroxyl functional groups on the cotton fabric surface are achieved by FC-dendrimer coating, enhancing its repellence and allowing unwanted water, oil and dirt to slide off so that the fabric self-cleans. High contact angle values for liquids mean that FC-dendrimer-treated cotton

fabrics have become hydrophobic. The treated cloth effectively separates water/oil combinations on its surface due to its hydrophobic properties.

Results showed that fabric coated with 60, 70, 80 g/L FC-dendrimer displayed the best performance in comfort. On the other hand, 90 and 100 g/L showed the best result in terms of water resistance. Therefore, FC-dendrimer treatment can produce more suitable textiles than untreated cotton for a wide range of functions, including anti-wetting, self-cleaning, oil-water separation, antimicrobial articles and protective textiles.

## **Limitations**

In this study, the spray rating did not change after five machine washes. On the other hand, the spray rating did not change after 5000 rub cycles. Furthermore, 70, 80, and 100 g/L FC-dendrimer treated fabric still maintained their hydrophobicity even after 10,000 rub cycles. As a result, after five machine washes and 10,000 rub cycles, the self-cleaning, oil-water separation, hydrophobic, antibacterial, UV resistant, and flame retardant qualities all preserved their efficacy.s. All the self-cleaning, oil-water separation, antibacterial, UV resistant and flame retardant properties mainly depend on the hydrophobic performance of the fabric for this study.

Some literature revealed that fluorocarbon-treated fabric has become unusable after 50 (fifty) washing cycles and 50,000 rub cycles. So, this issue of persistence of the effects of treatment needs further investigation.

Several types of dendrimers are available in the market. In this study, FC-dendrimer (Rucostar EEE6, Rudolf, Germany) has been used.

A detailed mechanism of FC-dendrimer interaction with the fabric was not shown. For this reason, it was not possible to demonstrate the cross-linking network between FC-dendrimer and cotton fabric. Furthermore, due to a lack of specific information on the FC-dendrimer chemical structure, it did not clearly describe the process of UV resistance. .. These will be of great interest to researchers for future investigation.

## **Declarations**

### **Compliance with ethical standards**

### **Conflicts of interest**

The authors declare they have no conflicts of interest.

### **Ethical standard**

This article does not involve the participation of humans or animals.

## References

1. AATCC Test Method 124-2018t (2018) Smoothness appearance of fabrics after repeated home laundering. AATCC Technical Manual, Research Triangle Park, NC 27709, USA, pp.195-198.
2. AATCC Test Method 127-2008 (2009) Water Resistance: Hydrostatic Pressure Test. AATCC Technical Manual, Research Triangle Park, NC 27709, USA, pp. 201-202.
3. AATCC Test Method TM 22-2005 (2009) Water Repellency: Spray Test. AATCC Technical Manual, Research Triangle Park, NC 27709, USA, pp. 67-69
4. AATCC Test Method: TM 147-2004 (2010) Determination of Zone of Inhibition by Qualitative Method. AATCC Technical Manual, Research Triangle Park, NC 27709, USA, 85 (2010), pp. 251-252
5. AATCC Test Method: TM 183-2004 (2010) Transmittance or blocking of erythemally weighted ultraviolet radiation through fabric, in: AATCC Technical Manual. AATCC Technical Manual. Research Triangle Park, NC 27709, USA, pp. 318-319
6. Abo-Shosha MH, El-Hilw ZH, Aly AA, Amr A, Nagdy ASIE (2008) Paraffin wax emulsion as water repellent for cotton/polyester blended fabric. *J Ind Text* 37(4): 315-325
7. Akbari S, Kozłowski RM (2019) A review of application of amine-terminated dendritic materials in textile engineering. *J Text Inst* 110(3): 460-467
8. ASTM D4966-98 (1989) Standard test method for abrasion resistance of textile fabrics (Martindale Abrasion tester method). ASTM International, West Conshohocken, USA.
9. Ajgaonkar DB (1998) Knitting Technology. Universal Publishing Corporation, Bombay, India, pp. 2-3
10. Altınışık A, Bozacı E, Akar E, Seki Y, Yurdakoc K, Demir A, Özdoğan E (2013) Development of antimicrobial cotton fabric using bionanocomposites. *Cellulose* 20: 3111-3121
11. ASTM D 1230-94 (1994) Standard Test Method for Flammability of Apparel Textile (45° Flamme test), American Society for Testing Materials, West Conshohocken, PA, USA
12. ASTM D 3786-87 (1987) Test Method for Hydraulic or Pneumatic Bursting Strength of Textile Fabrics-Diaphragm Bursting Strength Tester Method. American Society for Testing Materials, West Conshohocken, PA, USA.
13. ASTM D3776-96 (2002) Standard test methods for mass per unit area (weight) of fabric. ASTM International, West Conshohocken, PA, USA
14. ASTM D4966-98 (1989) Standard Test Method for abrasion resistance of textile fabrics (Martindale Abrasion tester method). ASTM International, West Conshohocken
15. Attia NF, Moussa M, Sheta AM, Taha R, Gamal H (2017) Synthesis of effective multifunctional textile based on silica nanoparticles. *Prog Org Coat* 106: 41-49
16. Atav R, Bariş B (2016) Dendrimer technology for water and oil repellent cotton textiles. *AATCC J Res* 3(2): 16-24
17. Baig U, Matin A, Gondal MA, Zubair SM (2019) Facile fabrication of superhydrophobic, superoleophilic photocatalytic membrane for efficient oil-water separation and removal of hazardous

- organic pollutants. *J Clean Prod* 208: 904-915
18. Behera BK, Hari PK (2010) *Woven textile structure: Theory and applications*. Elsevier, pp. 3-30
  19. Beumer R, Bloomfield S, Exner M, Fara G, Nath K, Scott E (2000) Microbial resistance and biocides: A review. *International Forum on Home Hygiene (IFH)*, in: *International Scientific Forum on Home Hygiene*, 2000
  20. BS 2544: 1954 (1954) Determination of Thickness of Textile Fabric. *British Standard Handbook* 11: 174
  21. BS 5636 (1990) Method of test for the determination of the permeability of fabrics to air. *British Standards Institute*, Berkshire, UK
  22. BS 7209 (1990) Specification for water vapor permeable apparel fabrics. *British Standards Institute*, Berkshire, UK
  23. Cao C, Cheng J (2018) Fabrication of robust surfaces with special wettability on porous copper substrates for various oil/water separations. *Chem Eng J* 347: 585-594
  24. Cerne L, Simoncic B (2004) Influence of Repellent Finishing on the Surface Free Energy of Cellulosic Textile Substrates. *Text Res J* 74(5): 426-432
  25. Chinta SK, Satish D (2014) Studies in waterproof breathable textiles. *Int J Recent Develop Eng Technol* 3: 16-20
  26. Chowdhury KP (2018a) Impact of different water repellent finishes on cotton double jersey fabrics. *J Text Sci Tech* 4(3): 85-99
  27. Chowdhury KP (2018b) Process intensification of fluorocarbon-free and fluorocarbon-based water repellent finishes on cotton knit fabrics. *J Text Eng Fashion Technol* 4(3): 232–240
  28. Chung C, Lee M, Choe E.K. (2004) Characterization of cotton fabric scouring by FT-IR ATR spectroscopy *Carbohydr Polym* 58: 417-420
  29. Colleoni C, Massafra MR, Migani V, Rosace G (2011) Dendrimer finishing influence on CO/PES blended fabrics color assessment. *J Appl Polym Sci* 120: 2122-2129.
  30. Crews PC, Clark DJ (1990) Evaluating UV absorbers and antioxidants for topical treatment of upholstery fabrics. *Text Res J* 60(3): 172-179
  31. Danish Environmental Protection Agency, *More Environmentally friendly Alternatives to PFOSCompounds and PFOA*, March 2005.
  32. Dashairya L, Sahu A, Saha P (2019) Stearic acid treated polypyrrole-encapsulated melamine formaldehyde superhydrophobic sponge for oil recovery. *Adv Compos Hybrid Mater* 2(1): 70-82
  33. De P, Sankhe MD, Chaudhari SS, Mathur MR (2005) UV-resist, water-repellent breathable fabric as protective textiles. *J Ind Text* 34: 209-222
  34. Dong C, Lu Z, Zhang F, Zhu P, Zhang L, Sui S (2015). Preparation and properties of cotton fabrics treated with a novel polysiloxane water repellent and flame retardant. *Mater Lett* 152: 276–279
  35. Flynn JH (2002). Applications to polymers and plastics, in *Handbook of Thermal Analysis and calorimetry*. <https://www.sciencedirect.com/topics/chemistry/polysiloxane>

36. Forsberg K, Van den Borre A, Iii NH, Zeigler JP (2014) Quick selection guide to chemical protective clothing (6<sup>th</sup> Edn). John Wiley & Sons, New Jersey, USA
37. Gal'braikh LS (2005) Modified fibre and film materials. *Fibre Chemistry* 37: 338-345
38. Ghosh S, Yadav S, Vasanthan N, Sekosan G (2010) A study of antimicrobial property of textile fabric treated with modified dendrimers. *J Appl Polym Sci* 115: 716-722
39. Guo Z, Liu W, Su B-L (2011) Superhydrophobic surfaces: from natural to biomimetic to functional. *J Colloid Interf Sci* 353: 335-355
40. Gupta S (2002) VK Kapoor-Fundamental of Mathematical Statistics. Sultan Chand and Sons, Educational Publishers, New Delhi, India
41. Haynes WM (2017) CRC Handbook of Chemistry and Physics (97th Edn.), Vol. 2016–2017, CRC Press, Taylor & Francis Group, Boca Raton, USA
42. Jain AK, Tesema AF, Haile A (2018) Development of multifunctional cotton using fluorocarbon resin. *J Eng Fibers Fabr* 1: 1-8.
43. Jenkins R, Snyder RL (1996) Introduction to X-ray powder diffractometry. Wiley-Interscience, New York, USA
44. Jeyasubramanian K, Hikku G, Preethi A, Benitha V, Selvakumar N (2016) Fabrication of water repellent cotton fabric by coating nano particle impregnated hydrophobic additives and its characterization. *J Ind Eng Chem* 37: 180-189
45. Kasturiya N, Bhargava G (2003) Liquid repellency and durability assessment: A quick technique. *J Ind Text* 32: 187-222
46. Khoddami A, Bazanjani S, Gong R (2015) Investigating the Effects of Different Repellent Agents on the Performance of Novel Polyester/Wool Blended Fabrics. *J Eng Fib Fabr* 10: 137-146
47. Khoddami A, Gong H, Ghadimi G (2012) Effect of wool surface modification on fluorocarbon chain re-orientation. *Fiber Polym* 13: 28-37
48. Krishnan S (1991) Technology of breathable coatings. *J Coated Fabrics* 21: 71-74
49. Lee S, Cho J-S, Cho G (1999) Antimicrobial and Blood Repellent Finishes for Cotton and Nonwoven Fabrics Based on Chitosan and Fluoropolymers. *Tex Res J*, 69(2): 104-112
50. Li J, Wang G, Meng Q, Ding C, Jiang H, Fang Y (2014) A biomimetic nano hybrid coating based on the lotus effect and its anti-biofouling behaviors. *Appl Surf Sci* 315: 407-414
51. Lidija C, Simoncic B (2008) The use of Zisman model in determining the critical surface tension of the water and oil repellent finished textiles. *Tekstilec* 51(4/6) 107-121
52. Lin J, Cai Y, Wang X, Ding B, Yu J, Wang M (2011) Fabrication of biomimetic superhydrophobic surfaces inspired by lotus leaf and silver ragwort leaf. *Nanoscale* 3: 1258-1262
53. Majumdar A, Gupta D, Gupta S (Eds.) (2019) Functional textiles and clothing. Springer.
54. Midha VK, Vashish R, Midha V (2014) Durability of fluoropolymer and antibacterial finishes on woven surgical gown fabrics. *Fashion and Textiles* 1: 12

55. Namligoz ES, Bahtiyari MI, Hosaf E, Coban S (2009) Performance comparison of new (dendrimer, nanoparticle) and conventional water, oil and stain repellents. *Fibres & Textiles in Eastern Europe*, 17: 76-81
56. Omae K, Takebayashi T, Ishizuka C, Uemura T (1998) Toxicity of Silicon Compounds in Semiconductor Industries Hiroshi NAKASHIMA. *J Occup Health* 40: 270–275
57. Pande S, Crooks RM (2011) Analysis of poly (amidoamine) dendrimer structure by UV–Vis spectroscopy. *Langmuir* 27: 9609-9613
58. Roey MV (1992) Water-resistant breathable fabrics. *J Coated Fabrics* 22: 20-31
59. Russell AD, Chopra I (1996) Understanding antibacterial action and resistance. Ellis Horwood Limited, London, United Kingdom
60. Sayed U, Dabhi P (2014) Finishing of textiles with fluorocarbons, in: *Waterproof and Water Repellent. Textiles and Clothing*, Elsevier, pp. 139-152.
61. Schindler WD, Hauser PJ (2004) *Chemical finishing of textiles*, Woodhead Publishing, Cambridge, UK, pp.74-84
62. Shekar RI, Kasturiya N, Raj H, Mathur G (2001) Studies on effect of water repellent treatment on flame retardant properties of fabric. *J Ind Text* 30: 222-254
63. Shekar RI, Yadav A, Kasturiya N, Raj H (1999) Studies on combined flame-retardant and water-repellent treatments on cotton drill fabric. *Indian J Fibre Text* 24: 197-207
64. Siddiqui AR, Maurya R, Balani K (2017) Superhydrophobic self-floating carbon nanofiber coating for efficient gravity-directed oil/water separation. *J Mater Chem A*, 5: 2936-2946
65. Singh AK, Singh JK (2016) Fabrication of zirconia based durable superhydrophobic–superoleophilic fabrics using non fluorinated materials for oil–water separation and water purification. *RSC Adv* 6: 103632-103640
66. Skin Cancer Foundation (2015). The Skin Cancer Foundation Shares Essential Sun Safety Tips for Outdoor Winter Sports. <http://www.skincancer.org/media-and-press/press-release-2015/winter-sports>.
67. Sun D, Wang W, Yu D (2017) Highly hydrophobic cotton fabrics prepared with fluorine-free functionalized silsesquioxanes. *Cellulose* 24: 4519–4531
68. Tomalia DA, Baker H, Dewald J, Hall M, Kallos G, Martin S, Smith P (1985) A new class of polymers: starburst-dendritic macromolecules. *Polym J* 17(1): 117-132
69. United States Environmental Protection Agency (2004) A Guide to the UV Index. <https://www.epa.gov/sites/production/files/documents/uviguide.pdf>.
70. Vigneswaran C, Chandrasekaran K, Senthilkumar P (2009) Effect of thermal conductivity behavior of jute/cotton blended knitted fabrics. *J Ind Text* 38: 289-307.
71. Wang C-X, Li Mao, Jiang G-W, Fang K-J, Tian A (2007) Surface modification with silicon sol on cotton fabrics for water-repellent finishing. *Res J Text Appl* 11: 27-34

72. Wang H, Song X, Xu L, Li X, Wang J, Zhao Y, Cai Z (2018) Fabrication of acid-resistant fabrics with fluoropolymer/SiO<sub>2</sub> nanocomposites for the application of protective clothing. *J Ind Text* 47: 727-740
73. Wang H, Xue Y, Ding J, Feng L, Wang X, Lin T (2011) Durable, self-healing superhydrophobic and superoleophobic surfaces from fluorinated-decyl polyhedral oligomeric silsesquioxane and hydrolyzed fluorinated alkyl silane. *Angewandte Chemie International Edition* 50: 11433-11436
74. Wang Z, Wang Y, Liu G (2016) Rapid and efficient separation of oil from oil-in-water emulsions using a Janus cotton fabric. *Angewandte Chemie International Edition* 55: 1291-1294
75. Windisch B, Vogtle F, Gestermann S, Hesse R, Schwierz H (2000) Functional dendrimers. *Prog Polym Sci* 25: 987-1041
76. Xu B, Cai Z, Wang W, Ge F (2010) Preparation of superhydrophobic cotton fabrics based on SiO<sub>2</sub> nanoparticles and ZnO nanorod arrays with subsequent hydrophobic modification. *Surf Coat Technol* 204: 1556-1561
77. Yang, M, Jiang, C, Liu W, Liang L, Pi K (2019) A less harmful system of preparing robust fabrics for integrated self-cleaning, oil-water separation and water purification. *Environ Pollut* 255: 1-9
78. Ye D, Farriol X (2005) Improving accessibility and reactivity of celluloses of annual plants for the synthesis of methylcellulose. *Cellulose* 12: 507-515
79. Yoshida N, Takeuchi M, Okura T, Monma H, Wakamura M, Ohsaki H, Watanabe T (2006) Superhydrophobic photocatalytic coatings utilizing apatite-based photocatalyst. *Thin Solid Films*. 502(1-2):108-111
80. Yuan S-J, Zhang J-J, Fan H-X, Dai X-H (2018) Facile and sustainable shear mixing/carbonization approach for upcycling of carton into superhydrophobic coating for efficient oil-water separation. *J Clean Prod* 196: 644-652
81. Zhou H, Wang H, Niu H, Gestos A, Lin T (2013) Robust, self-healing superamphiphobic fabrics prepared by two-step coating of fluoro-containing polymer, fluoroalkylsilane, and modified silica nanoparticles. *Adv Funct Mater* 23: 1664-1670

## Figures

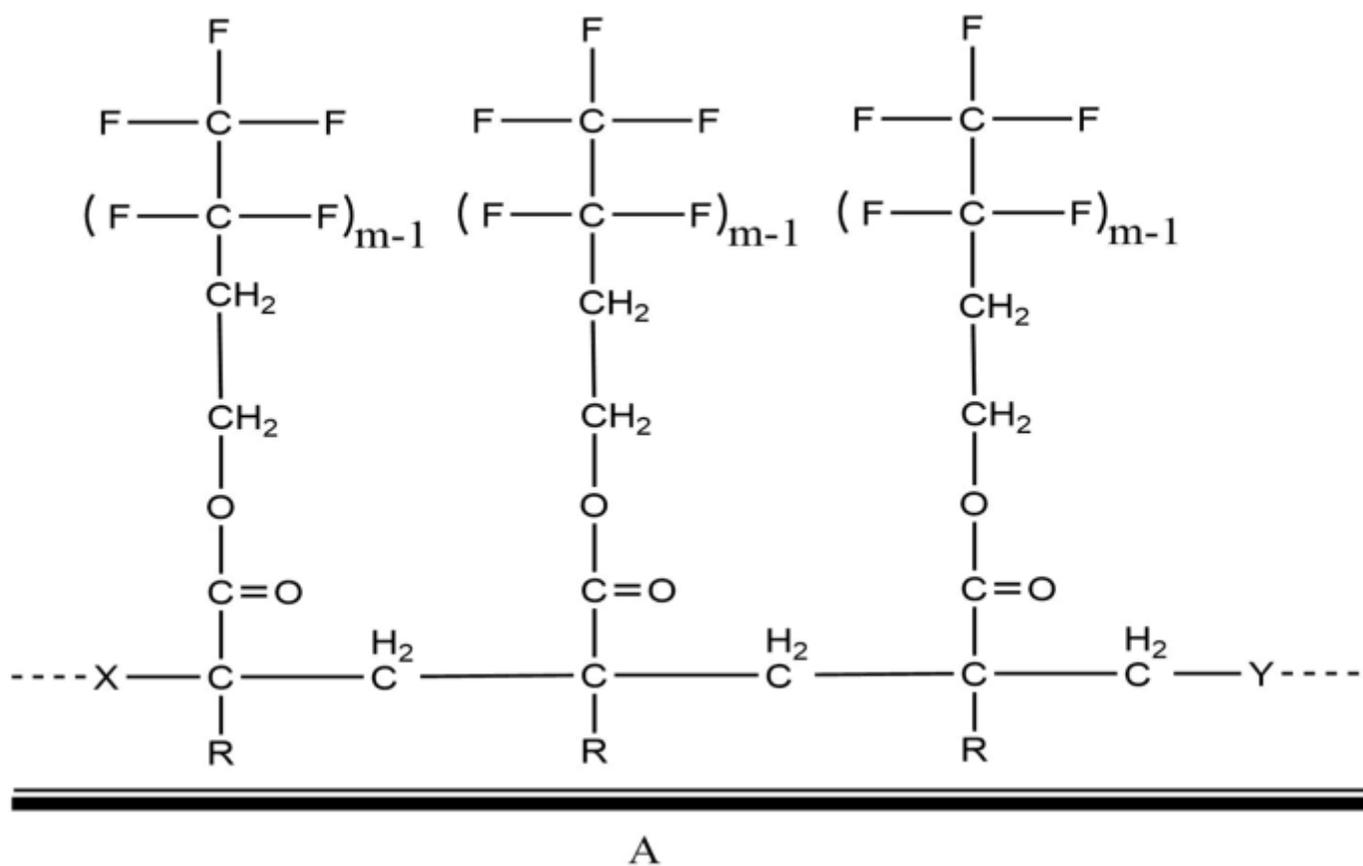


Figure 1

Fluorocarbon polymer on fibre surface. Where  $m$ ,  $X$  and  $Y$  are co-polymers mainly stearylacrylates,  $R$   $H$  or  $CH_3$  (polyacrylic or polymethacrylic acid esters), and  $A$  is the fibre surface.

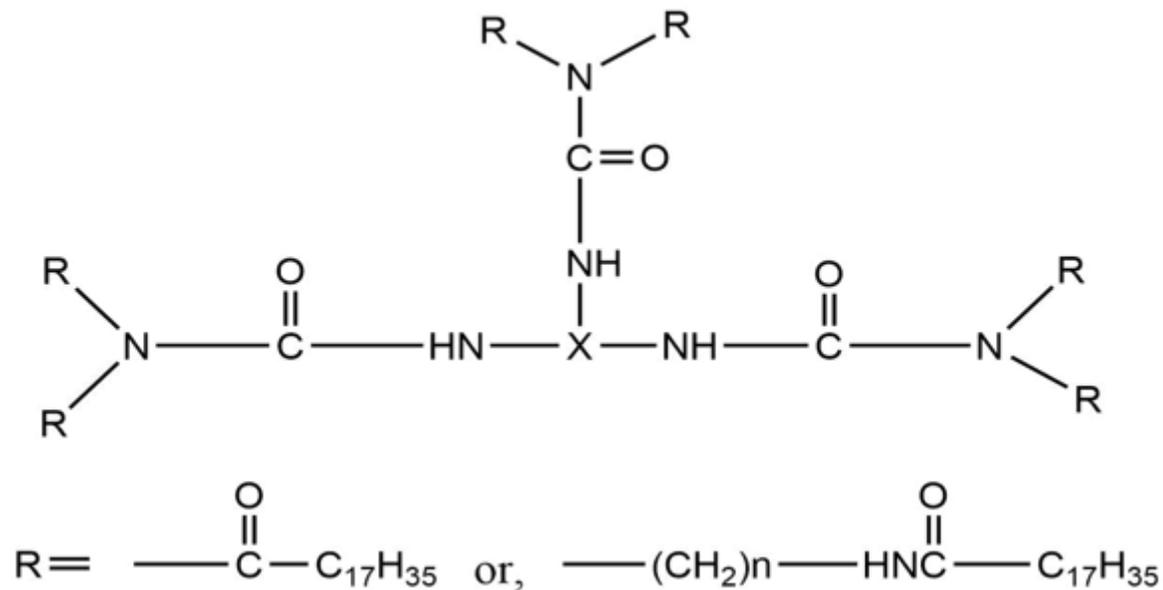
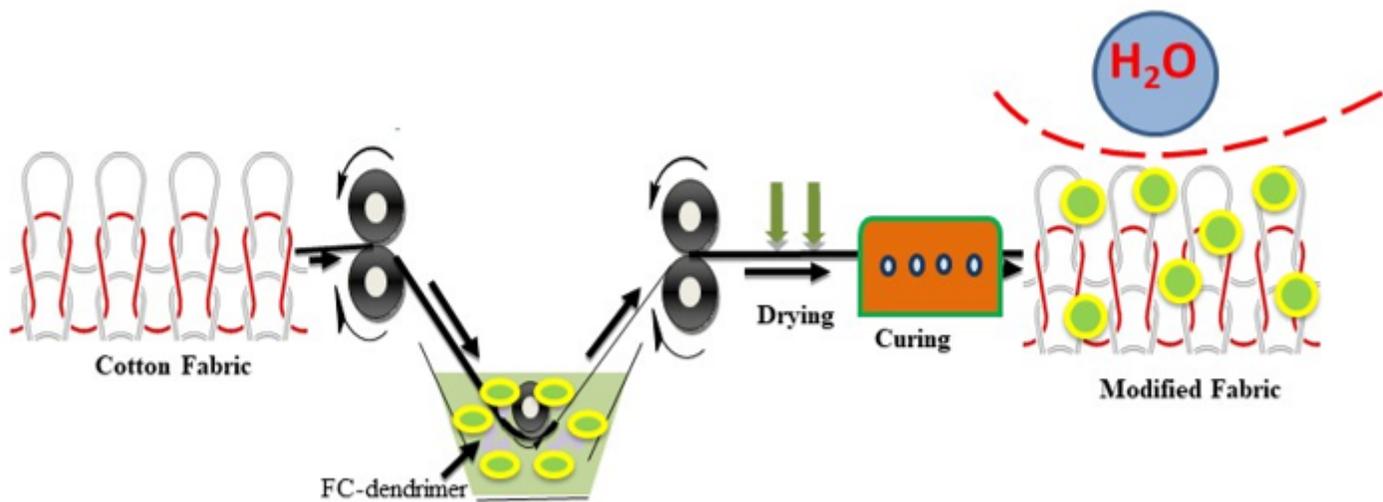


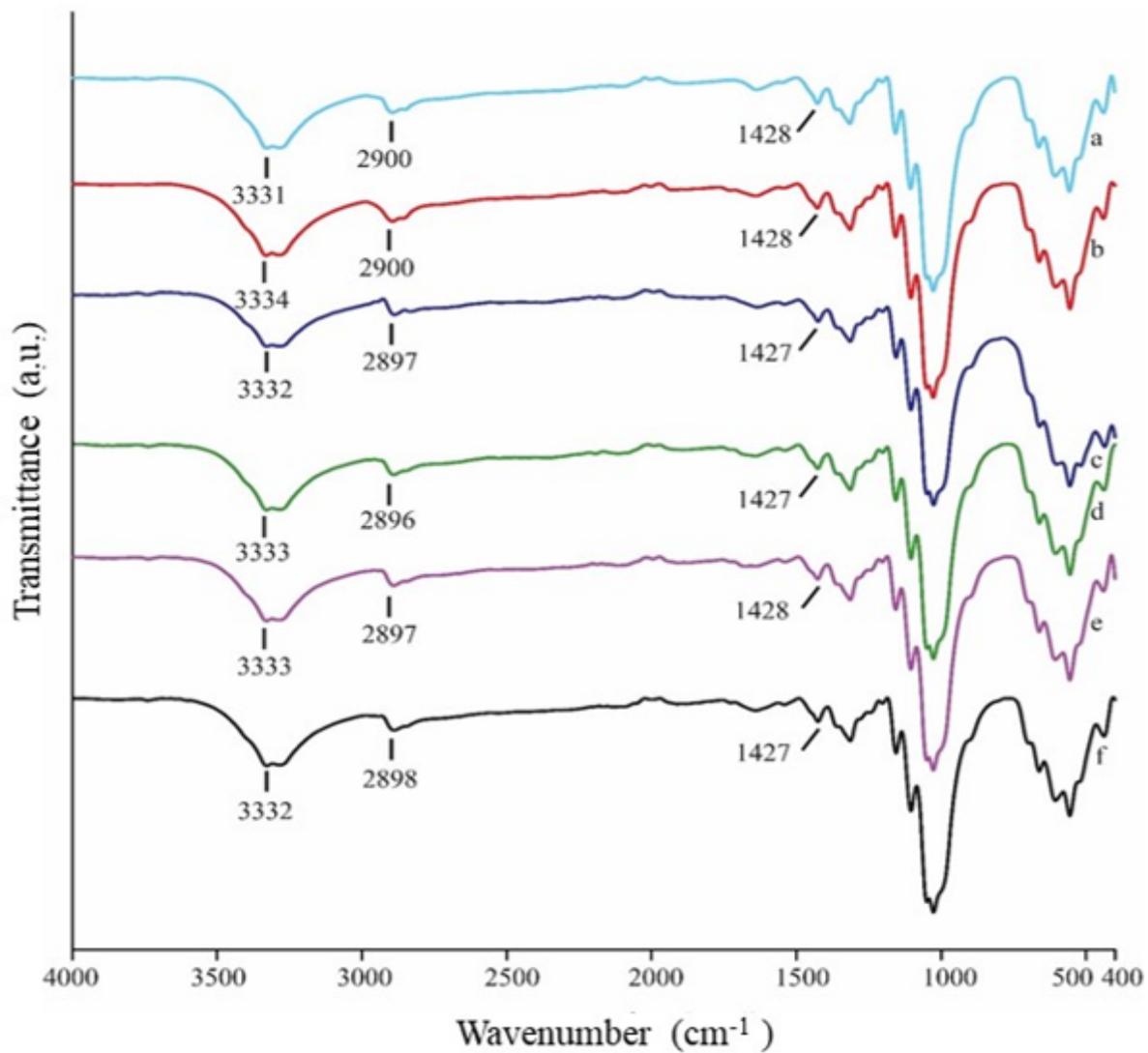
Figure 2

A dendrimer structure synthesized from three distearyl-amines or amides and a tri-functional isocyanate X (N=C=O).



**Figure 3**

Schematic diagram of Sample preparation process



**Figure 4**

FTIR spectra of (a) Untreated fabric, (b) 60 g/L FC-dendrimer, (c) 70 g/L FC-dendrimer, (d) 80 g/L FC-dendrimer, (e) 90 g/L FC-dendrimer and (f) 100 g/L FC-dendrimer treated fabric.

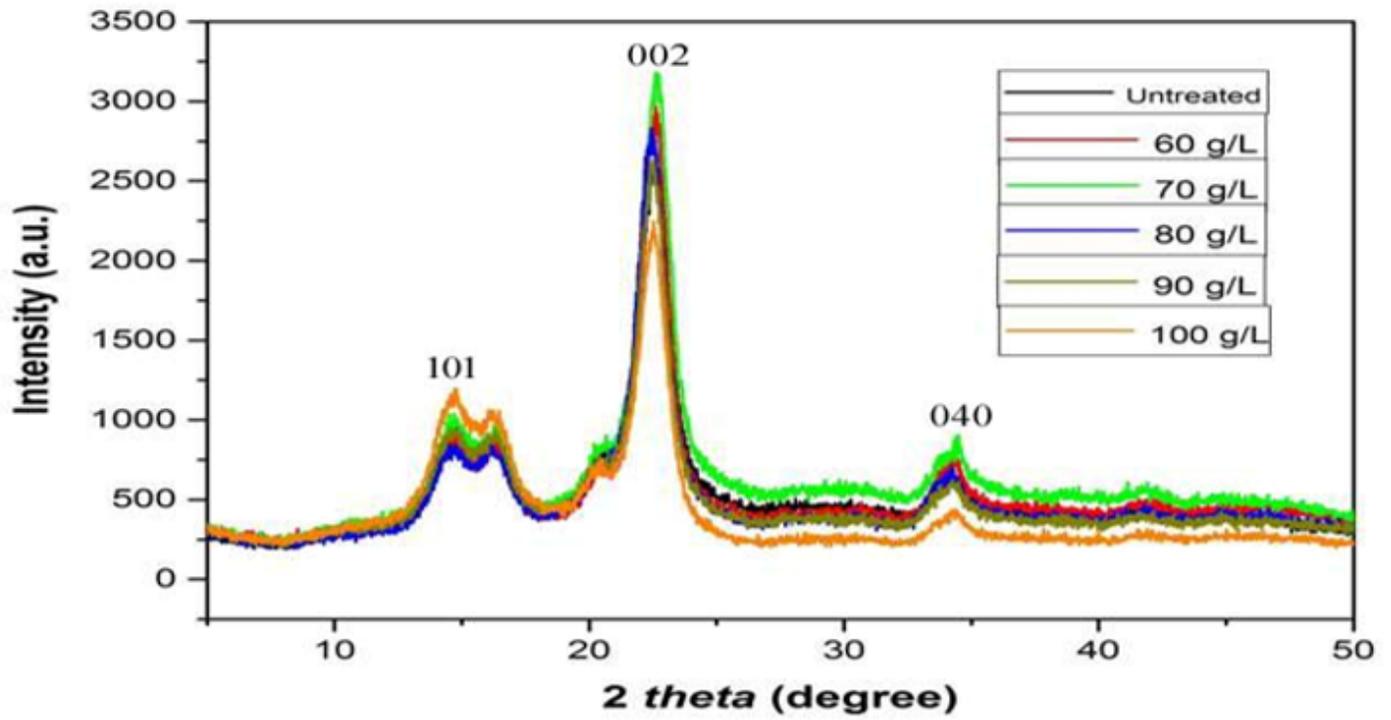
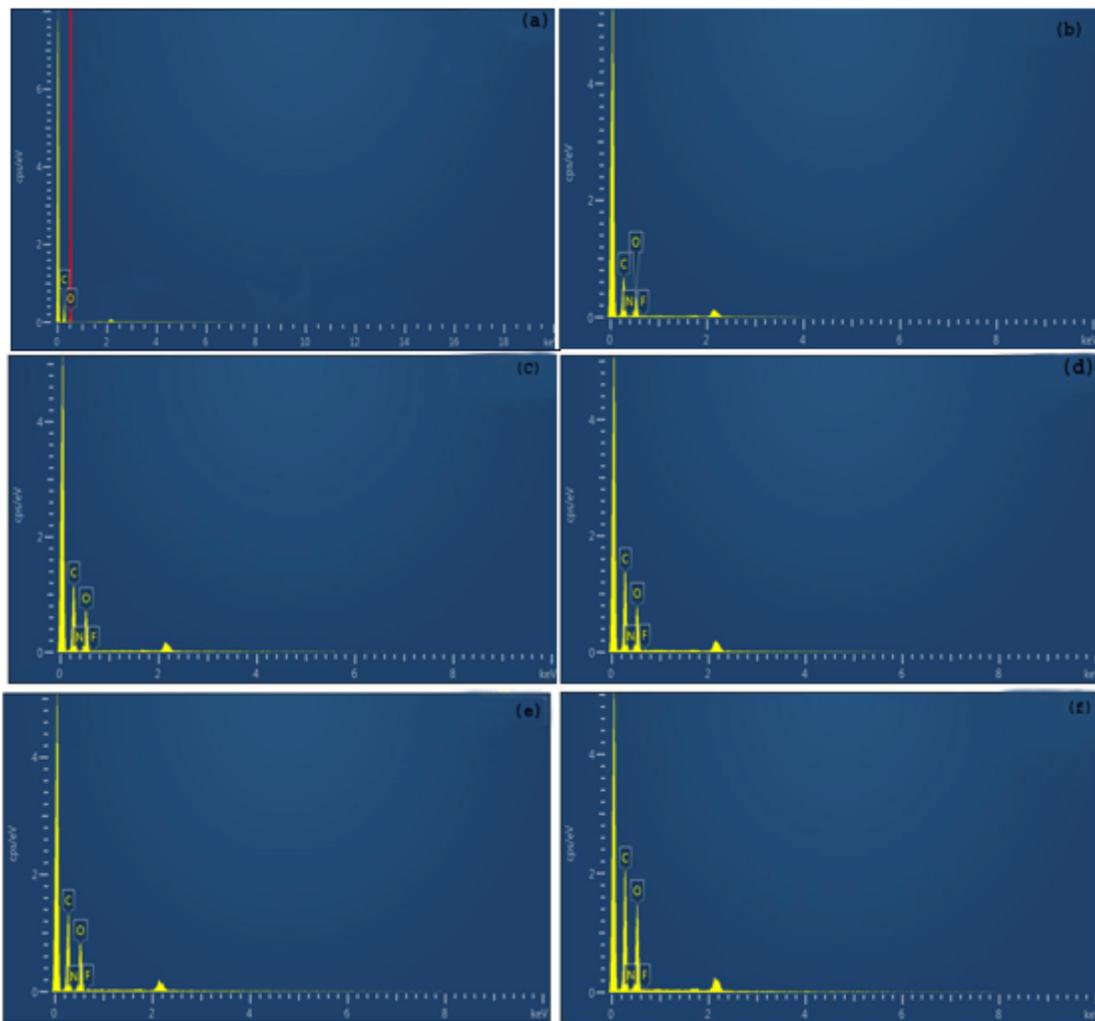


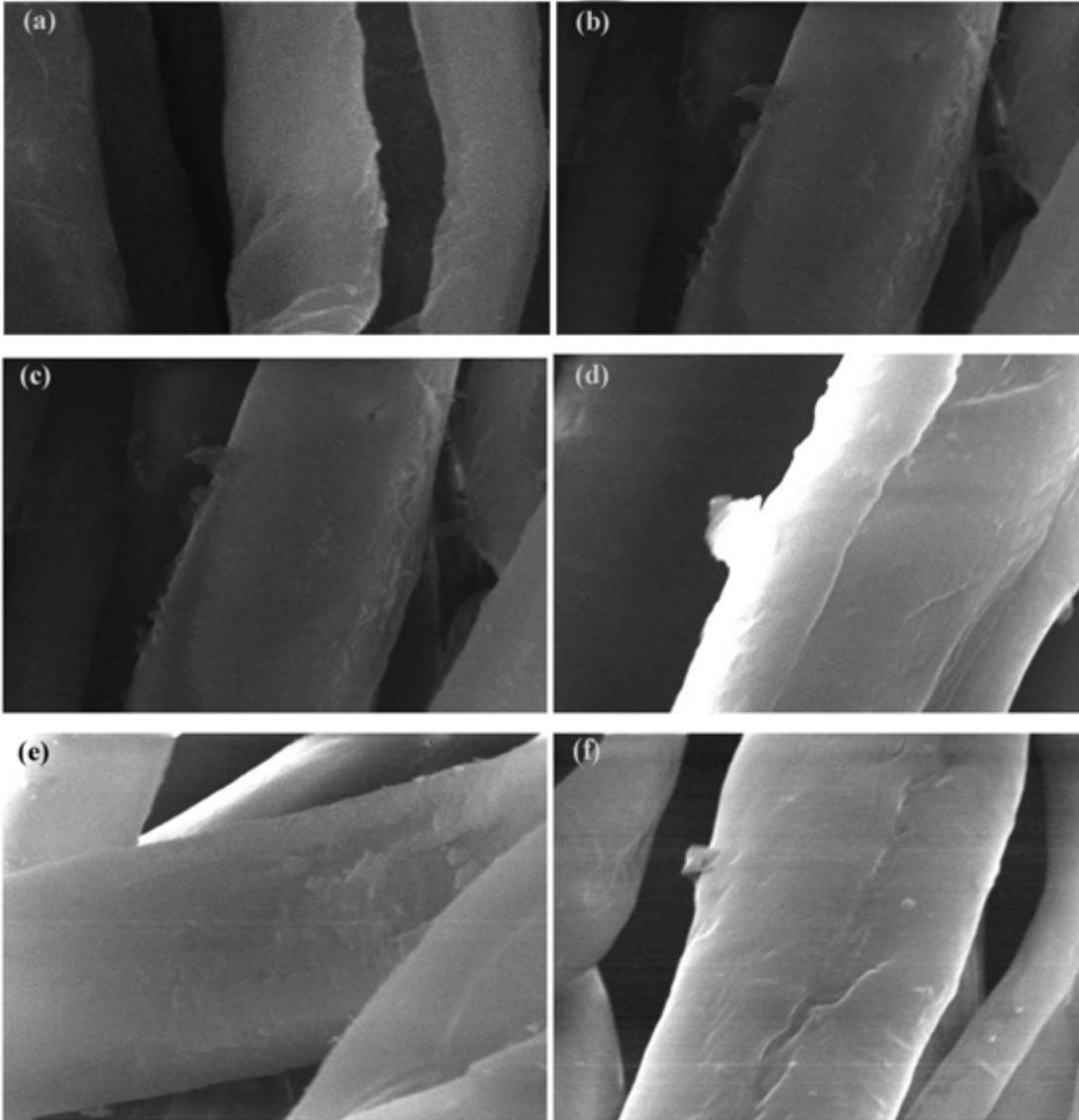
Figure 5

X-Ray Diffraction pattern untreated and FC-dendrimer treated fabrics.



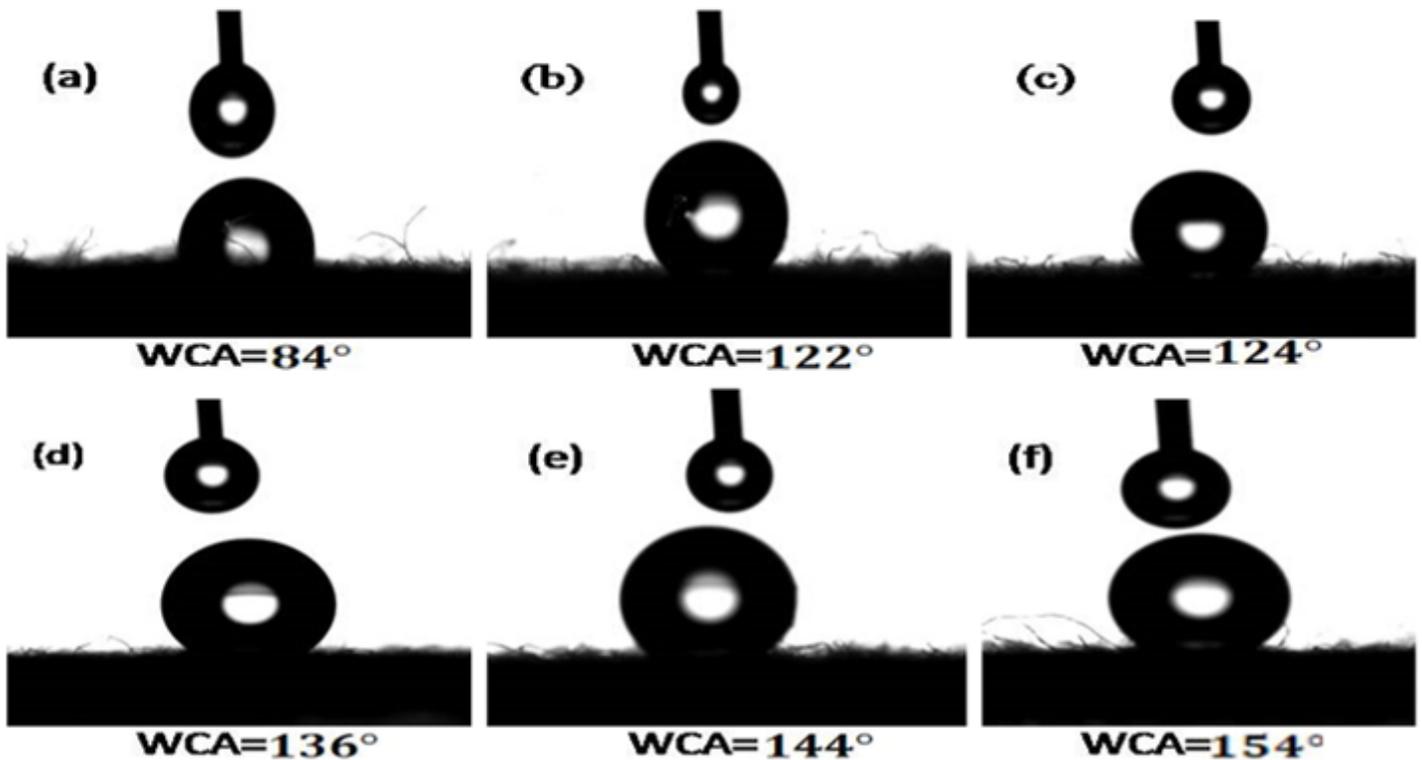
**Figure 6**

EDX photograph of (a) Untreated fabric, b) 60 g/L FC-dendrimer treated fabric, (c) 70 g/L FC-dendrimer treated fabric, (d) 80 g/L FC-dendrimer treated fabric, (e) 90 g/L FC-dendrimer treated fabric and (f) 100 g/L FC-dendrimer treated fabric.



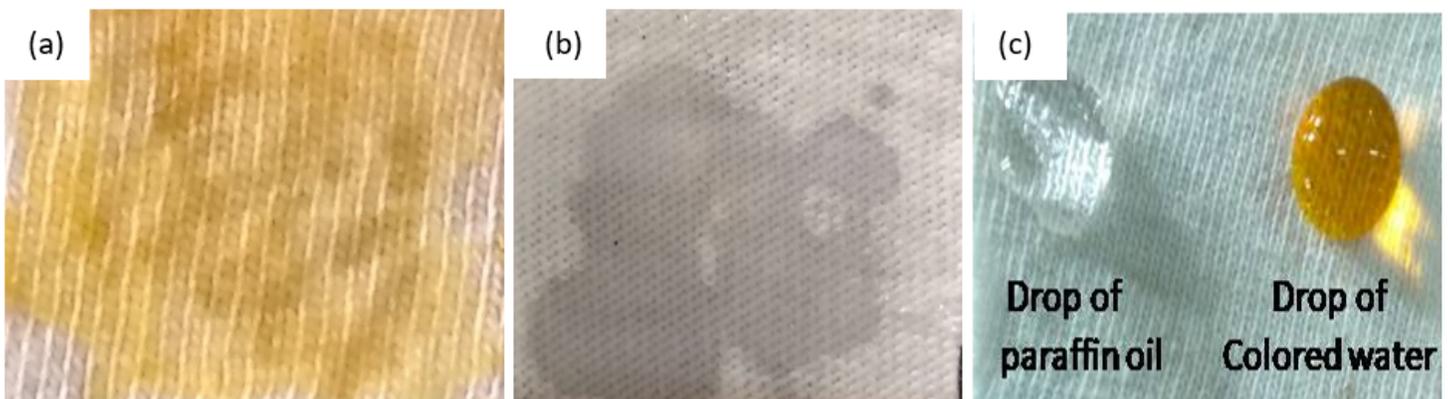
**Figure 7**

SEM photograph at 3000 magnification and 1 scale of (a) Untreated fabric, (b) 60 g/L FC-dendrimer, (c) 70 g/L FC-dendrimer, (d) 80 g/L FC-dendrimer, (e) 90 g/L FC-dendrimer and (f) 100 g/L FC-dendrimer treated fabric.



**Figure 8**

Water contact angle (WCA) of (a) Untreated fabric, (b) 60 g/L FC-dendrimer treated fabric, (c) 70 g/L FC-dendrimer treated fabric, (d) 80 g/L FC-dendrimer treated fabric, (e) 90 g/L FC-dendrimer treated fabric and (f) 100 g/L FC-dendrimer treated fabric



**Figure 9**

Water-oil repellent properties of (a) & (b) Untreated fabric and (c) 100 g/L FC-dendrimer treated fabric.

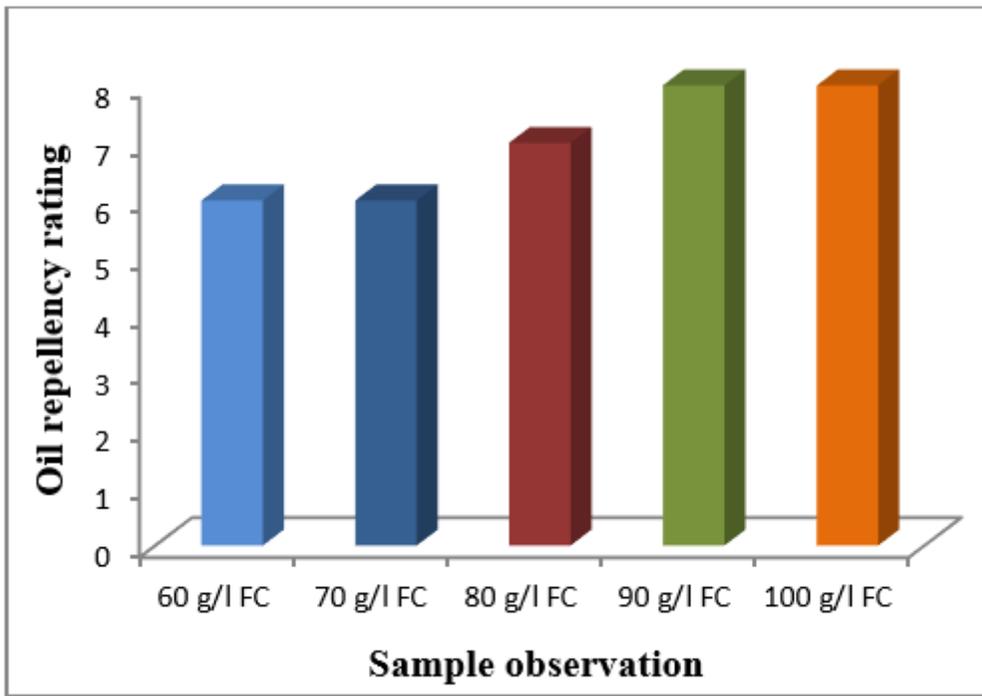


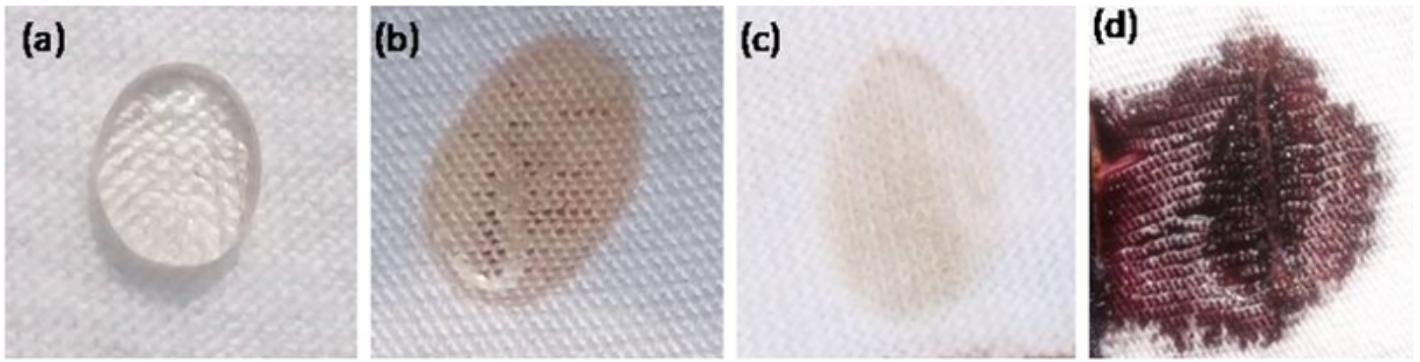
Figure 10

Oil repellency rating of the FC-dendrimer treated sample.



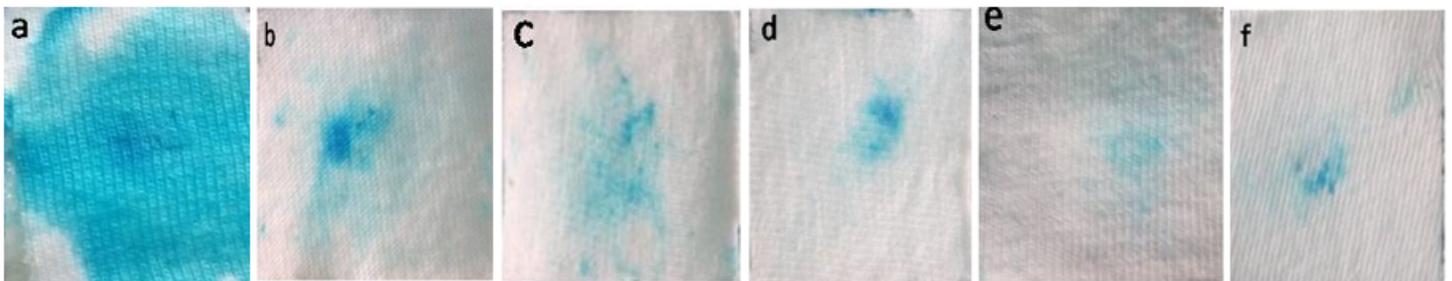
Figure 11

Schematic diagram of oil-water separation process.



**Figure 12**

Acid resistance performances of (a) 100 g/L FC-dendrimer treated fabric after 1 min., (b) Untreated fabric after 1 min., (c) 100 g/L FC-dendrimer treated fabric after 30 min. and (d) untreated fabric after 30 min.



**Figure 13**

Self-cleaning performances of (a) Untreated fabric, (b) 60 g/L FC-dendrimer treated fabric, (c) 70 g/L FC-dendrimer treated fabric, (d) 80 g/L FC-dendrimer treated fabric, (e) 90 g/L FC-dendrimer treated fabric and (f) 100 g/L FC-dendrimer treated fabric.

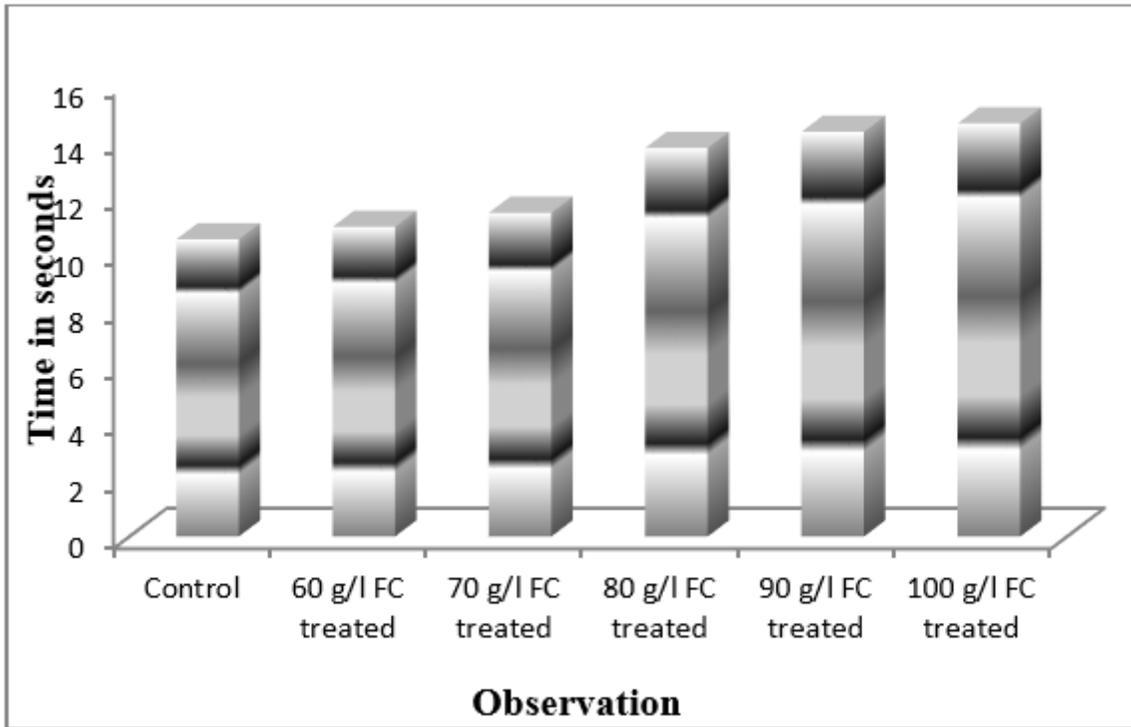
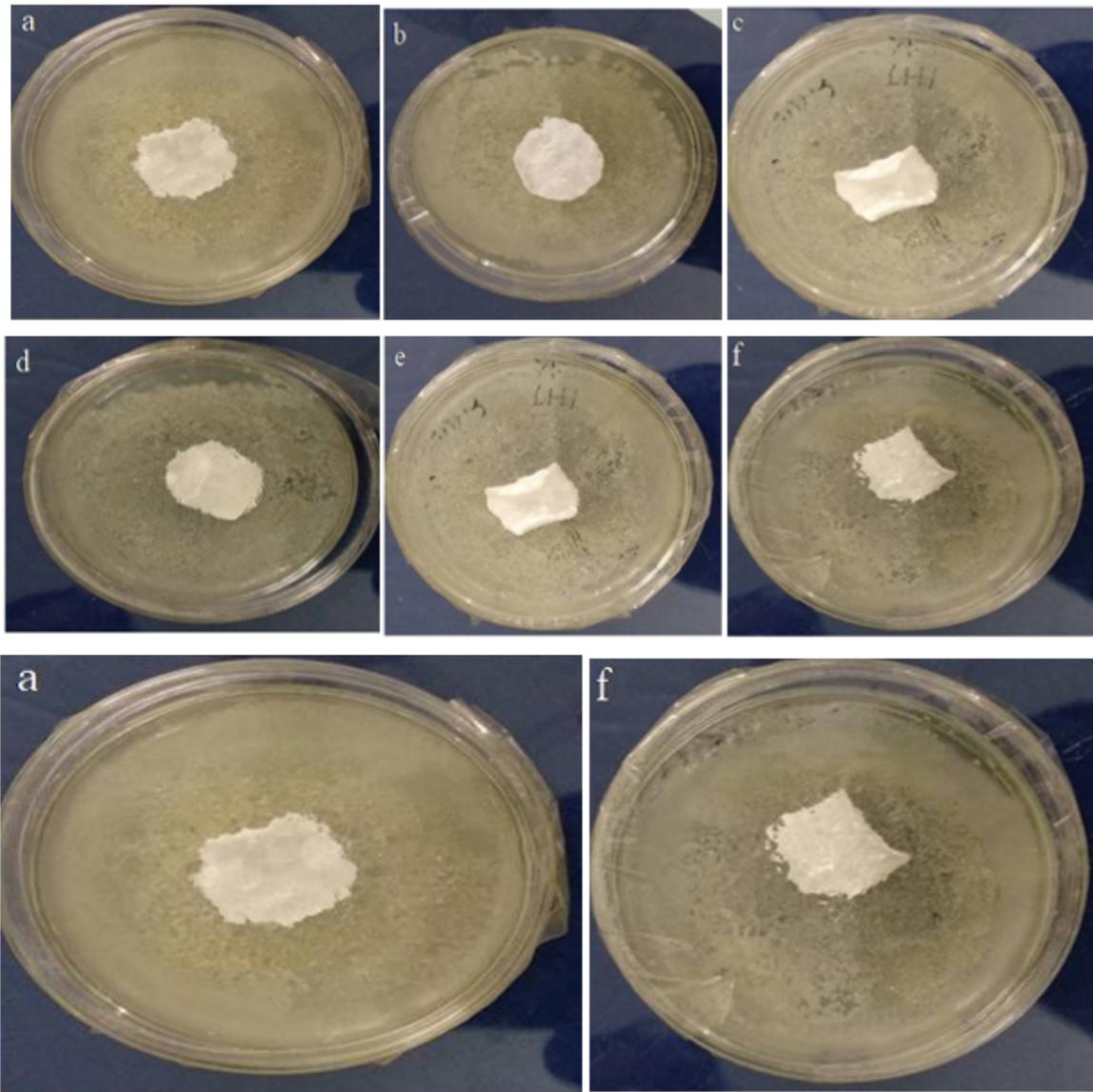


Figure 14

Burning required time of untreated and treated fabric.



**Figure 15**

Antibacterial activity of (a) Untreated fabric, (b) 60 g/L FC-dendrimer treated fabric, (c) 70 g/L FC-dendrimer treated fabric, (d) 80 g/L FC-dendrimer treated fabric, (e) 90 g/L FC-dendrimer treated fabric and (f) 100 g/L FC-dendrimer treated fabric.

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [graphicalabstract.png](#)