Egypt. J. Chem. **Vol. 67**, No.5 pp. 175 – 190 (2024)

Egyptian Journal of Chemistry

http://ejchem.journals.ekb.eg/

Hydrophobic, Breathable and Antibacterial Medical Textiles: Development and Potential Applications

Reem M. Nofal*

**Textile and clothing, Women's College for Arts, Science, and Education-*
Ain Shams University, Cairo, Egypt

Abstract

During the Corona pandemic until EG 5.2 appearance, the importance of medical textiles is emerged, as the WHO recommended wearing facemasks to protect both patients and the medical team from virus transmission. The mostly used facemasks are disposable nonwoven. So, the need to produce reusable, washable, and breathable facemask for daily use is emerged.

The present work focus on producing breathable and comfortable cloth masks to reduce risk of spreading infections. Also, the work focus in producing protective surgical and isolation gowns and medical sheets treated with different concentrations of SiO_2 and/or CS NPs particles. To impart medical fabrics resistance to stains and fluids and in the same time breathable and antibacterial. Breathability and air permeability are examined to clarify the breathing comfort during wearing facemasks. Different facemask layers number, materials and structures are examined. Facemask outermost layer treated with safe Fluro-Carbon resin. Gowns Super hydrophobicity has been characterized by measuring water contact angle before and after treatment with SiO_2 concentrations (1.5, 2, 3 % wt.). The antibacterial activity of chitosan nanoparticles treated fabrics has been measured by quantitative method. Water contact angle, wash fastness, EDX and SEM were also determined to evaluate medical gowns and sheets fabrics. The results clarify that breathability value < 40 Pa/Cm^2 is achieved by face masks no. 2, 11 and 12 respectively, accompanied by hydrophobic outermost layer. Consequently, it is recommended to be worn by patients to reduce risk of spreading infections the gowns fabric retains super hydrophobicity even after 25 industrial washing cycles and achieves high antibacterial protection rates against both *S. aureus and E. Coli,* so it can be used by health care professions.

Keywords: Cloth facemasks; Nano- Chitosan; Nano Silicon; Covid-19; EG 5.2 virus; Surgical gowns.

1 Introduction

The World Health Organization has announced the emergence of many epidemics and viruses all over the world such as SARS, H1NI, Ebola, Covid-19 and recently variant Eris (EG.5). all of them are harmful to human health and may lead to death [1, 2]. Many precautions have been taken by many countries, to prevent the spread of infection with these viruses, such as maintaining a safe distance between people, wearing face masks, and wearing eye protection glasses [3]. In the previous period, many countries were directed to conduct scientific tests and researches on textiles and fabrics that provide both comfort and protection factors from these dangerous respiratory viruses [4] . Many international bodies have published health procedures that oblige all health workers to wear protective face masks and eye wear when entering sterilization areas and surgical rooms, or when dealing with surgical tools and supplies [5]. Pollution that induced by small particulates matters (PMP) as viruses is of a great importance to prevent their spread by capturing emission sources of particulate [6]. Three different textile weave structures are used in producing facemasks as woven, knitted and nonwoven, the cheapest and most commonly used is nonwoven type, which is disposable. So, great demands are emerged to develop washable and protective facemasks [7, 8]. During covid -19 pandemic, an increasing demand to continuous usage of facemasks whether by health workers or in ordinary daily usage by persons. So, the need to fabricated washable facemasks as a substituent other disposable one, is increased [9]. Yet, several research studies have proven that economically the facemasks made from fabric can be washed, sterilized, and reused [10-

*Corresponding author e-mail: reem.nofal@women.asu.edu.eg
Receive Date: 26 August 2023, Revise Date: 17 October 2023, Accept Date: 07 November 2023
DOI: 10.21608/EJCHEM.2023.231703.8497

12]. Surgical masks that used by health workers, scientists, and ordinary people during Corona virus pandemic is composed of three layers as shown in fig.1. each layer has its own function as the outer most layer is hydrophobic barrier and breathable also. While, the middle layer acts as a filter, and the inner most layer is comfortable, absorbent to droplets emitted during inhalation and sneezing of the user. The expected overall function is to prevent spreading of viruses and microbes to and/or from others [13].

There are various degrees of protection that facemasks afford to wearers. The ones that worn by patients must worn to protect others from emitted fluids during sneezing and viruses. There are different factors that responsible for degree of mask protection, as manufacture way, layer's structure, overall design, construction and fitting. Also,nature of particles that carry viruses and their initial sizes.

Blood, air, and fluids that health workers teams are exposed to during work, are paths to virual and bacterial transmission. All medical sheets, gowns, and apparel can be treated in a manner that prevent infection spreading between both patients and medical workers [17-19].

Infection spreading between both patients and medical workers [17-19]. (fig. 2).

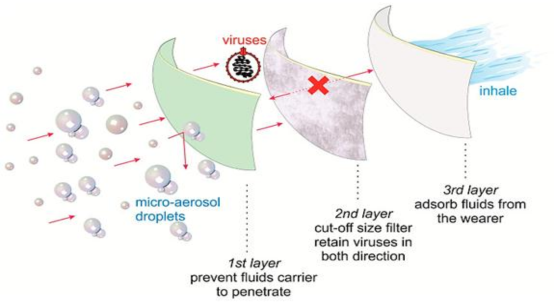


Figure 1 Illustration of ordinary non-woven surgical facemask layers [12]

Numerous studies discussed the efficacy of usage different materials in production of protective facemasks [14-16].

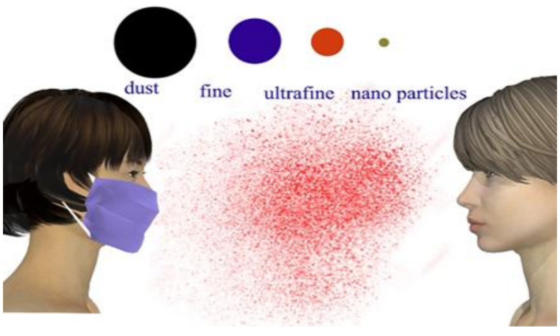


Figure 2 Inhaled particles sizes that can penetrate respiratory tract, from coarse dust 2.5 µm-10 µm, fine 10 µm to 100 nm, ultrafine 100 nm-10 nm and nano particles 10 nm-2nm- infectious particles transmission between infected and mask worn person by breathing and sneezing.

Many studies have worked to develop reusable and washable face masks with higher degrees of protection, filtration, hydrophobicity, antibacterial and antiviral [20, 21]. Imparting hydrophobicity to facemask outermost layer is a major aspect in protection from dermal infections, bacterial growth and fungi that induced bad odors during long term usage [13]. Another two important comfort properties to wearable facemasks which is breathability and air permeability [22, 23].

Chitosan is a promising material due to its unique properties [24, 25]. Chitosan is the N-deacetylated glucosamine obtained from chitin, which is stored in the fungi's cell wall of, or in the arthropod's exoskeleton such as crayfish, and crab. It consists of units linearly bounded by the β-1,4-glycosidic bond. Chitosan has superior chemical and biological properties including biocompatibility, nontoxicity, antibacterial, biodegradable and anticancer activity. Therefore, fields such as drugs, cosmetics, food processing, agriculture, and water treatment [26, 27]

Antibacterial mechanisms of chitosan could be assumed to be analogous to other cationic biocides through six steps: (i) adsorption of the bacteria cell; (ii) diffusion to the cell wall; (iii) absorption to cytoplasmic membranes; (iv) destruction of cytoplasmic membranes; (v) leakage of cytoplasmic components; (vi) death of bacteria cell. There is tremendous controversy about chitosan's inhibitory activity against various micro-organisms.[25, 27-29].

There is a lot of scientific researches that has dealt with the topic of medical fabrics, but the goal of the current research is to focus on creating a group of medical fabrics suitable for application in the field of face masks and medical gowns and sheets. Recently, many infectious diseases have appeared that require studying the science of medical textiles in a way that serves humanity to limit the spread of diseases and protect the medical team. The advantage of improving medical textiles properties, is to inhibit the growth of microorganisms by treatment of nano sized particles. In this research numerous fabric layers

(No. 2,3,4, and 5) of different combinations (cotton, polyester, spandex) and structures (woven and knitted) are used to produce protective facemask. The outer layer is treated with water repellent fluorocarbon safe material (RUCO-GUARD AFC6). The aim of the present work is to produce breathable, protective and comfortable cloth masks to protect the wearer from different inhalation viruses and splashes of others and patients.

Also, the present work focus in producing innovative protective surgical and isolation gowns made from cotton, polyester or cotton/polyester fabrics treated with different concentrations of silicone and/or Chitosan nanoparticles. To impart fabric a resistance to stains and fluids and in the same breathable and imparts antibacterial protection against-gram positive and gram-negative bacteria.

2 Experimental Work

2.1 Materials and methods

Chemicals

RUCO-GUARD AFC6- Cationic, C6-fluorocarbon resin, PFOA and PFOS-free was purchased from Rudolf-group, Greece. Silicon Dioxide nano powder -SiO_2 NPs- (10-20 nm particle size (BET)), 99.5% trace metal basis was purchased from Aldrich chemical. Chitosan, with medium molecular weight, viscosity 1860 cps, degree of deacetylation 79%) is supplied from Alfa Aesar Company, Penta sodium Tri Poly-Phosphate (TPP). Sodium Hydroxide (Modern Lab chemicals, Egypt).

Fabrics

1. **knitted fabric for face masks**

knitted fabrics (table 1) are produced from El-Shourbagy textile factory, Cairo, Egypt.

2 Experimental Work

2.1 Materials and methods

Chemicals

RUCO-GUARD AFC6- Cationic, C6-fluorocarbon resin, PFOA and PFOS-free was purchased from Rudolf-group, Greece. Silicon Dioxide nano powder -SiO_2 NPs- (10-20 nm particle size (BET)), 99.5% trace metal basis was purchased from Aldrich chemical. Chitosan, with medium molecular weight, viscosity 1860 cps, degree of deacetylation 79%) is supplied from Alfa Aesar Company, Penta sodium Tri Poly-Phosphate (TPP). Sodium Hydroxide (Modern Lab chemicals, Egypt).

Fabrics

2. **knitted fabric for face masks**

knitted fabrics (table 1) are produced from El-Shourbagy textile factory, Cairo, Egypt.

2.2 Methods

Design

In executing fig. 2, two software are used:

1-Adobe Photoshop CC 2021, version (22.4.2)

2- 3D software, CLO Standard Virtual design, version 5.1, 2019.

2.3 Treatment of facemask outer layer with water repellent material

Liquid Cationic RUCO-GUARD AFC6) C6-fluorocarbon resin, PFOA and PFOS-free. Concentration 50 g/L, pH: 5, Wet pickup: 70%, Drying: 100 °C for 5 min and Curing 140 °C for 2 min.

2.4 Preparation of Chitosan nanoparticles (CSNPs)

Chitosan nanoparticles were performed by improved ionotropic gelation method [30].

First dissolving chitosan in 1% (v/v) acetic acid with stirring process for 24 h., in 5.5 PH by using 0.01N Sodium Hydroxide, and dissolving (TPP) Tripolyphosphate alone in deionized H_2O to a final concentration of 0.1 mg/ml. At room temperature, the solution of Tripolyphosphate was then added to the Chitosan solution dropwise at varying ratios of Chitosan :TPP while being strongly stirred. After that, for 45 minutes the suspension was put in ultrasonic.

2.5 Preparation of SiO_2 nanoparticles suspension

In ethanol alcohol, different weight percent of SiO_2 NPs were resuspended, and ultrasonically treated for half hour, then treatment fabrics with concentrations (1.5, 2, 3 % wt.) [31].

2.6 Treatment of surgical gown fabrics with silicon oxide and/or Chitosan nanoparticles

The fabrics were treated via two separate steps. In the first step padding the fabrics in silicon oxide NPs sol at 30 °C for five minutes while stirring. The sol was applied to Cotton, Cotton/PET and PET fabrics by pad-dry-cure process. In the second step, these fabrics treated with the prepared chitosan nanoparticles with different concentrations (1.5, 2, 3 % wt.). subsequent treatment is carried out by dipping CSNPs solution with 1% binder (acrylate), for half an hour, then padding 100% wet pick up. Then fabric drying at 80°C for 5 minutes then subjected to curing at 140°C for 3 minutes. Finally, samples were washed and dried before being characterized and tested [32].

Analysis and testing

Cloth mask samples testing procedure

The facemask performance is determined according to their breathability and air permeability properties. primary test to evaluate the facemask performance is air permeability test in order to determine the right samples appropriate for the breathability test with respect to EN 14683:2019 standard test method. All suitable facemask samples are used for subsequent tests.

2.7 Air permeability:

Air permeability is the air flow percentage that passes vertically through a specific fabric area. The fabrics air permeability was determined according to ASTM D-737–18. The test was carried out on model 869 of Toyoseiki apparatus Permeameter. The test was carried out on different layers of fabric samples.

2.8 Breathability (Differential Pressure).

The indication of facemask comfort during breathing is by measuring differential pressure rate. The breathability is estimated by the differential pressure between the two opposite sides of the mask as air streams through them in a manner comparable to breathing process. The used apparatus was designed according to the standard EN 14683:2019-Annex C [33]. The apparatus is shown in (Hamouda et al., 2022) [30]. An electric vacuum pump was used to press air through both sides of a measured fabric surface area at a constant flow rate 8 L/min which resembles the ordinary breathing rate and air velocity of 27.2 cm/s according to EN 14683:2019.

2.9 Water contact angles (WCA)

Water Contact angle (WCA) measurements were analysed by a (phoenix series version 0.5) contact angle tester equipped with a high-resolution TV camera [34].

2.10 Wash fastness

Wash fastness is a specific obligation for textiles and is powerfully correlated with the adhesion of nano-particles to the fiber surface. The durability of the Silicon and/or Chitosan NPs treated fabrics were assessed wash fastness according to the AATCC test method 61–2003.

2.11 Bacterial resistance test

The antibacterial properties of untreated and silicone and/or chitosan nanoparticles treated fabrics- for surgical gowns were quantitatively evaluated by using plate count agar according to the AATCC test method 100–1999. The species of microorganisms used in this experiment were *Escherichia Coli* AATCC 2666 (Gram -Ve), and *Staphylococcus aureus* AATCC 6538 (Gram +Ve). The reduction of bacteria (R%) was calculated using the following equation (1)

$$R(\%) = (A-B) \times 100/A$$

Equation 1

Where A is the number of bacteria colonies from untreated control specimen,

B the number of bacterial colonies from treated specimen.

2.12 Spray resistance test

Device is spray tester -JIS L 1092-1986 according to ASTM- D 4941 at National Research Centre, Egypt.

2.13 Scanning Electron Microscope (SEM) and Electron Dispersion Emission X-ray (EDX)

photomicrographs of fibres surfaces are taken by Scanning Electron Microscope by using (TESCAN-VEGA 3, Czech Republic) with 30 kv scanning voltages coupled with an energy dispersive X-rays (EDX) analyser unit to find elemental composition analysis, at National Research Centre, Egypt.

3 Results and discussion

3.1 Treatment of fabrics with water, oil and soil repellent finishing polymer

Water, oil and soil-repellent resin are applied to the outer layer of facemasks in order to give hydrophobic barrier, functionalizing of isolation and surgical gowns with **RUCO-GUARD AFC6**. The prepared facemasks with different materials and layers as shown in table. 4 are subjected to breathability and air permeability tests. All uncomfortable facemask samples in breathing and air permeability are excluded.

Table 1 Fabric specification of knitted samples used in facemasks.

Sample code	Knitting structure	Material	Blending %	Yarn count /1	Stitch length (mm)	Fabric weight g/m^2	Thickness (mm)	Wales count per cm	Course count per cm	Fabric density، stitches/cm^2	Air permeability (Cm3/cm2/s)	Extension (mm)	Bursting strength (N/cm^2)
F1	Single jersey	Cotton	100	36	3	105	.4	16	16	256	109	23	264
F2		Cotton	100	30	3	142	.5	14	16	224	102	26.2	298
F3		Cotton/polyester	50/50	30	3	136	.5	14	18	252	112	25	487
F4		Cotton/polyester	50/50	30	3.5	113	.5	14	12	168	124	23	370
F5		Cotton/polyester/Spandex	50/40/ 10	30	3	220	.6	14	14	210	108	23	430
F6	Rib	Cotton	100	36	3	135	.6	12	14	168	109	22.5	255
F7		Cotton/polyester	50/50	36	3	142	.6	12	14	168	104	28	369
F8		Cotton/polyester	50/50	30	3	130	.7	12	14	168	90	17	490
F9		Polyester- mesh	90/10	30	3	70	.5	12	14	168	88	20	320

3. Microfiber woven polyester fabric for face masks

Fabrics are produced from El-Nahawy textile factory, Cairo, Egypt.

Table 2 Fabric specification of woven samples used in facemasks.

Fabric No.	Polyester microfiber	Yarn count (Denier) Filament (dpf)				Read count (Cm)	Drawing denting per dent	Weaving density	
		Warp		Weft				Ends/Cm	Picks/Cm
F10	Plain weave	75	36	150	144	20	2	38	**46**
F11	Twill weave	75	36	150	144	18	3	38	60

Fabric No.	Polyester microfiber	Wt/unit area (gms/m^2)	Thickness	Cover factor %		
				Warp direction	Weft direction	Total
F12	Plain weave	106	0.191	50.17	49.91	75.04
F13	Twill weave	123	0.182	65.45	49.91	85.70

Proposed fabrics used for protective surgical gowns:

Fabrics are produced from El-Shourbagy textile factory, Cairo, Egypt.

Table 3 Fabric specification of woven samples used in surgical gowns

Sample No.	Material	Fabric Structure	Wt./unit area (gm/m^2)	Thickness	Weaving Density	
					Ends/Cm	Picks/Cm
S1	Cotton	Plain	110	0.18	38	32
S2	Polyester	Plain	105	0.16	38	32
S3	Cotton /Polyester	Plain	115	0.19	38	32

Table 4 Procedure of testing the performance of facemask fabric layers

Facemask Code	No. of layers	Layers sequence	Water-repellent finish	Discarded samples as suitable face masks
1	3	F8	√	
		F12	-	√
		F13	-	
2	2	F5	√	
		F8	-	
3	2	F7	√	
		F12	-	√
4	4	F3	√	√
		F13	-	
		F7	-	
		F3	-	
5	3	F12	√	√
		F8	-	
		F8	-	
6	3	F13	√	√
		F5	-	
		F3	-	
7	3	F8	√	√
		F13	-	
		F8	-	
8	5	F1	√	

		F1	-	
		F2	-	
		F2	-	
		F6	-	
9	4	F2	√	
		F5	-	
		F6	-	
		F5	-	
10	3	F1	√	√
		F13	-	
		F2	-	
11	2	F9	√	
		F1	-	
12	5	F9	√	
		F6	-	
		F9	-	
		F4	-	
		F4	-	
13	4	F8	√	
		F5	-	
		F9	-	
		F4	-	
14	4	F4	√	
		F5	-	
		F4	-	
15	3	F4	√	
		F7	-	
		F4	-	
16	4	F1	√	
		F9	-	
		F2	-	
		F2	-	

3.2 Effect of water repellent treatment and fabric layers on mask breathability [ΔP] (differential pressure)

The breathability or the differential pressure test is a major requirement of comfort in breathing during facemask wearing. In this study the effect of using different fabric materials -as cotton, microfiber polyester and cotton/polyester/ Lycra-, number of mask fabric layers, layers sequence and treatment with safe water/oil repellent resin safe Fluro- Carbon (RUCO-GUARD AFC6) to the outermost layer.

Breathability after and before water treatment are assessed as shown in fig. 3 and 4. The finishing is to impart the outer layer of face mask the ability to be repellent against water, oil, soil, body fluids, blood splashes and in the same time breathable.

According to the EN 14683:2019 standard test method, there are two important requirements in facemasks classification, first (BFE) bacterial filtration efficiency, second, breathability. Type (1) of face masks is used in order to reduce or prevent the infection from spreading, especially in pandemic times, so, it should be worn by patients, but not be worn by medical workers. While, type (2) of facemasks should achieved high rates of bacterial filtration efficiency. These types recommended to be used by professional medical workers. And type (3), are intended to be hydrophobic and resistant to body fluids, splashes, and blood. With high BFE rates. Both type 1and 2 masks require breathability rates less than 60 Pa/Cm^2 [35, 36].

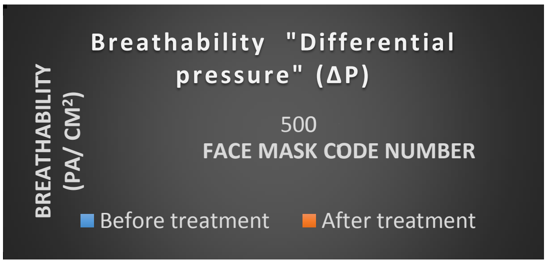


Figure 3 Breathability values of face masks composed of both knitted and woven fabrics different layers.

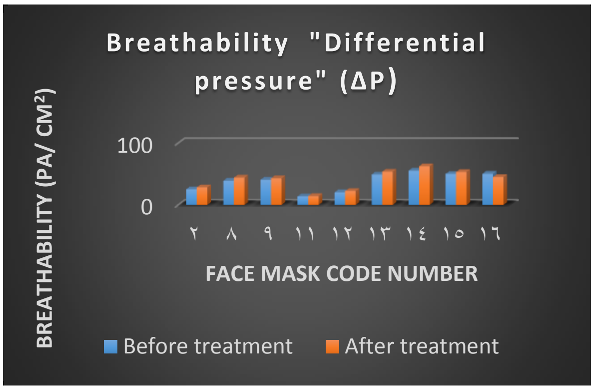


Figure 4 Breathability values of face masks composed of knitted fabrics only with different layers.

The differential pressure value is divided by the surface area (cm^2) of the mask to estimate the breathability, where the higher ΔP values indicated harder breathing for the users. Delta P can be measured through Eq. (1), where PM signifies the mean value of the differential pressure of the test sample, in Pa[36].

Data revealed in fig. 3, shows breathability values of face masks composed of both knitted and woven fabric layers, with different layer numbers. It was noticed that adding polyester microfiber woven fabrics reduced the ability of breathing greatly whether plain or twill structure. This is due to small tight micro gapes and pores of woven structure and nature of micro measure of polyester fibers that is added extra tightness to fabric gapes. According to EN 14683:2019 standard test method, indicated a harder breath for the facemask wearer, all facemasks include woven fabrics are excluded and discarded as all recorded above 200 Pa/Cm^2 breathability, which mean hard breathing during wearing facemask.

While breathability values of face masks that composed of knitted fabrics with different layers numbers achieved acceptable breathing values as revealed in fig.4. Both type I and II masks require breathability value <40 Pa/Cm^2, this is achieved by face masks 2, 11 and 12 which is 28.4, 14.2, and 22.54 Pa/Cm^2 respectively. So, it is recommended to be worn by patients to reduce risk of spreading infections especially in pandemic situations. And type IIR requires breathability value < 60 Pa/Cm^2, is achieved by face masks code 8, 9, 13, 15, and 16 that breathability reaches to 44, 42.8, 53.4,53.2,45 Pa/Cm^2 respectively. Which makes it suitable to be worn by professional medical team after BFE test suitability.

It was indicated from fig.3, and that after treatment with water repellent resin, breathability decreases with neglected values, as a result of coating layer. the best breathability values by sample 9 (F2/F5/F6/F5) which is 100% cotton and cotton/polyester/spandex, and 11 (F1/F9) which is composed of 100% cotton and spandex/ polyester single jersey structure.

3.3 Effect of water-oil repellent treatment and fabric layers on mask air permeability

Air permeability of facemasks fabrics is a great factor in breathing comfort to the facemask wearer. Face mask layers numbers, and structures, different combinations and materials have a great influence in air permeability values as indicated in fig. 5 and 6. Air permeability after and before treatment with Fluro Carbon resin was also assessed to clarify the effect of resin treatment on air passage values through fabrics. The effect is slightly decreased air permeability but nearly neglected, as the water repellent treatment not covers air gapes and pores in fabric structure but only coat yarns.

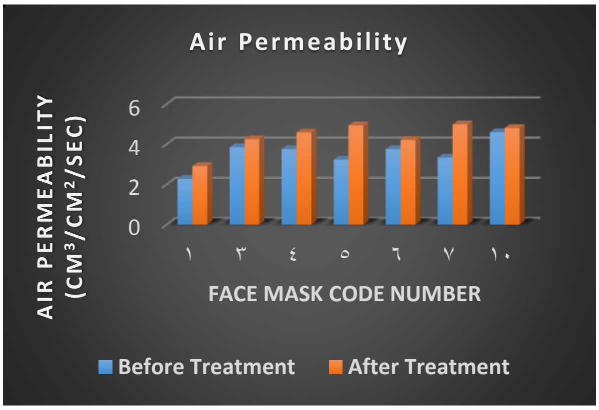


Figure 5 Air permeability values of face masks composed of both knitted and woven fabrics different layers.

Data revealed in fig. 5, indicated that sample codes 1, 3, 4, 5,6,7, and 10 achieves the lowest unacceptable values of air permeability. This is attributed to the presence of polyester microfiber woven fabric within facemask included layers -whether plain or twill-. The air permeability values are 2.92, 4.25, 4.59, 4.95, 4.22, 4.99, and 4.82 cm^3/cm^2/sec respectively. These low values attributed to compact fabric structure that prevent the passage of air through fabric pore's structure. Data in fig. 5. revealed that all face masks layers containing plain and twill woven polyester microfiber fabrics achieved low air permeability, are excluded as suitable and breathable face masks in this study.

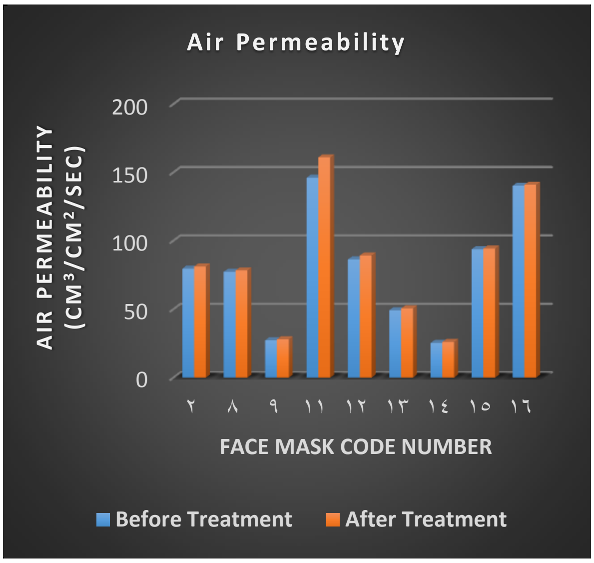


Figure 6 Air permeability values of face masks composed of knitted fabrics only with different layers.

In (fig. 6) air permeability values for all samples including knitted Cotton or Cotton/Polyester are greater than woven fabrics. The highest value is sample code 11 that achieves 161 $cm^3/cm^2/sec$, it is consists of two layers, the first layer is 100% Cotton that characterized with lowest stitch density, long loop length, and high porosity and the second is 100% polyester mesh structure, polyester yarns have smooth surface which increased the air gaps in the fabric compared with cotton fibres which characterized by natural fibres crimps which facilitate air passage through fabric. Followed by sample No. (16) that achieves 140.92 $cm^3/cm^2/sec$. and samples 2, 9, and 13, and 14 recorded 81.15, 28.01, 92.54, 50.54, and 25.98 $cm^3/cm^2/sec$ respectively. It was noticed that all facemasks containing spandex as F5 (Cotton/polyester/Spandex), recorded slight less air permeability values due to the presence of spandex with different yarn count and ratios producing narrowing of the loops to each other, increasing the stitches density and decreasing the fabrics porosity [37].

Cotton fabrics achieves lower air permeability rates, due to its naturally crimp, especially weaving with spandex ratios. While, polyester is characterized by smooth surface, that increased the air gaps. Therefore, the fabrics produced with cotton yarns have more intra-yarn air paths with lower inter-yarn air spaces that caused a reduction in the air permeability of fabrics. By increasing facemask layers number, the air permeability is decreased [38].

Fabric structure porosity is responsible for air permeability values. It determines the thermal insulation effectiveness, comfort and fabric performance as a barrier [38]. Several studies discussed the woven fabrics porous structure. The woven structure, has the greatest inner geometry, which resembles a tube-like porous structure compared with, knitted or nonwoven structures, [39]. Increasing the mask porosity will increase the air permeability but will decrease levels of protection since the viruses and bacteria that caused infection, can easily penetrate and pass through the fabric openings [22, 23].

3.4 Spray rating test:

The resistance to body fluids and blood of facemasks, medical sheets and gowns fabrics is an important aspect in protecting wearers. Blood splashes and fluids that can penetrate the medical fabrics can transfer infections to heath workers and others. According to the ASTM- D 4941 standard, similar test is spray test assessed the resistance to fluids penetration of the face mask outer layer to water, which is in contact with the fabric surface of the test sample [39].

Table 5 Spray resistance test of different fabric materials and structures.

Sample Code	Material	Water repellent (Before treatment)	Water repellent (After treatment)
F1	100% Cotton	20%	70%
F4	Cotton/polyester	40%	70%
F5	Cotton/polyester/Spandex	50%	90%
F7	Cotton/polyester	50%	80%
F8	Cotton/polyester	40%	80%
F9	Polyester- mesh	50%	90%
F12	Polyester (micro fiber)-plain	0%	100%
F13	Polyester (micro fiber)- twill	0%	100%

Eight fabric samples are examined water spray resistance before and after water/oil repellent treatment. Both plain and twill microfiber polyester fabrics before resin treatment are completely absorbing water splashes, but after treatment with water repellent polymer (50 g/L) it is completely 100% resistant to water penetration. This is ideal for surgical gowns and other medical sheets to protect the wearer from blood, body fluids splash as super hydrophobic fabric. Otherwise, all Cotton and Cotton/Polyester became resistant to water in variable degrees range from 70 to 90%. This is recommended as outermost layer of facemask to be greatly resistant to fluids and sneezing splashes of patients.

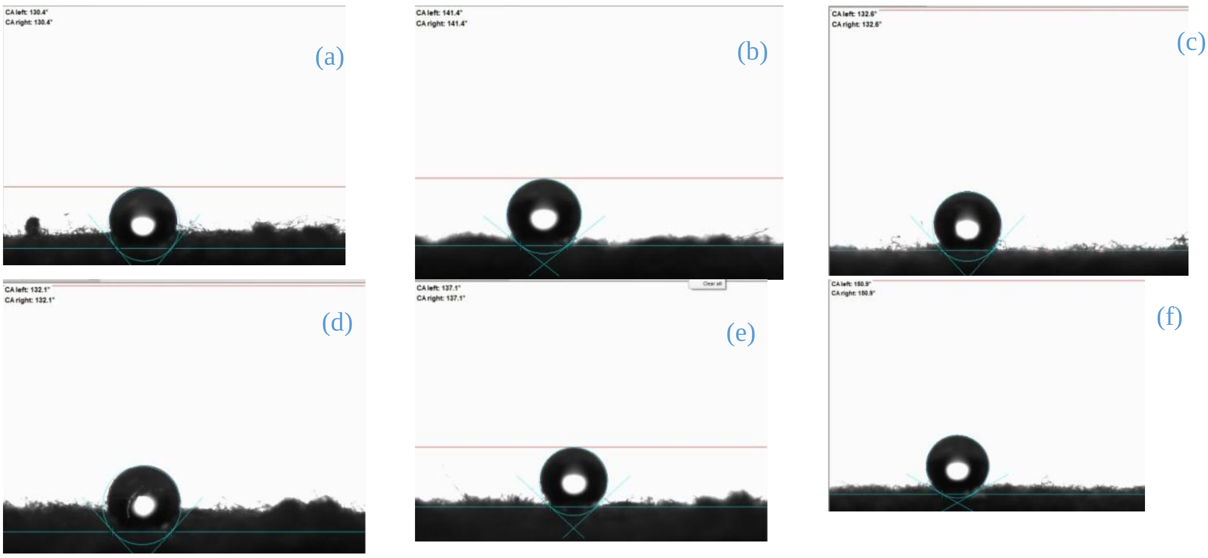
3.5 Effect of Silicone Dioxide nanoparticles concentration on water contact angle of treated fabrics for surgical gowns application

Silicon nano particles treatments are used to impart fabrics superhydrophobic surface. SiO_2 NPs concentrations (1.5, 2, and 3 %wt.) are treated 100% Cotton, Cotton/Polyester and 100% polyester by dip/pad/dry/cure technique. Using Silicone softeners can enhance fabric surface softness, improve elasticity and increases flexibility, and achieves greater fabrics smoothness than other soft finishes [40]. Other advantages of using silicone include less yellowing, non-foaming physical characteristics and effect, higher hydrophobic nature of fibers [41].

Silicone softeners small particle size, shows improved performance and better softness to an extraordinary extent due to deep penetration and lubrication at the fiber level [42]. Super hydrophobicity has been characterized by measuring water contact angle after treatment with silicon oxide NPs as showed in table 6 and fig. 7. Data revealed that by increasing Silicon NPs concentrations from 1.5, 2, then 3% wt. the water contact angle increased for cotton, polyester and cotton/polyester fabrics. The untreated fabrics WCA is recorded zero, by increasing SiO_2 concentration loaded on cotton fabrics, WCA increases from 130.4°, 132.1° and reaches to 132.8°. while polyester increases from 132.6, 141.4 and reaches to 148.7, for 1.5, 2 and 3% wt. conc. So, the best concentration of Silicon NPs is 3 % that recorded 132.8°, 142.4°, and 148.7° for cotton, cotton/polyester and polyester fabrics [42].

Table 6 Effect of Silicon nanoparticles concentration of treated fabrics on contact angle.

Silicon Dioxide conc.	Contact angle (°)		
	Cotton	Cotton/polyester	Polyester
Untreated	0	0	0
1.5 %wt.	130.4	150.9	132.6
2%wt.	132.1	137.1	141.4
3%wt.	132.8	142.4	148.7



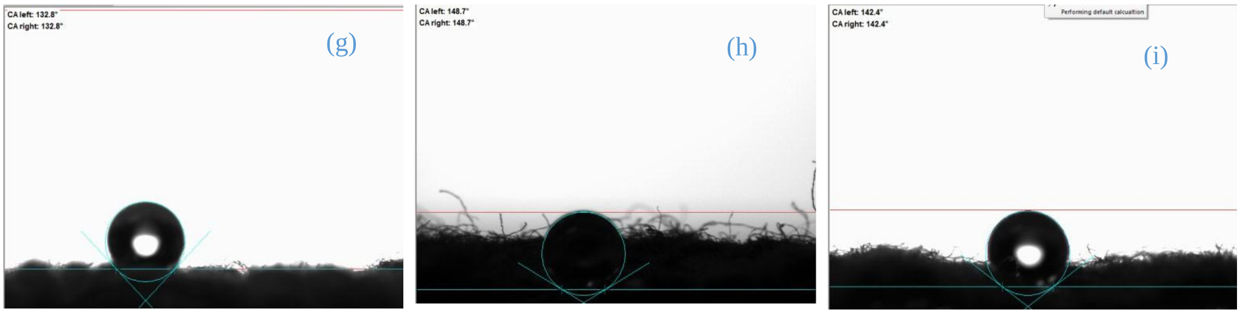


Figure 7 Contact angle of Silicon nanoparticles concentrations, (a) cotton, (b) polyester, (c) cotton/polyester for 1.5 % wt. SiO_2, and (d) cotton, (e), polyester, (f) cotton/polyester for 2 % wt. SiO_2, and (g) cotton, (h) polyester, (i) cotton/polyester for 3% wt. SiO_2.

Table 7 Effect of washing cycles of Silicon NPs treated fabrics on contact angle.

Silicon Dioxide conc. (3%wt.)	**Contact angles after washing cycles**					
	0	**5**	**10**	**15**	**20**	**25**
Cotton	132.8	132	128.5	127.6	125.2	122.2
Cotton/polyester	142.4	141.5	140.5	140	139	137
Polyester	148.7	147.3	146	146	144	142

3.6 Antibacterial effect for silicon and/or chitosan nanoparticles treated fabrics

Antibacterial fabrics are of a great interest due to its ability to restrict infection transmission, provides protection from microbial presence, and odor control [43].

The effect of NPs finishing on bacterial resistance of Cotton, Polyester, and Cotton/Polyester fabrics against both gram positive and negative bacteria are represented in table 7. The treatment is intended to be applied in protective textiles as surgical and isolation gowns and sheets in medical sector. The treatment with 3%wt, silicon (best concentration in achieving water resistance values), and different concentrations of Chitosan NPs (0.5, 1.5, 3% wt.), and the best achieved results of Chitosan NPs concentration to resist bacteria is combined with Silicon (3% wt.), so simultaneous 3%wt. SiO_2, 3% wt. CS NPs are also assessed.

Generally, there are variances in microbial reduction percentage between bacteria main types, regardless the finishing type. this is probably due to the cell walls nature and structure differences between two types, as in the *Escherichia Coli* has slack and thinner cell walls [28, 44].

Table 8 Effect of nanoparticles type and concentration on the *Staphylococcus aureus and* the *Escherichia Coli* reduction percentage on treated fabrics.

Nano type	**Concentration (% wt.)**	**Bacterial Reduction (%)**					
		Cotton		**Polyester**		**Cotton/ Polyester**	
		S.aureus	*E.Coli*	*S.aureus*	*E.Coli*	*S.aureus*	*E.Coli*
Untreated	0	0	0	0	0	0	0
SiO_2	3 % wt.	72%	70%	74%	71%	73%	71%
Chitosan	0.5 % wt.	94.1%	90.4%	95.2%	92.8%	94%	92.6%
Chitosan	1.5 % wt.	95%	92.8%	95.9%	93%	95.3%	93%
Chitosan	3 % wt.	96.9%	95%	96.7%	94.1%	96.6%	93.8%
SiO_2 / Chitosan	3/3 % wt.	98%	95%	98.9%	95%	98.3%	95%

The antibacterial activity resulted from fabrics coated with chitosan NPs showed very good bacterial reduction efficiency for both types of bacteria. By increasing Chitosan NPs concentrations, the bacterial reduction percentage is increased for both types of bacteria. These results may be due to the antibacterial activity of chitosan that is assigned to the amino groups, which in acidic media form ammonium salts [24, 29, 45, 46].

According to (Saw, 2011), there are two mechanisms proposed for chitosan antibacterial activity. The first; its polycationic nature interferes with bacterial metabolism by stacking the cells' surface. The second mechanism is binding between chitosan and DNA to inhibit mRNA synthesis [47-50].

Treated fabrics with 3% wt. Chitosan nanoparticles, showed optimum bacterial resistance reaches to 96.9%, 96.7%, 96.6%, for gram positive *S. aureus*, and to 95%, 94.1%, and 93.8% against *E. Coli,* for Cotton, polyester, and Cotton /Polyester fabrics respectively.

The purpose of this study is to impart super hydrophobic fabrics by using nano Silicon, so 3% wt. that give optimum hydrophobicity, is after treated with CS NPs to also give better bacteriophagic (bacteria killing) property. Furthermore, Si-based nanoparticles formed from NPs Si layers can also present antibacterial activity because they can denature microbial proteins and interfere with the replication of bacterial DNA [51].

Treatment with nano Silicon particles only, 3% wt. gives a reasonable reduction in bacterial growth, whether positive or negative strains. Bacterial reduction reaches to 72, 74, and 73%, for *S. aureus*, and improved to reach 70, 71, and 71%, against *E. Coli,* for Cotton, polyester, and Cotton /Polyester fabrics respectively.

Treated fabrics with 3% wt. pretreatment with Silicon NPs/ and posttreatment with Chitosan nanoparticles, showed optimum bacterial reduction reaches to 98, 98.9, and 98.3%, for gram positive *S. aureus*, and to 95, 95, and 95%, against *E. Coli,* for Cotton, polyester, and Cotton /Polyester fabrics respectively. These improved results may be attributed to the antibacterial activity of CS and Si NPs as shown table 8.

There are three antibacterial mechanisms of nano Silicon. Firstly, the electric charge carried on the surface inhibits the growth of bacteria. Secondly, SiO_2 NPs can change the wettability of the material and destroy the environment for bacterial reproduction. At last, Si reacts with water in the environment, in which some products drive bacterial lysis through chemical reactions on the surface [52, 53].

3.7 Characterization of the treated fabrics (SEM)

The morphological features of the Cotton fabric samples treated with Silicon and/or Chitosan nanoparticles and their elemental composition were studied using Scanning Electron Microscope (SEM). Fig. 8 (a), showed pristine cotton fibers. In fig. 8 (b), it can be observed the micrographs 1000 X. that cotton fibers are coated with water- repellent Fluro-Carbon polymer. And fig.8 (c) is showed pristine cotton fibers. While, fig 8. (d), showing nano Silica, The SiO_2 was observed as fine nanosized particles (3%wt.) coated cotton fibers, (e) 3%wt. Chitosan nanoparticles loaded on fibers as coated layers, and (f) shows the distribution of both Silicon Dioxide and Chitosan nanoparticles on Cotton fibers surface.

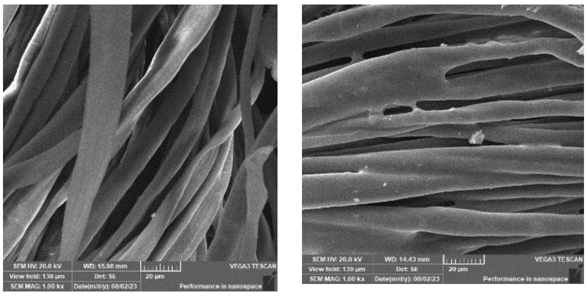


Figure 8 SEM images for the cotton fabric treated with Fluro Carbon resin at 1000× magnifications (a) untreated, (b) treated.

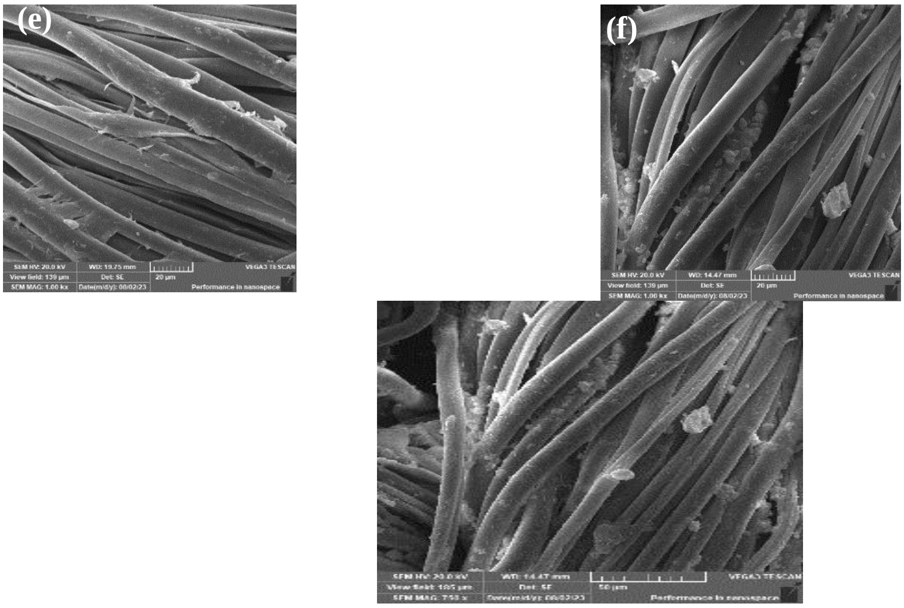


Figure 9 SEM images at 1000× magnifications for the cotton fabric treated with (c) untreated cotton, (d) Silicon NPs, (e) Chitosan NPs, (f) Silicon NPs/ Chitosan NPs, (9) 750x Silicon NPs/ Chitosan NPs.

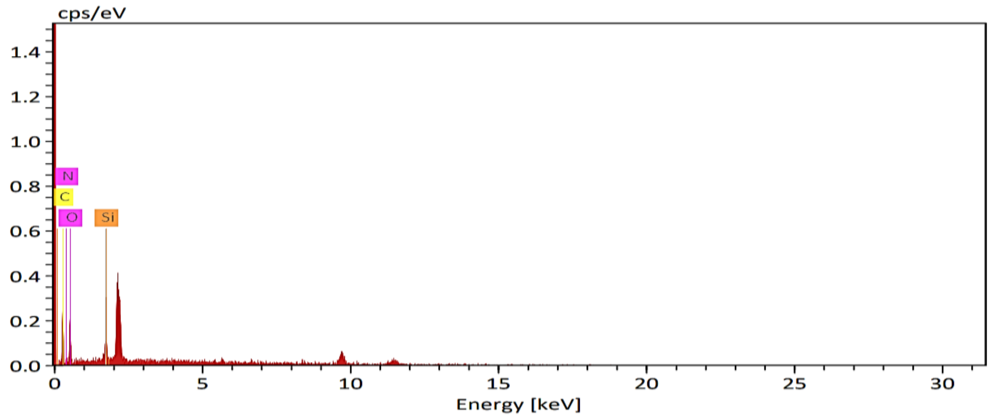


Figure 10 EDX spectrum of the Cotton fabric treated with SiO_2 NPs/C-HNPs.

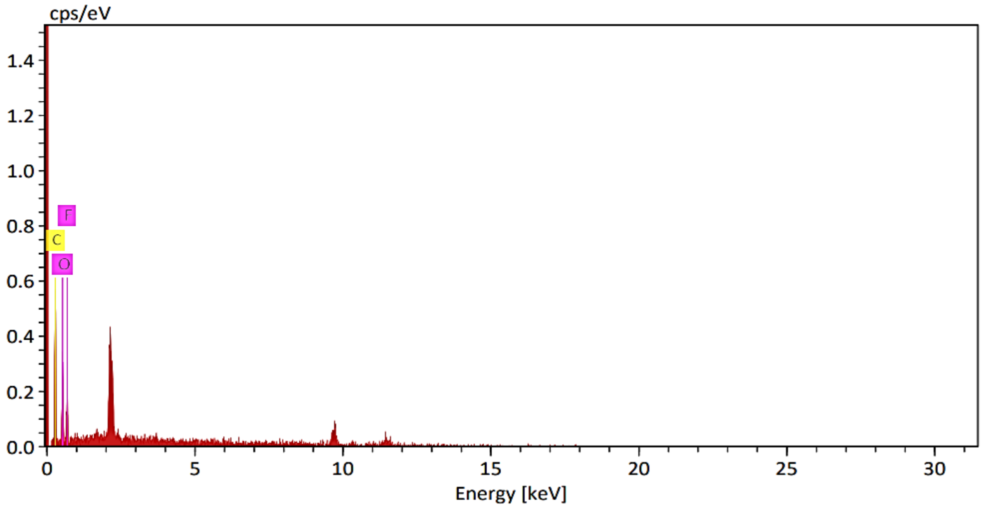


Figure 11 EDX spectrum of the cotton fabric treated with water repellent Fluro Carbon Polymer.

The elemental composition analysed by EDX for Cotton treated samples with CSNPs and/ SiO_2 NPs as shown in fig. 10. It is clear from the EDX spectra at peaks at 1.9 KeV, which confirm the presence of Silicon nanoparticles. Besides, elements such as Carbon, Oxygen, Nitrogen that present in Chitosan nanoparticles. Also fig.11, shows typical optical absorption peak which confirm the presence of Fluro-Carbon at treated Cotton.

Conclusion

The present work focus on p
different concentrations of silicon oxide and/or chitosan nano particles.

In this study the effect of using different fabric materials (cotton, polyester, and/or spandex), number of mask layers (2, 3, 4, and 5 layers), layers sequence and treatment the outermost layer of facemask with safe water/oil repellent cationic resin, in order to develop protective, comfortable and breathable cloth facemask.

It was reported by air permeability and breathability values of facemasks, that adding polyester microfiber woven fabric layer reduced the ability to breathing greatly whether plain or twill structure. So, all woven microfiber fabrics are discarded as suitable facemasks.

Breathability values of face masks composed of knitted fabrics, with different layers numbers, are high and achieves acceptable breathing values. Air permeability values for all samples including knitted Cotton or Cotton/Polyester are greater than woven fabrics. The highest value is sample code 11, that composed of two layers.

Treatment with water/oil, and stain resistant cationic polymer, imparts the outer most layer hydrophobicity and in the same time sustains acceptable rates of breathability.

In medical sheets and gowns application, both plain and twill microfiber polyester fabrics before resin treatment is completely absorbing water splashes, but after treatment with water repellent polymer, it is completely 100% resistant to water penetration. This is ideal for using in surgical gowns and other medical sheets to protect the wearer from blood, and different body fluids splashes.

By increasing Silicon nanoparticles concentrations, the water contact angle is increased for cotton, polyester and cotton/polyester fabrics and so, the hydrophobicity is increased and sustains its hydrophobicity until 25 industrial washing cycles. The best concentration of Silicon NPs is 3 % that achieves highest super hydrophobicity is after treated with Chitosan NPs.

The antibacterial activity resulted from fabrics coated with chitosan nanoparticles, showed very good bacterial reduction efficiency for both types of bacteria. By increasing Chitosan NPs concentrations, the bacterial reduction percentage is increased for both *Escherichia Coli* and *Staphylococcus aureus* bacteria.

Pretreatment with Silicon Dioxide nanoparticles, and after treatment with Chitosan nanoparticles to different fabrics. treated fabrics are suitable to be applied in isolation and surgical gowns and medial sheets that is hydrophobic and also, antibacterial against two pathogenic strains of bacteria.

Declaration of conflicting interests:

The author declared no potential conflicts of interest with respect to the research, authorship, and/ or publication of this article.

ORCID ID:

https://orcid.org/0000-0001-5066-6685

Acknowledgement

The author gratefully acknowledges Faculty of Women for Science, Art, and Education- Ain Shams University, for financial support and for facilities provided through project entitled: (Covid 19: A Multidisciplinary Research Study of the Current and Future Pandemic).

References

1. Morens, D.M. and A.S. Fauci, *Emerging infectious diseases: threats to human health and global stability*. PLoS pathogens, 2013. **9**(7): p. e1003467.
2. Carrasco-Hernandez, R., et al., *Are RNA viruses candidate agents for the next global pandemic? A review*. ILAR journal, 2017. **58**(3): p. 343-358.
3. Cheng, K.K., T.H. Lam, and C.C. Leung, *Wearing face masks in the community during the COVID-19 pandemic: altruism and solidarity*. The Lancet, 2022. **399**(10336): p. e39-e40.
4. Saville, B.P., *Physical testing of textiles*. 1999: Elsevier.
5. Leonas, K.K., C.R. Jones, and D. Hall, *The relationship of fabric properties and bacterial filtration efficiency for selected surgical face masks*. JTATM, 2003. **3**: p. 1-8.

6. Mao, J., et al., *Particulate matter capturing via naturally dried ZIF-8/graphene aerogels under harsh conditions.* IScience, 2019. **16**: p. 133-144.
7. Choi, D.Y., et al., *Al-coated conductive fibrous filter with low pressure drop for efficient electrostatic capture of ultrafine particulate pollutants.* ACS applied materials & interfaces, 2017. **9**(19): p. 16495-16504.
8. Jeong, S., et al., *High efficiency, transparent, reusable, and active PM2. 5 filters by hierarchical Ag nanowire percolation network.* Nano letters, 2017. **17**(7): p. 4339-4346.
9. Smith, J.D., et al., *Effectiveness of N95 respirators versus surgical masks in protecting health care workers from acute respiratory infection: a systematic review and meta-analysis.* Cmaj, 2016. **188**(8): p. 567-574.
10. Choi, D.Y., et al., *Washable antimicrobial polyester/aluminum air filter with a high capture efficiency and low pressure drop.* Journal of hazardous materials, 2018. **351**: p. 29-37.
11. De Man, P., et al., *Sterilization of disposable face masks by means of standardized dry and steam sterilization processes; an alternative in the fight against mask shortages due to COVID-19.* Journal of Hospital Infection, 2020. **105**(2): p. 356-357.
12. Wibisono, Y., et al., *Facile approaches of polymeric face masks reuse and reinforcements for micro-aerosol droplets and viruses filtration: A review.* Polymers, 2020. **12**(11): p. 2516.
13. Saber, D. and K. Abd El-Aziz, *Advanced materials used in wearable health care devices and medical textiles in the battle against coronavirus (COVID-19): A review.* Journal of Industrial Textiles, 2022. **51**(1_suppl): p. 246S-271S.
14. Konda, A., et al., *Aerosol filtration efficiency of common fabrics used in respiratory cloth masks.* ACS nano, 2020. **14**(5): p. 6339-6347.
15. Liao, L., et al., *Can N95 respirators be reused after disinfection? How many times?* ACS nano, 2020. **14**(5): p. 6348-6356.
16. Grinshpun, S.A., et al., *Performance of an N95 filtering facepiece particulate respirator and a surgical mask during human breathing: two pathways for particle penetration.* Journal of occupational and environmental hygiene, 2009. **6**(10): p. 593-603.
17. Goldmann, D.A., *The role of barrier precautions in infection control.* Journal of Hospital Infection, 1991. **18**: p. 515-523.
18. Midha, V.K., S. Joshi, and A. Dakuri, *Surgical gown fabrics in infection control and comfort measures at hospitals.* Indian Journal of Fibre & Textile Research (IJFTR), 2022. **47**(1): p. 96-104.
19. Kilinc, F.S., *A review of isolation gowns in healthcare: fabric and gown properties.* Journal of engineered fibers and fabrics, 2015. **10**(3): p. 155892501501000313.
20. Lee, K.-P., et al., *Reusable face masks as alternative for disposable medical masks: factors that affect their wear-comfort.* International Journal of Environmental Research and Public Health, 2020. **17**(18): p. 6623.
21. Swennen, G.R.J., L. Pottel, and P.E. Haers, *Custom-made 3D-printed face masks in case of pandemic crisis situations with a lack of commercially available FFP2/3 masks.* International Journal of Oral and Maxillofacial Surgery, 2020. **49**(5): p. 673-677.
22. Kulichenko, A.V., *Theoretical analysis, calculation, and prediction of the air permeability of textiles.* Fibre Chemistry, 2005. **37**(5): p. 371-380.
23. Jayaraman, S., *Pandemic Flu—Textile Solutions Pilot: Design and Development of Innovative Medical Masks.* Georgia Institute of Technology. Atlanta, GA. Submitted to CDC, 2012.
24. Mohamed, F.A., M.M. Reda, and H. Ibrahim, *Enhancement of Dyeing and Antimicrobial Properties of Chitosan and Chitosan Nanoparticles-Treated Cotton and Viscose Fabrics with Acid Dyes.* Egyptian Journal of Chemistry, 2022. **65**(13): p. 339-344.
25. Ali, M.A., E.A. Bydoon, and H.M. Ibrahim, *Bioactive Composite Nonwoven Surgical Dressing based on Cellulose Coated with Nanofiber Membrane using the layer-by-layer technique.* Egyptian Journal of Chemistry, 2022. **65**(4): p. 525-542.
26. Ibrahim, M.A., et al., *A Review of Chitosan and Chitosan Nanofiber: Preparation, Characterization, and Its Potential Applications.* Polymers, 2023. **15**(13).
27. Ibrahim, H.M., M. Mostafa, and N.G. Kandile, *Potential use of N-carboxyethylchitosan in biomedical applications: Preparation, characterization, biological properties.* International Journal of Biological Macromolecules, 2020. **149**: p. 664-671.
28. Abou-Zeid, N.Y., et al., *Preparation, characterization and antibacterial properties of cyanoethylchitosan/cellulose acetate polymer blended films.* Carbohydrate Polymers, 2011. **84**(1): p. 223-230.
29. Salama, R., H. Osman, and H.M. Ibrahim, *Preparation of biocompatible chitosan nanoparticles loaded with Aloe vera extract for use as a novel drug delivery mechanism to improve the antibacterial characteristics of cellulose-based fabrics.* Egyptian Journal of Chemistry, 2022. **65**(3): p. 581-595.
30. Ibrahim, H.M., et al., *Chitosan nanoparticles loaded antibiotics as drug delivery biomaterial.*

Journal of Applied Pharmaceutical Science, 2015. **5**(10): p. 85-90.
31. El-Bisi, M.K., et al., *Super hydrophobic cotton fabrics via green techniques.* Der Pharma Chemica, 2016. **8**(19): p. 57-69.
32. Ibrahim, H.M., M.M. Saad, and N.M. Aly, *Preparation of single layer nonwoven fabric treated with chitosan nanoparticles and its utilization in gas filtration.* International Journal of ChemTech Research, 2016. **9**(6): p. 1-16.
33. Hamouda, T., et al., *Preparation of cellulose-based wipes treated with antimicrobial and antiviral silver nanoparticles as novel effective high-performance coronavirus fighter.* International Journal of Biological Macromolecules, 2021. **181**: p. 990-1002.
34. Anitha, S., et al., *Optical, bactericidal and water repellent properties of electrospun nano-composite membranes of cellulose acetate and ZnO.* Carbohydrate polymers, 2013. **97**(2): p. 856-863.
35. Kwong, L.H., et al., *Review of the breathability and filtration efficiency of common household materials for face masks.* ACS nano, 2021. **15**(4): p. 5904-5924.
36. En, B.S., *14683: 2019: Medical Face Masks—Requirements and Test Methods.* European Committee for Standardization: Brussels, Belgium, 2019: p. 23.
37. Marmarali, A.B., *Dimensional and physical properties of cotton/spandex single jersey fabrics.* Textile research journal, 2003. **73**(1): p. 11-14.
38. Hamouda, T., et al., *Breathability performance of antiviral cloth masks treated with silver nanoparticles for protection against COVID-19.* Journal of Industrial Textiles, 2022. **51**(9): p. 1494-1523.
39. Elnashar, E.A., *Volume porosity and permeability in double-layer woven fabrics.* AUTEX Research Journal, 2005. **5**(4): p. 207-217.
40. Reddy, N., A. Salam, and Y. Yang, *Effect of structures and concentrations of softeners on the performance properties and durability to laundering of cotton fabrics.* Industrial & engineering chemistry research, 2008. **47**(8): p. 2502-2510.
41. Schindler, W.D. and P.J. Hauser, *Chemical finishing of textiles*. 2004: Elsevier.
42. Holme, I., *Innovative technologies for high performance textiles.* Coloration Technology, 2007. **123**(2): p. 59-73.
43. Eid, B.M., et al., *Durable Antibacterial Functionality of Cotton/Polyester Blended Fabrics Using Antibiotic/MONPs Composite.* Fibers and Polymers, 2019. **20**(11): p. 2297-2309.
44. Kumar, M.N.V.R., *A review of chitin and chitosan applications.* Reactive and functional polymers, 2000. **46**(1): p. 1-27.
45. El-Alfy, E.A., et al., *Preparation of biocompatible chitosan nanoparticles loaded by tetracycline, gentamycin and ciprofloxacin as novel drug delivery system for improvement the antibacterial properties of cellulose based fabrics.* International Journal of Biological Macromolecules, 2020. **161**: p. 1247-1260.
46. Mosaad, R.M., et al., *Enhancement of Antimicrobial and Dyeing Properties of Cellulosic Fabrics via Chitosan Nanoparticles.* Polymers, 2022. **14**(19).
47. Saw, C.L.L., *Science against microbial pathogens: Photodynamic therapy approaches.* Science against Microbial Pathogens: Communicating Current Research and Technological Advances; Mendez-Vilas, A., Ed, 2011: p. 668-674.
48. Chandrasekaran, M., K.D. Kim, and S.C. Chun, *Antibacterial activity of chitosan nanoparticles: A review.* Processes, 2020. **8**(9): p. 1173.
49. Negi, A. and K.K. Kesari, *Chitosan nanoparticle encapsulation of antibacterial essential oils.* Micromachines, 2022. **13**(8): p. 1265.
50. Wu, Y., et al., *Effects of two-organic-acid-dissolved chitosan on antibacterial properties of bamboo pulp-based fabrics.* Journal of Engineered Fibers and Fabrics, 2021. **16**: p. 15589250211018197.
51. Zhong, F., et al., *Porous silicon photonic crystals coated with Ag nanoparticles as efficient substrates for detecting trace explosives using SERS.* Nanomaterials, 2018. **8**(11): p. 872.
52. Bock, R.M., et al., *Bacteriostatic behavior of surface modulated silicon nitride in comparison to polyetheretherketone and titanium.* Journal of Biomedical Materials Research Part A, 2017. **105**(5): p. 1521-1534.
53. Sheng, C., et al., *One-step hydrothermal method to prepare superhydrophobic cotton fabric with antibacterial properties.* Journal of Engineered Fibers and Fabrics, 2021. **16**: p. 15589250211066095.