CHAPTER 4

RESULTS AND DISCUSSION

In the present study attempt has been made to improve the performance of various woven and nonwoven fabrics used in manufacture of surgical gown and drapes. The fabric surfaces have been modified by applying thin coating of nano cellulose. The nano cellulose solution has been prepared of different cellulose concentrations without adding cross-linking material and also adding cross-linking material of different concentrations (as discussed in Section 3.3.2). The surface treated fabrics have been evaluated for various characteristics such as change in fabric mass, fabric thickness, tensile strength, air permeability, water repellence and fabric stiffness. The results of these characteristics have been given and analysed in Section 4.1 to 4.6. Some of the fabric specimens have been given antibacterial treatment by applying neem seed oil. These fabrics have been evaluated for resistance to bacterial growth by performing culture test using gram positive and gram-negative bacterium. The results of these culture tests have been summarised and analysed in Section 4.7.

4.1 Fabric mass density

Nano cellulose coating has been applied to the fabric surface to improve fabric performance especially the water repellence. In the resultant fabric it is expected that generally mass density of the fabric changes as nano cellulose particles add on the surface of the fabric. The change in mass density of coated fabric depends on concentration of nano cellulose solution and amount of cross-linking agent added to the solution.

The three types of coated fabrics have been evaluated for the change in the mass density. The resultant average mass density has been tabulated as the %increase in the nominal mass density of respective sample fabric. The fabric coating was done using nano cellulose solution of three different concentrations viz. 10gpl, 20gpl and 30gpl. Each of these solutions has been prepared without cross-linking material and also by adding 5gpl and10gpl cross-linking agent by weight. The values of %increase in mass density of all the 27specimen coated with cellulose solution of different concentrations have been given in Table 4.1.

Table 4.1 Increase in fabric mass density with cellulose solution of different concentrations (%)

Type of fabric	Nano cellulose 10gpl			Nano cellulose 20gpl			Nano cellulose 30gpl		
	Cross-linking agent (gpl)			Cross-linking agent (gpl)			Cross-linking agent (gpl)		
	0	5	10	0	5	10	0	5	10
Cw	3.97	10.62	6.77	8.35	8.11	46.97	12.95	12.8	13.83
Ve	44.59	40.2	41.77	53.43	71.19	64.55	89.26	101.58	136.77
Vp	22. 55	20.3	36.38	33.57	31.4	37.45	44.55	38.66	63.5

The effect of amount of cross-linking agent in nano cellulose solution of 10gpl, 20gpl and 30gpl concentrations on increase in mass density of fabric has also been shown in Fig. 4.1, Fig. **4.2** and Fig. 4.3 respectively.

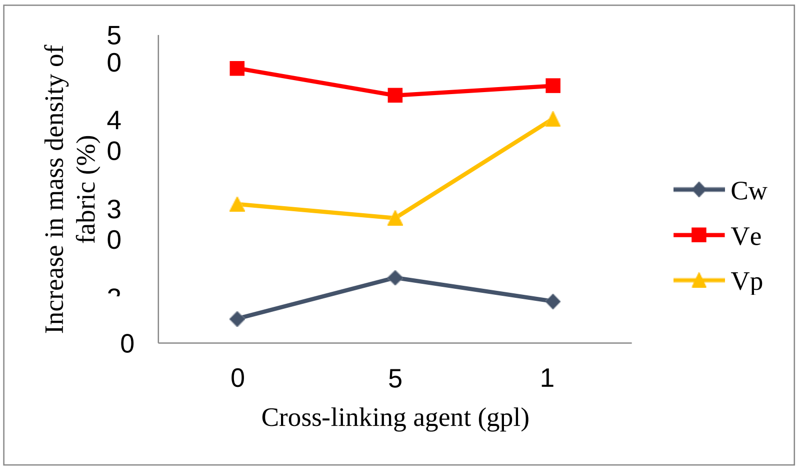

Fig. 4.1 Effect of cross-linking agent concentration with 10gpl nano cellulose concentration on increase in fabric mass density

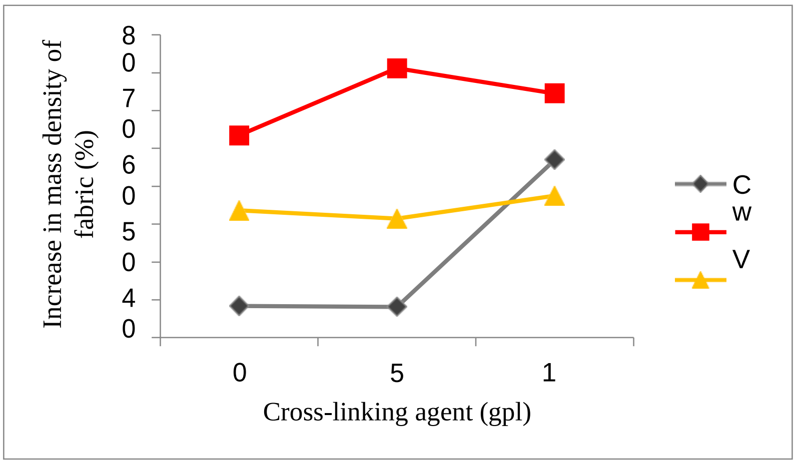

Fig. 4.2 Effect of cross-linking agent concentration with 20gpl nano cellulose concentration on increase in fabric mass density

In most cases, it has been observed that the mass density of the fabric increases after applying the nano cellulose coating on the fabric surface. The increase in fabric mass is mainly due to add on of cellulose particles and partly cross-linking materials. This behaviour of increase in mass density can be attributed to the fabric structure, pore size and surface characteristics of fabric etc. It is also affected by the concentration of nano cellulose solution and the amount of binding agent added and other parameters of coating process. It has been observed that generally with increase in nano concentration, fabric mass density also increases.

From the graphs it is observed that as compared to untreated fabric, mass of coated woven fabric is on average increased in the range of only 5 to 10%; where as it is increased in range of 20 to 40% in case of plain nonwoven fabric and 40 to 80 % in embossed nonwoven fabric. In case of cotton woven fabric there is marginal increase in mass with increase in concentration from 10gpl to 30gpl. But in case of embossed nonwoven it increases many fold. It can be clearly seen that only in few cases; this trend has not been observed. This may be due to variation in fabric mass and uneven application of coating material as the process is manual.

Table 4.2 shows the %increase in fabric mass density with cellulose solution of different concentrations with and without addition of cross-linking material. From the graphs it is seen that effect of increase in mass density with increase in cross-linking material is very marginal in all the fabrics. It also shows increase in fabric mass for all the specimen of woven and nonwoven fabrics irrespective of addition of cross linking material in to cellulose solution.

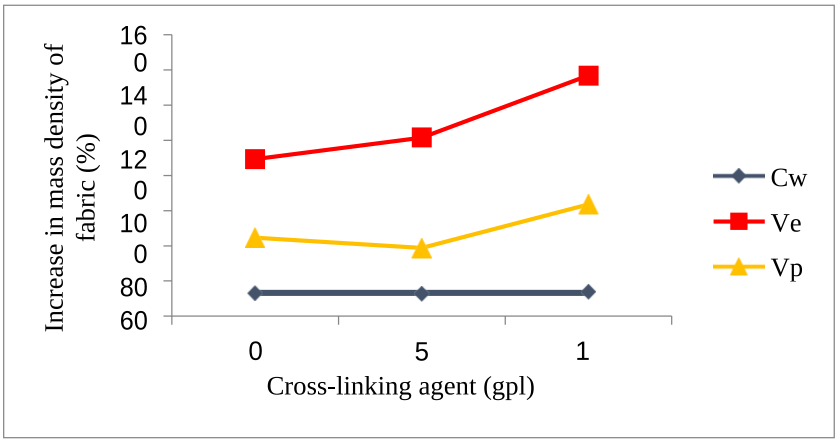

Fig. 4.3 Effect of cross-linking agent concentration with 30gpl nano cellulose concentration on increase in fabric mass density

Table 4.2 Increase in fabric mass density at different cross linking agent in cellulose solution (%)

Type of fabric	Without cross-linking agent			Cross-linking agent 5gpl			Cross-linking agent 10gpl		
	Nano cellulose (gpl)			Nano cellulose (gpl)			Nano cellulose (gpl)		
	10	20	30	10	20	30	10	20	30
Cw	3.97	8.35	12.95	10.62	8.11	12.8	6.77	46.97	13.83
Ve	44.59	53.43	89.26	40.2	71.19	101.58	41.77	64.55	136.77
Vp	22.55	33.57	44.55	20.3	31.4	38.66	36.38	37.45	63.5

As the cotton fabric is compact woven fabric made of plain weave, the nano cellulose cannot penetrate much into the fabric. On the other hand nonwoven fabric has comparatively a smooth surface, highly porous structure made from fibrous web of smooth finer fibres; hence more nano cellulose can be accommodated in the fabric. As compared to plain nonwoven fabric, the nonwoven embossed fabric being more porous and having an uneven surface can accommodate/pick up more nano cellulose particles showing highest increase in mass density as compared to that of plain woven and plain nonwoven fabric. The air voids formed into fibre web provide the room for cellulose particles to be trapped in nonwoven fabric structure.

The effect of concentrations of nano cellulose solution on increase in mass density of fabric without cross-linking material is shown in Fig.4.4. From the graphs it is seen that there is increase in mass density with increase in concentration of cellulose solution without adding the cross-linking material in all the fabrics. However the increase in mass is found higher in case of nonwoven fabrics.

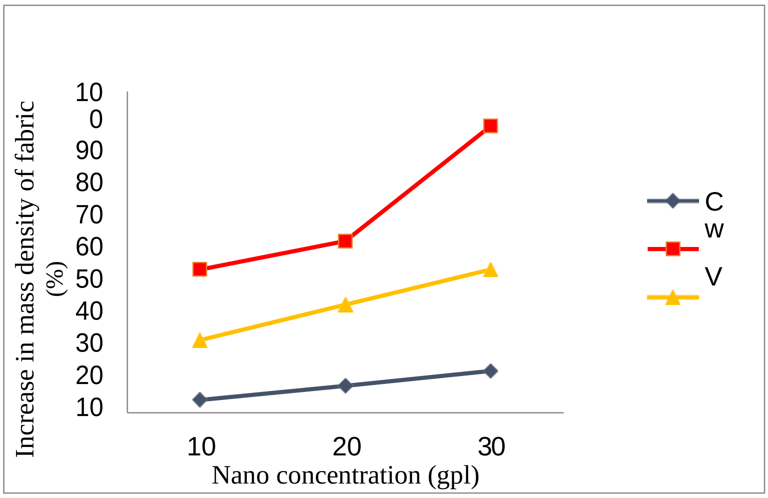

Fig. 4.4 Effect of nano cellulose concentration without cross-inking agent on increase in fabric mass density

Fig. 4.5 and Fig. 4.6 show the effect of addition of cross-linking material of 5gpl and 10gpl in nano cellulose solution on increase in fabric mass density respectively. It shows that increase in cross-linking material in the solution increases the mass density of fabric as compared to that of fabrics coated without cross-linking material. There is marginal increase in mass when amount of cross-linking material increased from 5gpl to 10gpl. However the increase is found higher in mass density of nonwoven fabrics as compared to that of woven fabric.

The increase in mass density can influence the other physical and performance characteristics of the coated fabric as compared to that of nominal fabric viz. tensile strength, air permeability, abrasion resistance, water repellence, thermal comfort etc. The evaluation of these properties of coated fabrics needs to be analysed for consideration of design of surgical textiles.

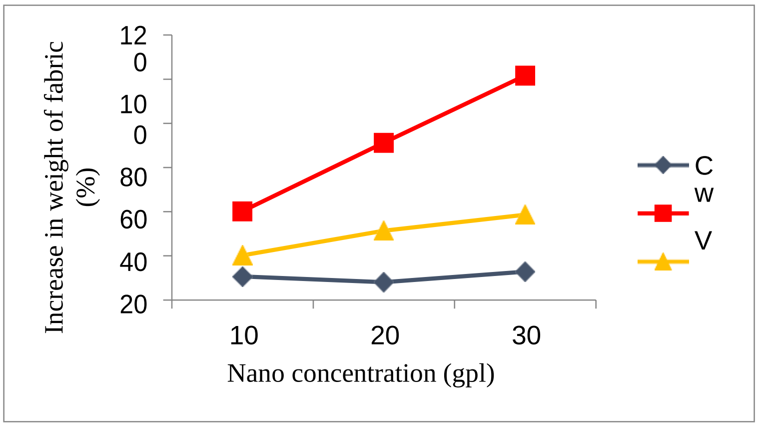

Fig. 4.5 Effect of nano cellulose concentration with 5gpl cross-linking agent on increase in fabric mass density

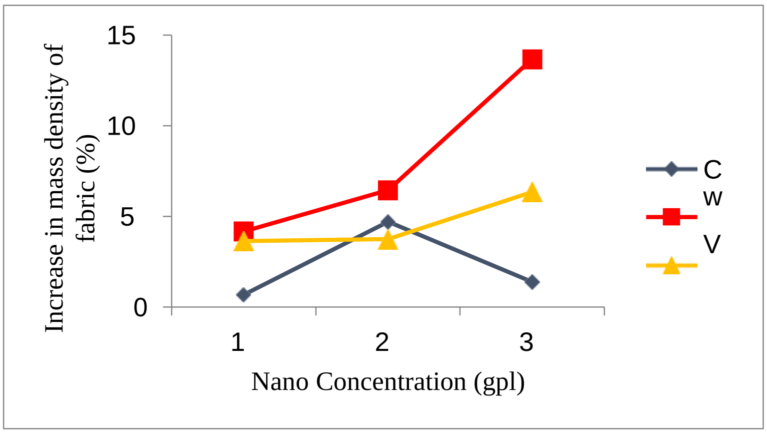

Fig. 4.6 Effect of nano cellulose concentration with 10gpl cross-linking agent on increase in fabric mass density

4.2 Tensile strength

The tensile strength of nominal fabrics occupied from the market has been evaluated using standard test procedure for both woven and nonwoven fabrics. After coating of these fabrics with nano cellulose solution of different concentrations, their tensile strength in machine and cross machine direction also has been evaluated.

4.2.1 Machine direction

Tensile strength of woven fabric is generally higher than that of nonwoven fabrics if the mass density and fibres of the fabric do not differ much. Tensile strength of any given woven fabric in machine direction is generally higher than that of cross machine direction. This is because stronger warp threads are to be used as one of the requirements of efficient manufacture process. The warp threads are supposed to be stronger as stress exerted on warp sheet during shed formation is higher than that of on weft yarns during the pick insertion. Hence amount of twist in warp yarns is generally kept slightly higher than that of weft yarns for same yarn counts. However for nonwoven fabrics the tensile strength mainly depend on the type of orientation of fibres in the web; other parameters are mass of web, fibre strength and bonding method used in manufacture of nonwoven fabric. The samples of woven and nonwoven fabrics have been prepared after treating them in the nano cellulose solution for coating the fabric surface as explained in Section 3.3.2.

Application of coating of certain particles using adhesive materials on fabrics modifies the fabric surface. When fabrics are treated using nano cellulose particles which stick to the fabric surface and partly also penetrate in to the fabric, which improves fibre to fibre bonding in the treated fabrics. The certain cross linking materials are preferred to be added in the coating solution for better fastness of coat for long duration performance of the fabric. The presence of cross-linking agent can also improve the bonding of nano cellulose particles with the fabric, which in turn can impart cohesiveness to the fabric structure.

The various fabrics have been coated using different concentrations of nano cellulose solution. After curing and drying of these fabrics the tensile properties of this specimen have been evaluated. The average tensile strength in machine direction of a woven and nonwoven fabrics treated in various concentration of cellulose solution has been given in Table 4.3. The tensile strength of woven cotton fabric is higher than that of two nonwoven viscose fabrics.

Table 4.3 Tensile strength in machine direction with different concentration of cellulose solution (N)

Type of fabric	Nano cellulose 10gpl			Nano cellulose 20gpl			Nano cellulose 30gpl		
	Cross-linking agent (gpl)			Cross-linking agent (gpl)			Cross-linking agent (gpl)		
	0	5	10	0	5	10	0	5	10
Cw	123.36	154.56	140.08	131.13	145.01	141.3	148.21	143.85	137.61
Ve	53.5	51.16	54.29	32.83	57.21	66.16	57.78	67.56	97.99
Vp	89.44	103.58	107.51	90.02	99.44	102.21	110.3	89.03	121.22

The effect of amount of cross-linking agent in nano cellulose solution of 10 gpl, 20 gpl and 30 gpl concentrations on tensile strength of fabric in machine direction has been shown in Fig. 4.7, Fig. 4.8 and Fig. 4.9 respectively.

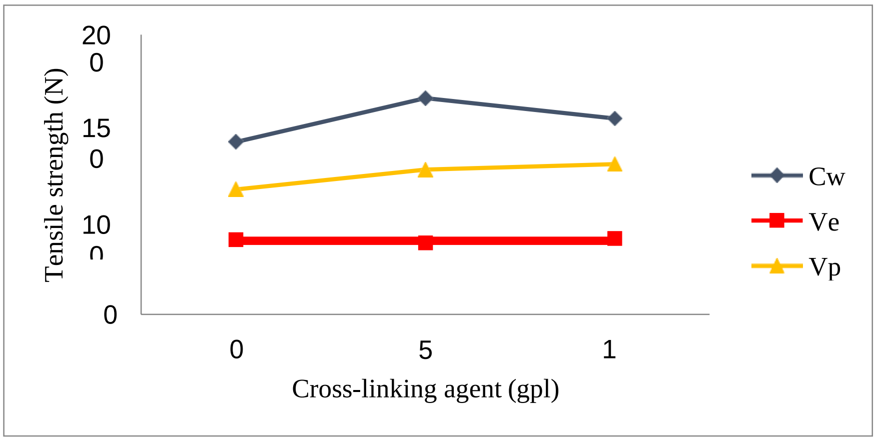

Fig. 4.7 Effect of cross-linking agent concentration with 10gpl nano cellulose concentration on tensile strength in machine direction

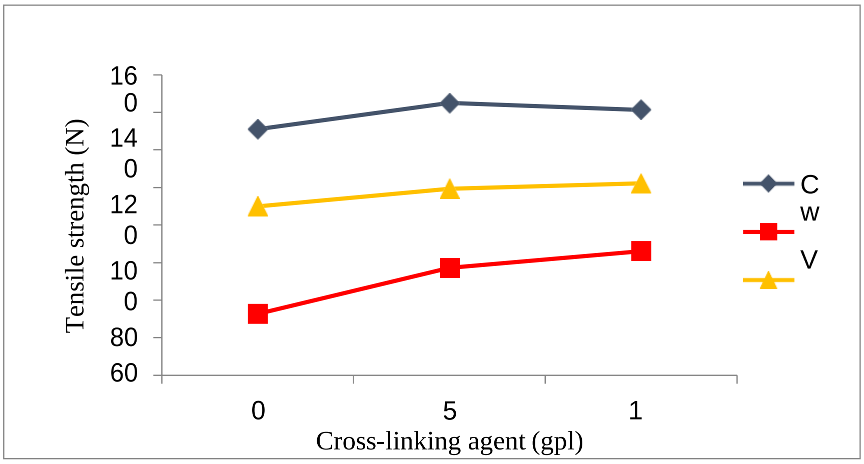

Fig. 4.8 Effect of cross-linking agent concentration with 20gpl nano cellulose concentration on tensile strength in machine direction

It can be seen from the Table 4.3 and Fig 4.7, Fig. 4.8 and Fig. 4.9 that the tensile strength of samples is lower in case of 10gpl concentration of nano cellulose and it increases with higher concentration of nano cellulose i.e. 20gpl and 30gpl. This behaviour can be attributed to the locking property of nano cellulose particles. In case of lower concentration, the nano cellulose particles are lower, so satisfactory binding is observed. Increase in concentration of nano cellulose, as the nano cellulose concentration binding increases, the tensile strength also increases. The tensile strength is lower in case of fabric coated without cross-linking agent. It is generally increased at higher concentration of cross-linking agent.

This behaviour can be attributed to the fabric structures and fibre strength of cotton and viscose samples. The dry and wet strength of cotton fibre is better than that of viscose fibre. Again, the woven structure is generally stronger than nonwoven structure made from same polymeric material, if their mass densities do not differ much. In case of woven fabric stressed in machine direction, load is shared by warp threads held firmly in both the jaws hence, woven cotton fabric samples have shown better strength. On other hand in case of nonwoven structure load transfer mechanism is very different. Load applied on the fabric is transferred through web of staple fibres held in the jaw. Due to fibre slippage factor and straightening of fibres in the nonwoven fabric full utilisation fibre strength in to fabric strength does not occur resulting into lower tensile strength.

The tensile strength in cross machine direction of fabric coated using different concentrations of cross-linking agents in cellulose solution has been given in Table 4.4.

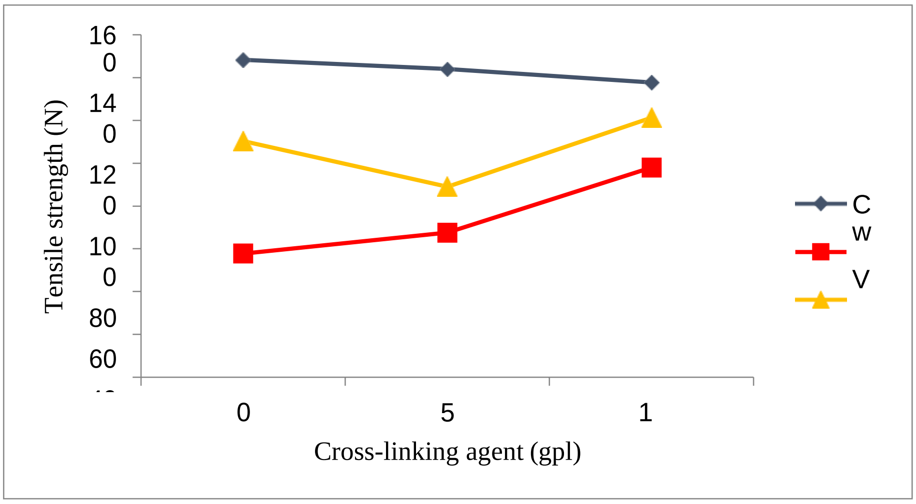

Fig. 4.9 Effect of cross-linking agent concentration with 30gpl nano cellulose concentration on tensile strength in machine direction

Table 4.4 Tensile strength in machine direction at different cross-linking agent in the solution (N)

Type of fabric	Without cross-linking agent			Cross-linking agent 5gpl			Cross-linking agent 10 gpl		
	Nano cellulose (gpl)			Nano cellulose (gpl)			Nano cellulose gpl		
	10	20	30	10	20	30	10	20	30
Cw	123.36	131.13	148.21	154.56	145.01	143.85	140.08	141.3	137.61
Ve	53.5	32.83	57.78	51.16	57.21	67.56	54.29	66.16	97.99
Vp	89.44	90.02	110.3	103.58	99.44	89.03	107.51	102.21	121.22

This behaviour of the fabric samples can be attributed to the effect of cross-linking agent on nano cellulose particles. In the absence of cross-linking agent, nano cellulose particles adhere to the fabric surface and also settle in the pores of the fabric sample. But, presence of cross-linking agent, binds them very well to the fabric improving the cohesiveness of fabric elements resulting in to increasing their tensile strength. Overall increase in tensile strength found in woven cotton fabric is in the range of 10 to 15%, and where as the increase in strength of nonwoven is higher in the range of 20 to 30 %. The average increase in strength of plain nonwoven and embossed nonwoven fabrics is 17% and 24% respectively. This is attributed to at par with the increase in mass density and improvement in cohesiveness of fabric structure due to nano cellulose coating of these fabrics. The effect of concentrations of nano cellulose solution without cross-linking material on tensile strength of fabric in machine direction is shown in Fig.4.10.

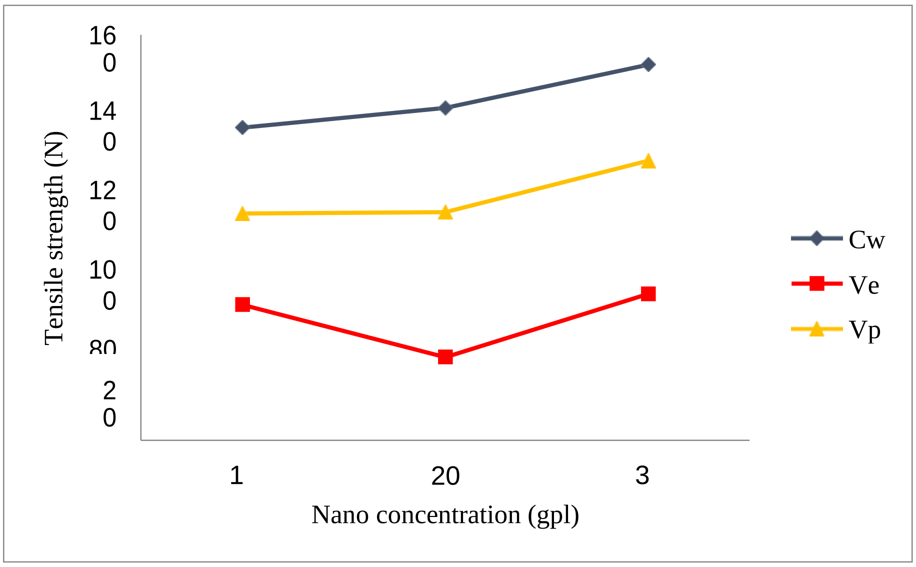

Fig. 4.10 Effect of nano cellulose concentration without cross-linking agent on tensile strength in machine direction

Fig. 4.11 and Fig. 4.12 show the effect of addition of 5gpl and 10gpl cross-linking material in nano cellulose solution on tensile strength of coated fabrics in machine direction respectively. It can be seen that adding the crosslinking material in to cellulose solution does not affect the strength of the fabrics.

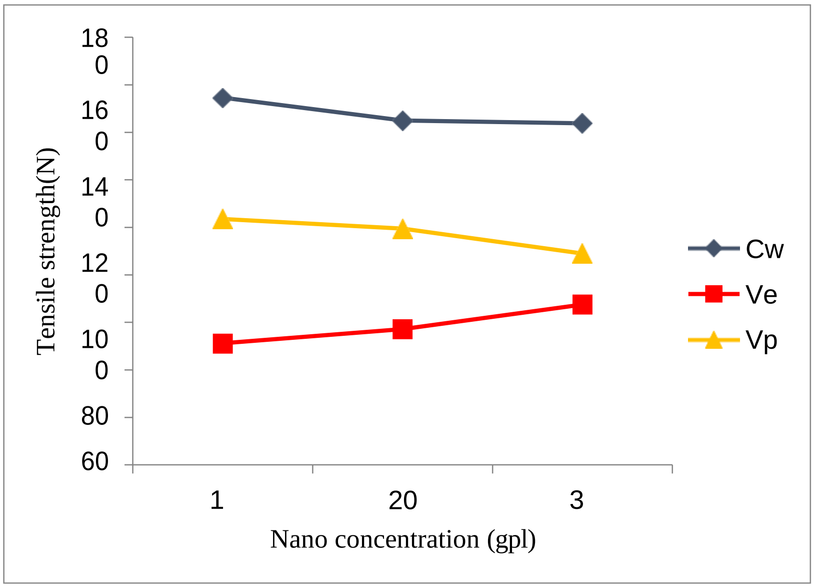

Fig. 4.11 Effect of nano cellulose concentration with 5gpl cross-linking agent on tensile strength in machine direction

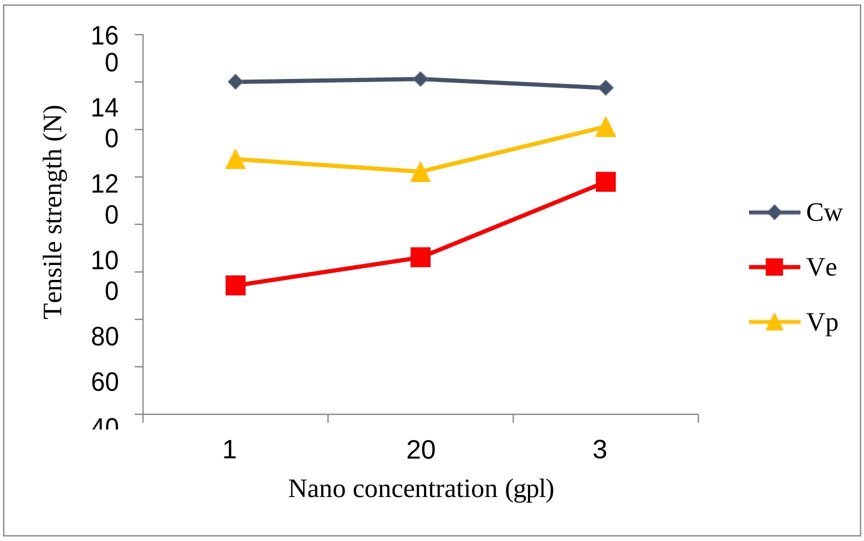

Fig. 4.12 Effect of nano cellulose concentration with 10gpl cross-linking agent on tensile strength in machine direction

4.2.2 Cross machine direction

The average tensile strength in cross machine direction of a woven fabric and two nonwoven fabrics coated using nano cellulose solution having various concentrations and using different concentrations of cross-linking agents has been given in Table 4.5. Like machine direction strength, the tensile strength of woven cotton fabric in cross machine direction is also higher as compared to that of two nonwoven viscose fabrics. The effect of concentration of nano cellulose solution on tensile strength have been compared and shown in Fig. 4.13, Fig. 4.14 and Fig. 4.15. The tensile strength in cross machine direction of cotton fabric samples is higher than that of two viscose fabric samples. This behaviour can be attributed to the fabric structures and fibre strength of cotton and viscose samples.

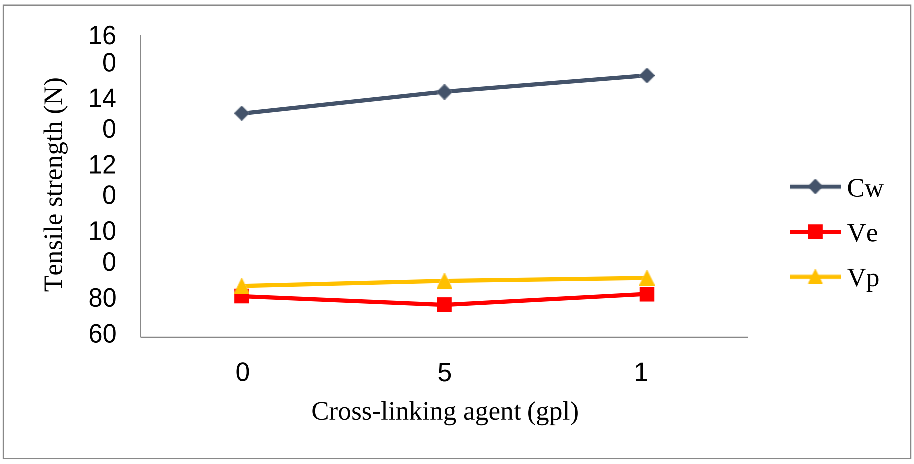

Fig. 4.13 Effect of cross-linking agent concentration with 10gpl nano cellulose on tensile strength in cross machine direction

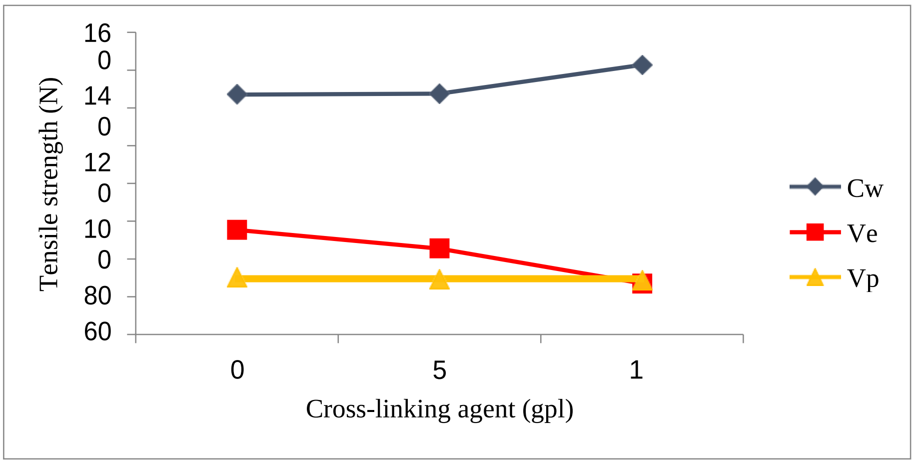

Fig. 4.14 Effect of cross-linking agent concentration with 20gpl nano cellulose on tensile strength in cross machine direction

Table 4.5 Tensile strength in cross machine direction with different concentration of cellulose solution (N)

Type of fabric	Nano cellulose 10gpl			Nano cellulose 20gpl			Nano cellulose 30gpl		
	Cross-linking agent (gpl)			Cross-linking agent (gpl)			Cross-linking agent (gpl)		
	0	5	10	0	5	10	0	5	10
Cw	118.43	129.87	138.49	127.07	127.52	142.74	138.13	139.95	137.74
Ve	21.72	17.17	22.79	55.4	45.58	27.07	55.7	25.69	69.66
Vp	27.18	29.75	31.33	30.37	29.2	28.76	29.61	34.72	31.06

Hence, in this case, cotton fabric samples show better strength while viscose non-woven fabric samples show satisfactory tensile strength. The orientation of fibre in both these nonwoven is such that majority of the fibres are oriented in the machine direction. The tensile strength in cross machine direction of nonwoven fabrics is only about 30 to 50% that of machine direction.

The tensile strength of samples of lower concentration of nano cellulose is less but it increase with increase in concentration of nano cellulose. This behaviour can be attributed to the locking property of nano cellulose particles. In case of lower concentration, the fewer nano cellulose particles are available. With increase in concentration of nano cellulose, the bonding among the fibres increases, resulting in to higher tensile strength. The tensile strength in cross machine direction of fabric coated using different concentrations of cross-linking agents in cellulose solution has been given in Table 4.6.

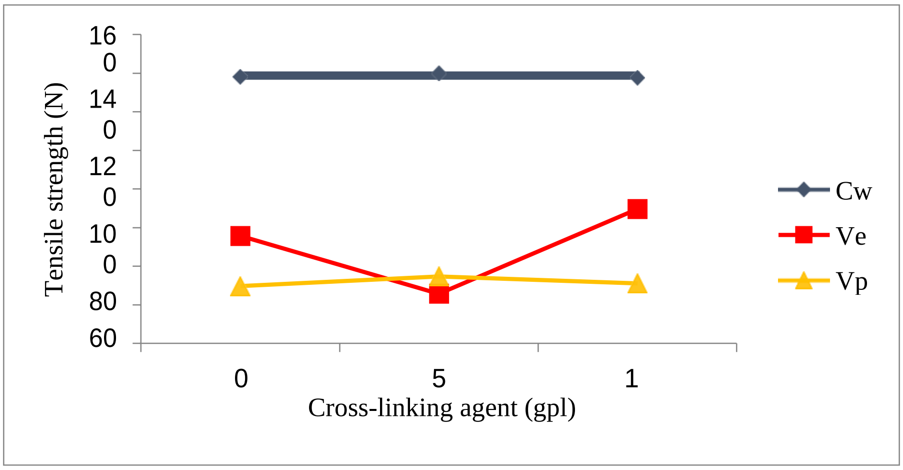

Fig. 4.15 Effect of cross-linking agent concentration with 30gpl nano cellulose on tensile strength in cross machine direction

Table 4.6 Tensile strength in cross machine direction at different cross-linking agent in the solution (N)

Type of fabric	Without cross-linking agent			Cross-linking agent 5gpl			Cross-linking agent 10 gpl		
	Nano cellulose (gpl)			Nano cellulose (gpl)			Nano cellulose (gpl)		
	10	20	30	10	20	30	10	20	30
Cw	118.43	127.07	138.13	129.87	127.52	139.95	138.49	142.74	137.74
Ve	21.72	55.4	55.7	17.17	45.58	25.69	22.79	27.07	69.66
Vp	27.18	30.37	29.61	29.75	29.2	34.72	31.33	28.76	31.06

The effect of concentration of cellulose solution without cross-linking material on tensile strength of fabric in cross machine direction is shown in Fig.4.16. The Fig. 4.17 and Fig. 4.18 show the effect of addition of 5gpl and 10gpl cross-linking material in cellulose solution on tensile strength of coated fabrics in cross machine direction respectively. Effect of adding the crosslinking material in to cellulose solution is negligible on the strength of the fabrics.

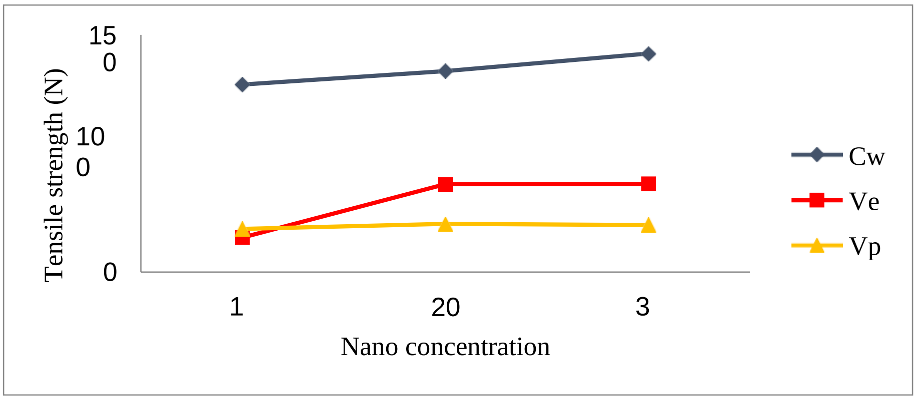

Fig. 4.16 Effect of nano cellulose concentration without cross-linking agent on tensile strength in cross machine direction

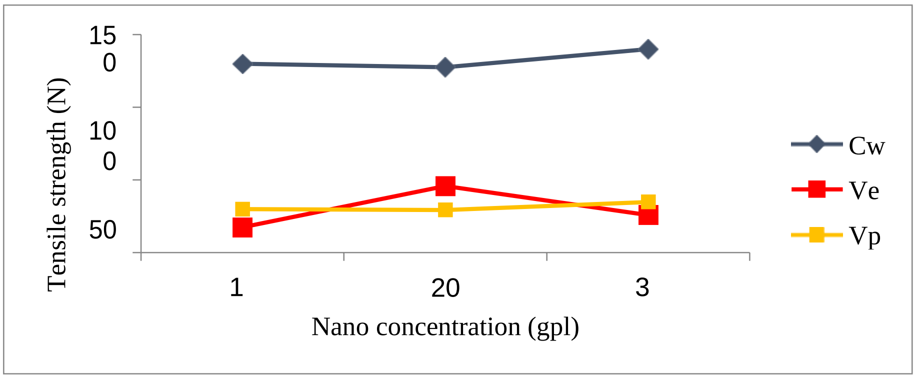

Fig. 4.17 Effect of nano cellulose concentration with 5gpl cross-linking agent on tensile strength in cross machine direction

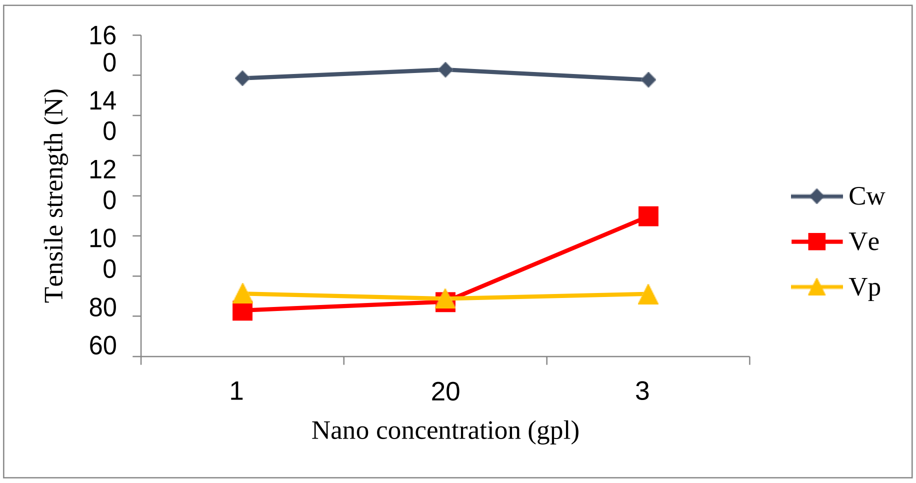

Fig. 4.18 Effect of nano cellulose concentration with 10gpl cross-linking agent on tensile strength in cross machine direction

4.3 Air permeability

Air permeability of the fabric depends upon the pore size of the fabric. Larger the pore size higher would be the air permeability and vice a versa. Application of nano cellulose coating reduces the pore size due to the accumulation of nano cellulose particles in to the pores. Nano cellulose particles also penetrate and settle in fabric on the surface. Presence of cross-linking agent binds the nano particles strongly with the fabric. The air permeability value of the fabrics coated using nano cellulose solution having various concentrations have been given in Table 4.7.

The effect of various cross-linking agent concentration in nano cellulose solution on air permeability of fabrics has been shown in Fig. 4.19, Fig. 4.20 and Fig. 4.21.

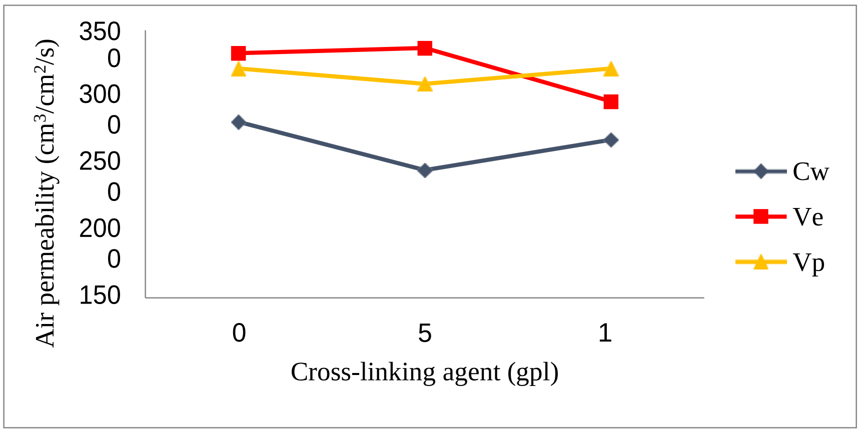

Fig. 4.19 Effect of cross-linking agent concentration with 10gpl nano cellulose concentration on air permeability

Table 4.7 Air permeability of fabrics with different nano cellulose concentration ($cm^3/cm^2/s$)

Type of fabric	Nano cellulose 10gpl			Nano cellulose 20gpl			Nano cellulose 30gpl		
	Cross-linking agent (gpl)			Cross-linking agent (gpl)			Cross-linking agent (gpl)		
	0	5	10	0	5	10	0	5	10
Cw	2300	1666	2066	1934	2067	2000	2300	2300	566.6
Ve	3200	3266	2566	2100	1934	2800	2233	1667	233.3
Vp	3000	2800	3000	2500	2413	2600	2500	1600	1300

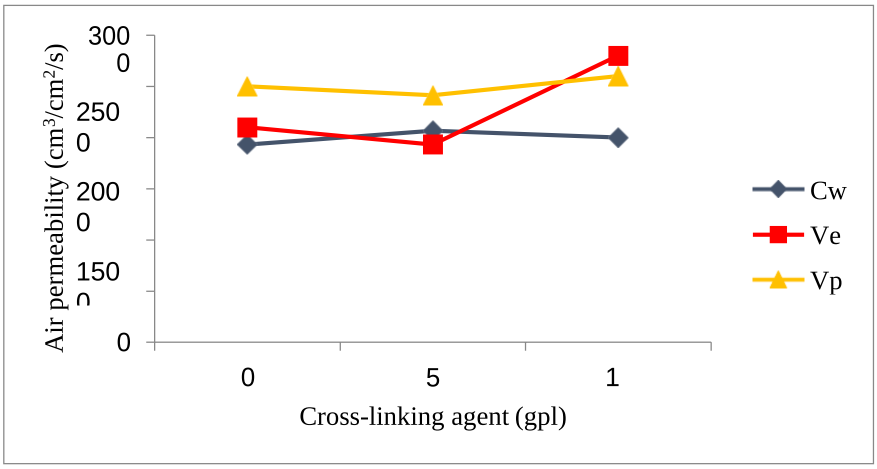

Fig. 4.20 Effect of cross-linking agent concentration with 20gpl nano cellulose concentration on air permeability

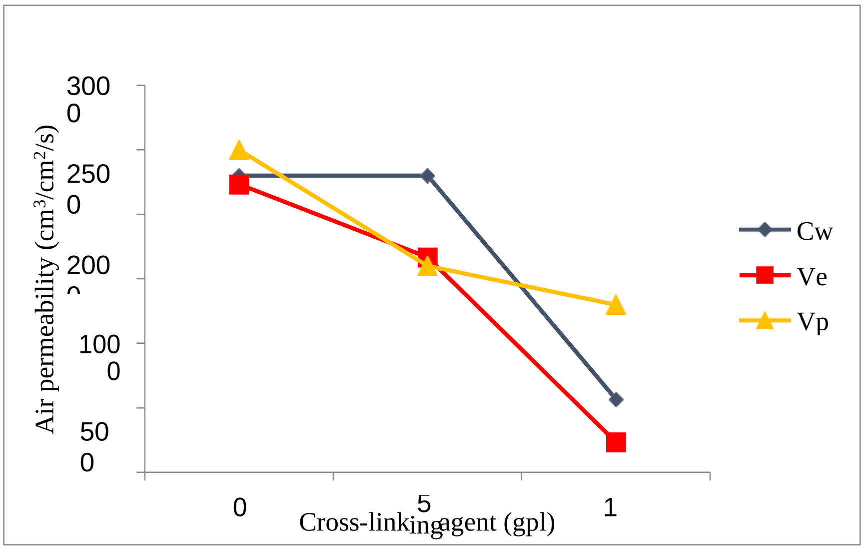

Fig. 4.21Effect of cross-linking agent concentration with 30gpl nano cellulose concentration on air permeability

Table 4.8 Air permeability of fabrics with different concentrations of cross-linking agent ($cm^3/cm^2/s$)

Type of fabric	Without cross-linking agent			Cross-linking agent 5gpl			Cross-linking agent 10 gpl		
	Nano cellulose (gpl)			Nano cellulose (gpl)			Nano cellulose (gpl)		
	10	20	30	10	20	30	10	20	30
Cw	2300	1934	2300	1667	2067	2300	2067	2000	566.7
Ve	3200	2100	2234	3267	1934	1667	2566	2800	233.3
Vp	3000	2500	2500	2800	2413	1600	3000	2600	1300

In all the cases compared to original fabric, the air permeability has been reduced. It has been observed that woven cotton fabric shows about 7 to 10% low air permeability depending on the nano cellulose concentration. The plain nonwoven shows 15 to 30% reduction in air permeability. Whereas embossed nonwoven fabric did not show any consistent behaviour regarding air permeability; the reduction was up to 50% as compared to untreated fabric. As woven fabric structure is compact, coating does not reduce pore size, the air permeability is found lower but reduction is marginal with the application of nano cellulose. In comparison to plain non-woven the surface and structure of embossed non-woven viscose is uneven, the reduction in air permeability is much higher.

The air permeability is the highest in case of cellulose concentration of 10gpl and the lowest in case of nano cellulose concentration of 30gpl. This behaviour can be attributed to the fact that as nano cellulose concentration increases; more nano particles are available to penetrate in to fabric covering the surface of the fabric. The effect of concentrations of nano cellulose solution without cross-linking material on air permeability of fabric is shown in Fig.4.22.

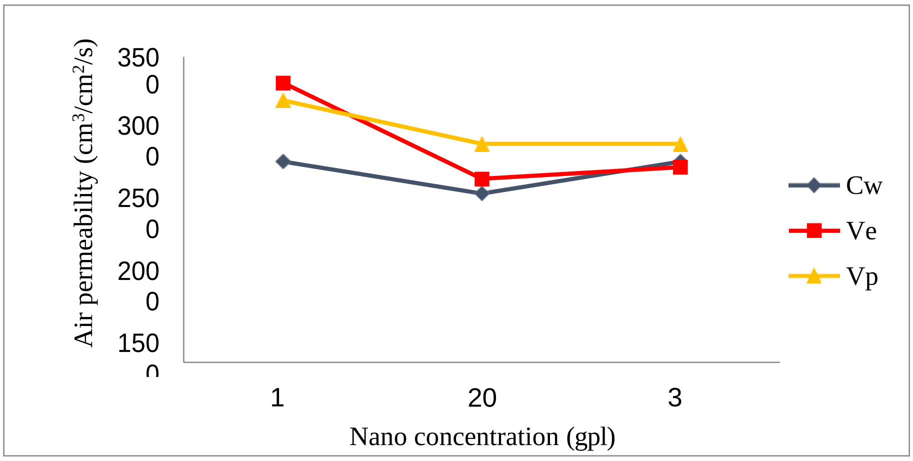

Fig. 4.22 Effect of nano cellulose concentration without cross-linking agent on air permeability

The Fig. 4.23 and Fig. 4.24 show the effect of addition of 5gpl and 10gpl cross-linking material in cellulose solution on air permeability of coated fabrics in respectively. The coating of nano cellulose layer and its penetration and settling in the pores of fabric hinders the passage of air through fabric. So the fabrics treated with higher concentration of nano cellulose show lesser air permeability. It has been observed that the reduction in air permeability is higher in fabric treated with addition of 5gpl and10gpl crosslinking agent as compared to that of without cross-linking agent. This behaviour can be attributed to the better fixing of nano cellulose to the fabric surface and the pores of the fabric in the presence of cross-linking agent. Overall fabrics treated with nano cellulose show reduction in the air permeability in general but it is sufficient enough to provide the required thermal comfort.

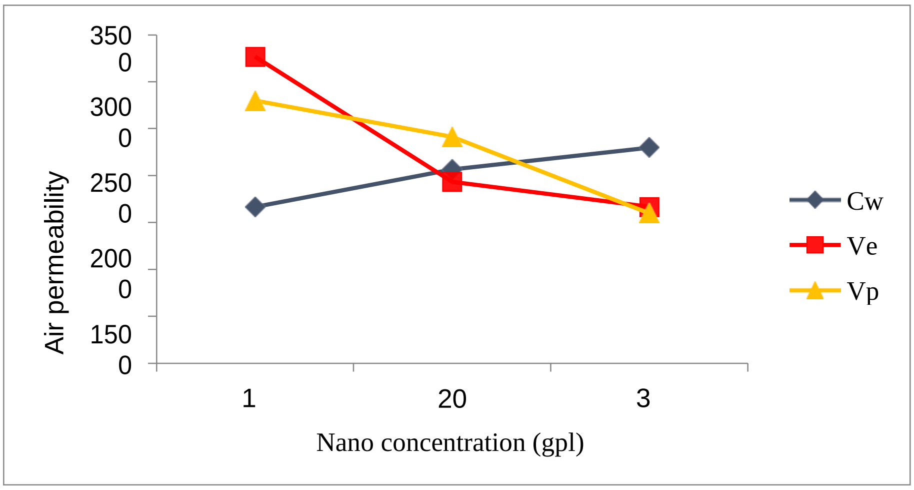

Fig. 4.23 Effect of nano cellulose concentration with 5gpl cross-linking agent on air permeability

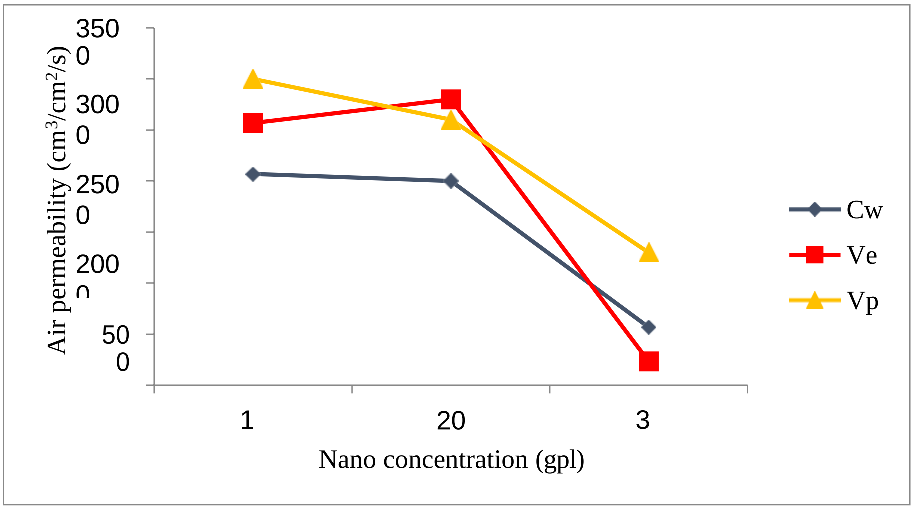

Fig. 4.24 Effect of nano cellulose concentration with 10gpl cross-linking agent on air permeability

4.4 Water repellence

Nano cellulose particles present on the surface of the fabric in the form of coating can likely to resist the flow of water through the fabric samples during water repellence test. A presence of cross-linking agent binds the nano particles strongly to the fabric. The water repellence grade of fabric coated using nano cellulose solution having various concentrations have been evaluated and average value have been given in Table 4.9. The effect of various cross-linking agent concentration in nano cellulose solution on water repellence of fabrics has been shown in Fig. 4.25, Fig. 4.26 and Fig. 4.27. The woven cotton fabric samples show very high water repellence grade except for few cases. On the other hand embossed nonwoven viscose fabric samples show poor or satisfactory water repellence.

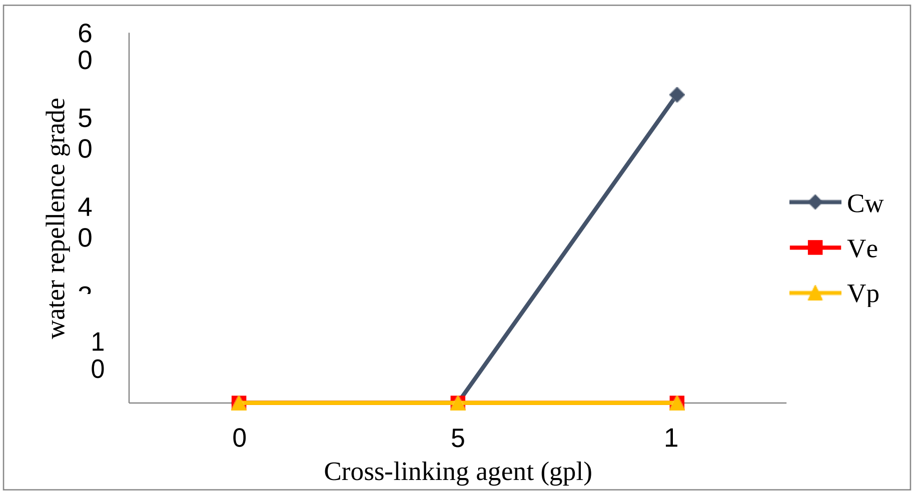

Fig. 4.25 Effect of cross-linking agent concentration on water repellence grade with 10gpl nano cellulose concentration

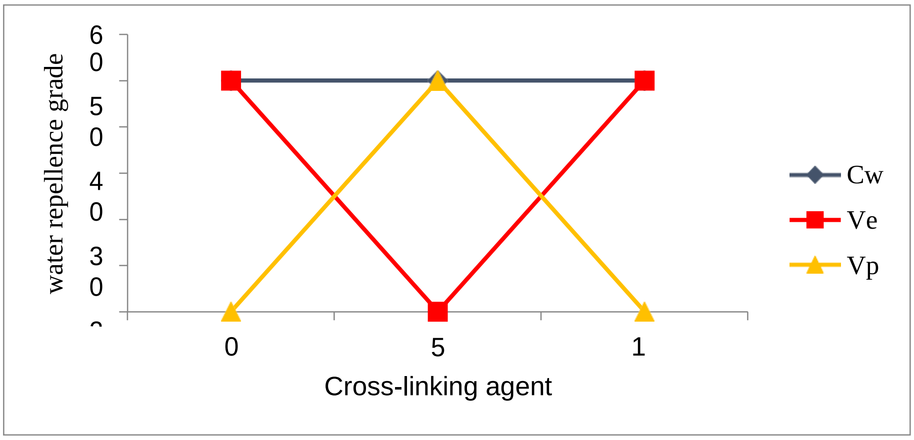

Fig. 4.26 Effect of cross-linking agent concentration with 20gpl nano cellulose concentration on water repellence grade

Table 4.9 Water repellence grade of fabrics with different cellulose concentration

Type of fabric	Nano cellulose 10gpl			Nano cellulose 20gpl			Nano cellulose 30gpl		
	Cross-linking agent (gpl)			Cross-linking agent (gpl)			Cross-linking agent (gpl)		
	0	5	10	0	5	10	0	5	10
Cw	0	0	50	50	50	50	0	70	90
Ve	0	0	0	50	0	50	0	50	50
Vp	0	0	0	0	50	0	0	80	90

Only plain non-woven viscose fabric samples show good water repellence. The water repellence of the fabrics after the treatment of nano cellulose, depend on concentration of nano cellulose. This behaviour of the fabric samples can be attributed to the fabric structure. As cotton fabric is a plain woven fabric, owing to bigger pores, nano cellulose particles could penetrate much and be deposited much on fabric sample surface. Opposite to that, in case of non-woven viscose fabric samples, the nano cellulose particles could not much penetrate well and again, they also can not stick to the fabric sample surface due to compact surface formed due to finer fibres. Hence nonwoven fabric samples show very poor water repellence.

In case of fabrics treated with 10gpl cellulose concentration, it does not show good water repellence, but increasing the concentration of nano cellulose improves the water repellency of the fabrics. This behaviour can be attributed to the concentration of nano cellulose in the bath, lower concentrations of nano cellulose offer less nano particles, to be adhered to the fabric sample. The water repellence value of the fabrics coated using nano cellulose solution with different cross-linking agent concentrations have been given in Table 4.10.

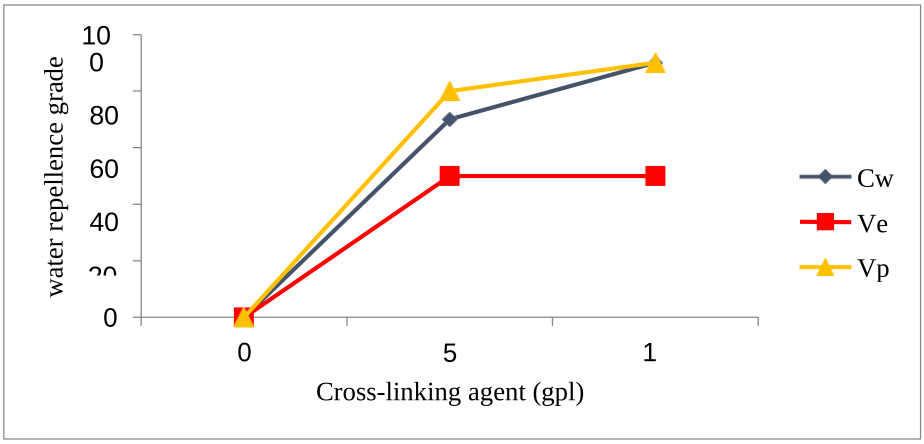

Fig.4.27 Effect of Cross-linking agent concentration with 30gpl nano cellulose concentration on water repellence grade

Table 4.10 Water repellence grade of fabrics with different cross-linking agent concentrations

Type of fabric	Without cross-linking Agent			Cross-linking agent 5gpl			Cross-linking agent 10gpl		
	Nano cellulose (gpl)			Nano cellulose (gpl)			Nano cellulose (gpl)		
	10	20	30	10	20	30	10	20	30
Cw	0	50	0	0	50	70	50	50	90
Ve	0	50	0	0	0	50	0	50	50
Vp	0	0	0	0	50	80	0	0	90

Hence after conditioning process, when water repellency was checked, fabric sample showed poor water repellency, as penetration of water droplets be easy through the fabric surface. On other hand in case of 30gpl nano concentration, more nano cellulose particles found adhered to the fabric sample, which during conditioning, make them settled into the pores of the fabric samples as well as on the surface of the fabric samples. Hence better water repellence is observed. Looking at the Tables and line diagrams, it can be concluded that the without using the cross-linking agent, the water repellence of fabric samples is poor. Increasing the concentration of cross-linking agent, water repellence of fabric samples generally improves.

This behaviour of the fabric samples can be attributed to the effect of cross-linking agent on nano cellulose particles. In the absence of cross-linking agent, nano cellulose particles adhere to the fabric surface and also settle in the pores of the fabric samples. But, presence of cross-linking agent, binds them very well to the fabric and hence at 10gpl cross-linking material concentration, nonwoven fabrics show better water repellence.

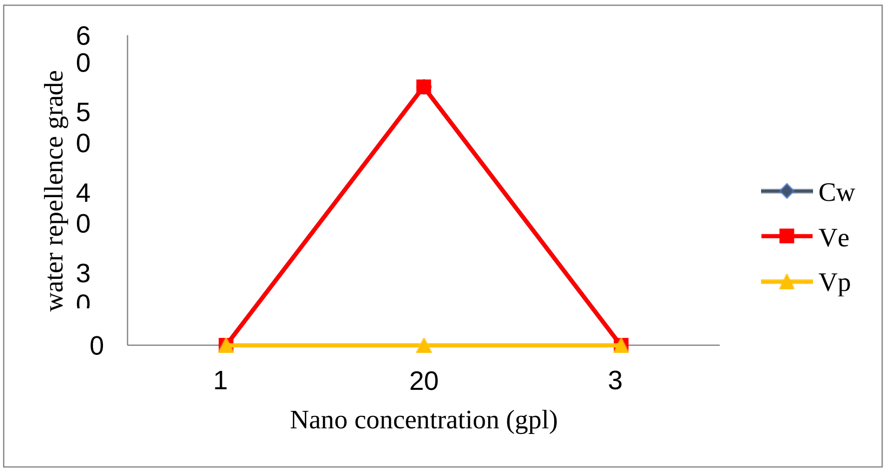

Fig. 4.28 Effect of nano cellulose concentration without cross-linking agent on water repellence grade

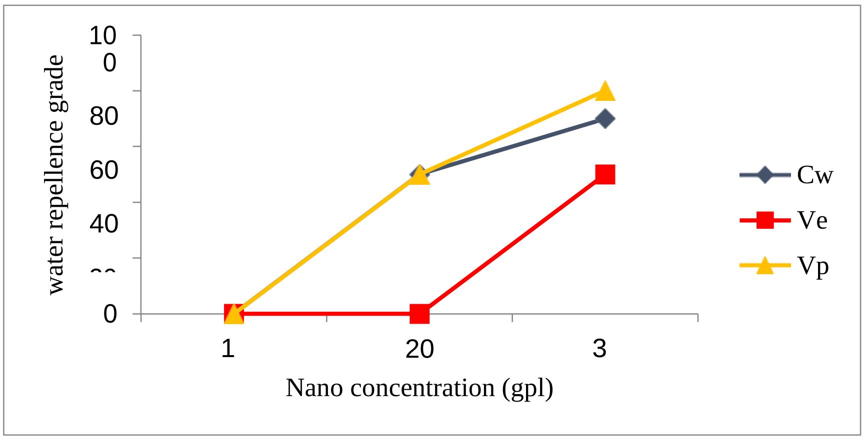

Fig 4.29 Effect of cellulose concentration with 5gpl cross-linking agent on water repellence grade

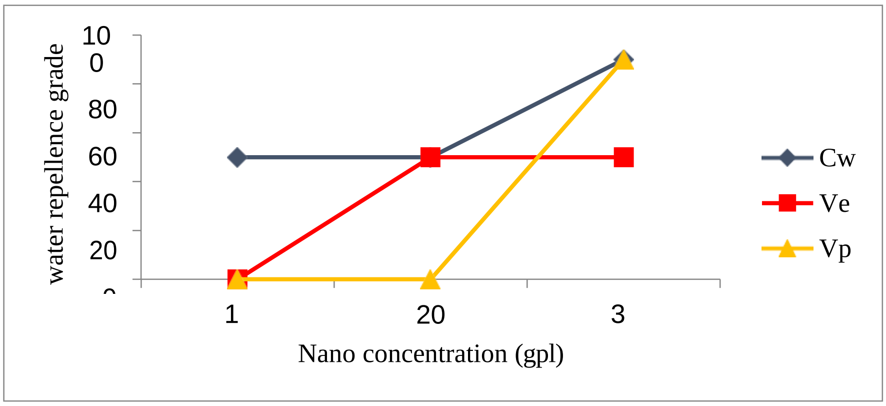

Fig. 4.30 Effect of cellulose concentration with 10gpl cross-linking agent on water repellence grade

4.5 Fabric Stiffness

Bending length and flexural rigidity of the fabric are measure of fabric stiffness, which is associated closely with fabric handle. Bending modulus is affected by fabric thickness, bending length and areal density of the fabric. The areal density (gsm) and fabric thickness of the fabric have been measured and used to calculate the bending modulus. Coating of nano cellulose affects the above mentioned properties of the fabric and hence bending modulus is also affected. Using the fabric stiffness tester, the stiffness of the fabric has been measured in machine direction and cross machine direction of the fabric.

4.5.1 Bending modulus in machine direction

The bending modulus in machine direction of fabrics coated using cellulose solution having various concentrations have been given in Table 4.11. The effect of concentration of cross-linking agent in the cellulose solution on bending modulus of fabric in machine direction has been shown in Fig. 4.31, Fig. 4.32 and Fig. 4.33.

Table 4.11 Bending modulus in m/c direction at different concentration of cellulose solution (kg/cm^2)

Type of fabric	Nano cellulose 10gpl			Nano cellulose 20gpl			Nano cellulose 30gpl		
	Cross-linking agent (gpl)			Cross-linking agent (gpl)			Cross-linking agent (gpl)		
	0	5	10	0	5	10	0	5	10
Cw	5.83	7.01	3.88	3.44	3.32	6.26	16.02	15.39	19.28
Ve	16.51	7.87	12.84	23.62	17.49	12.88	15.56	19.99	15.97
Vp	21.90	2.21	6.72	7.28	8.80	6.23	6.75	15.61	7.86

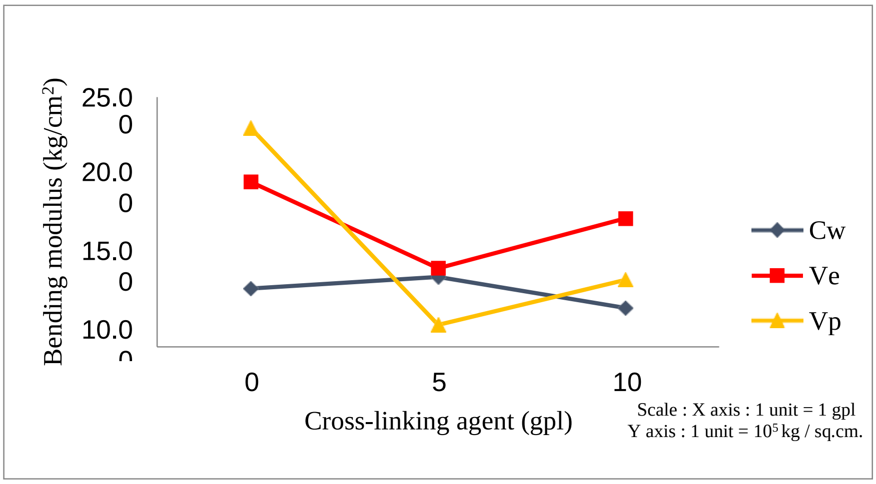

Fig. 4.31 Effect of cross-linking agent concentration with 10gpl cellulose concentration on bending modulus in machine direction

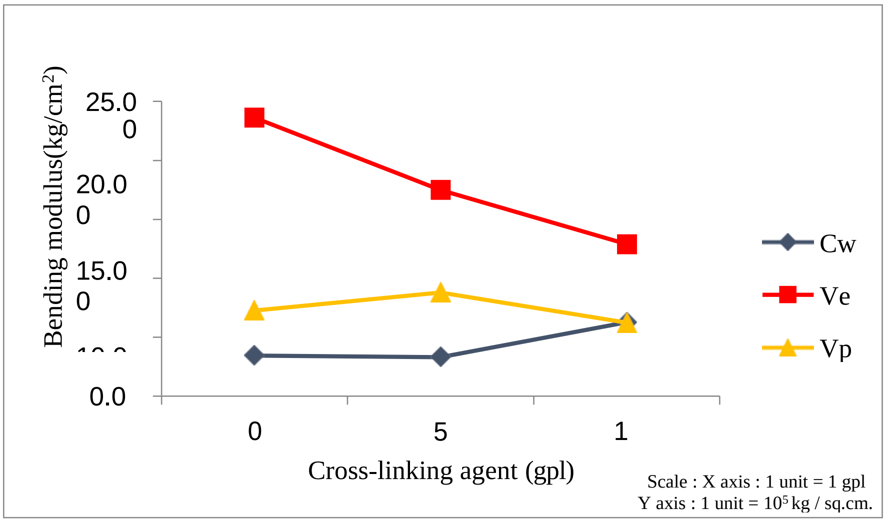

Fig. 4.32 Effect of cross-linking agent concentration with 20gpl cellulose concentration on bending modulus in machine direction

From data and line diagrams, it can be seen that the bending modulus is the lowest in case of woven cotton fabric, while it is high for both the viscose nonwoven fabrics. In case of a plain woven fabric, yarns are twisted bodies so the cellulose particles may not penetrate inside the yarn structure. So, the flexibility of the fabric remains intact due to lower pick up of nano cellulose. While in viscose nonwoven fabrics are having porous structure due to hydro entangled bonding. So nano cellulose particles find enough room and can penetrate them well and after conditioning become stiff. So, bending modulus in these cases is higher. It can be seen that bending modulus is in general lower in case of 10gpl concentration of nano cellulose, while it is higher in case of 30gpl concentration of nano cellulose.

This behavior can be attributed to the concentration of nano cellulose in the bath. 10gpl concentration of nano cellulose offers lesser nano particles, to be adhered to the fabric sample. Hence after conditioning process, fabric sample is flexible. Hence its bending modulus is lower. Opposite to that, at 30gpl nano concentration, more nano cellulose particles are present to adhere to the fabric sample, which during conditioning, made the fabric sample stiffer. So, 10gpl concentration of nano cellulose, showed low bending modulus and 30gpl nano cellulose concentrations showed higher bending modulus. The bending modulus of fabric coated using different concentrations of cross-linking agents have been given in and Table 4.12. The effect of concentration of cross-linking agent in the cellulose solution has been shown in Fig. 4.34, Fig. 4.35 and Fig 4.36.

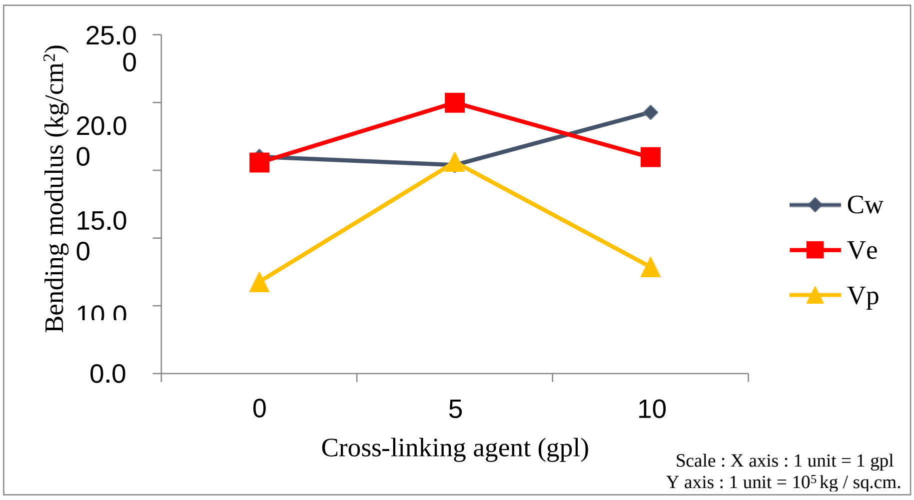

Fig. 4.33 Effect of cross-linking agent concentration with 30gpl cellulose concentration on bending modulus in machine direction

Table 4.12 Bending modulus in m/c direction at different cross-linking agent concentrations (kg/cm^2)

Type of fabric	Without cross-linking agent			Cross-linking agent 5gpl			Cross-linking agent 10gpl		
	Nano cellulose (gpl)			Nano cellulose (gpl)			Nano cellulose (gpl)		
	10	20	30	10	20	30	10	20	30
Cw	5.83	3.44	16.02	7.01	3.32	15.39	3.88	6.26	19.28
Ve	16.51	23.62	15.56	7.87	17.49	19.99	12.84	12.88	15.97
Vp	21.90	7.28	6.75	2.21	8.80	15.61	6.72	6.23	7.86

From these graphs it is observed that, absence of cross-linking agent shows generally lower bending modulus, while 10gpl concentration of cross-linking agent generally showed high bending modulus. This behaviour of the fabric samples can be attributed to the effect of cross-linking agent on nano cellulose particles. In the absence of cross-linking agent, nano cellulose particles adhere to the fabric surface and also settle in the pores of the fabric sample. But, presence of cross-linking agent, binds them very well to the fabric and hence at 10gpl concentration, after conditioning of the samples, they become stiffer hence show higher bending modulus.

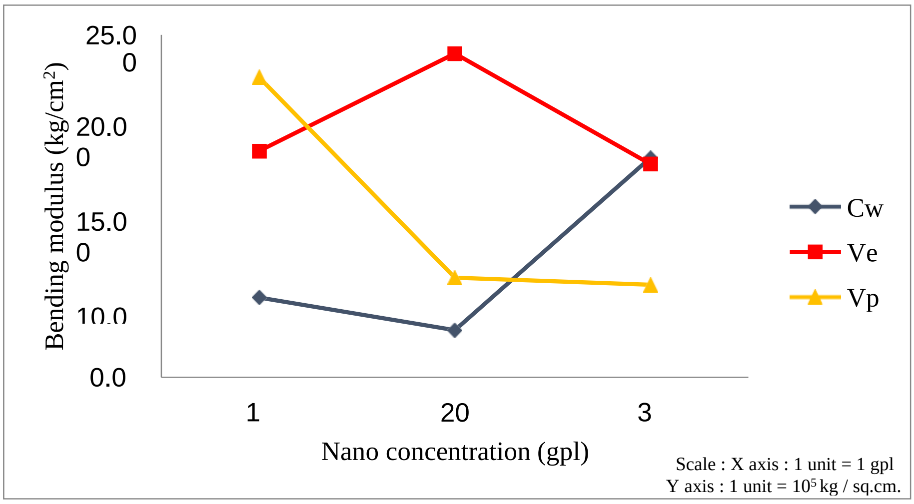

Fig. 4.34 Effect of nano cellulose concentration without cross-linking agent on bending modulus in machine direction

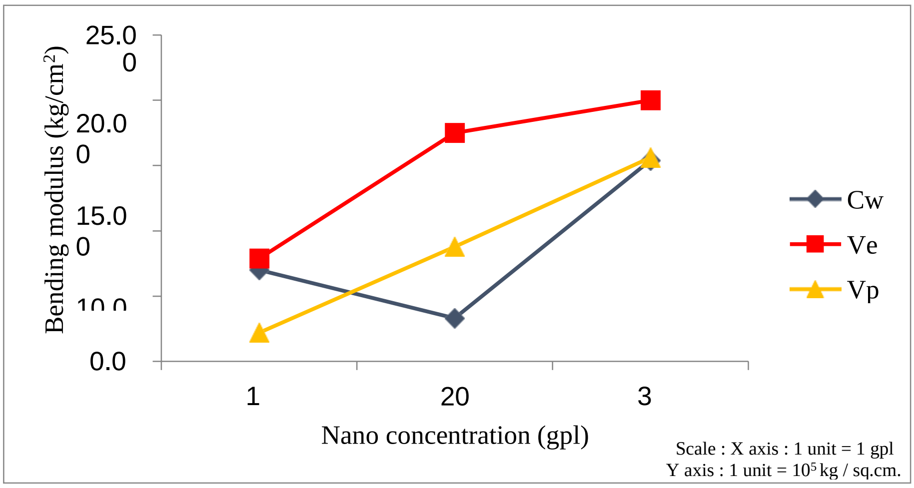

Fig. 4.35 Effect of nano cellulose concentration with 5gpl cross-linking agent on bending modulus in machine direction

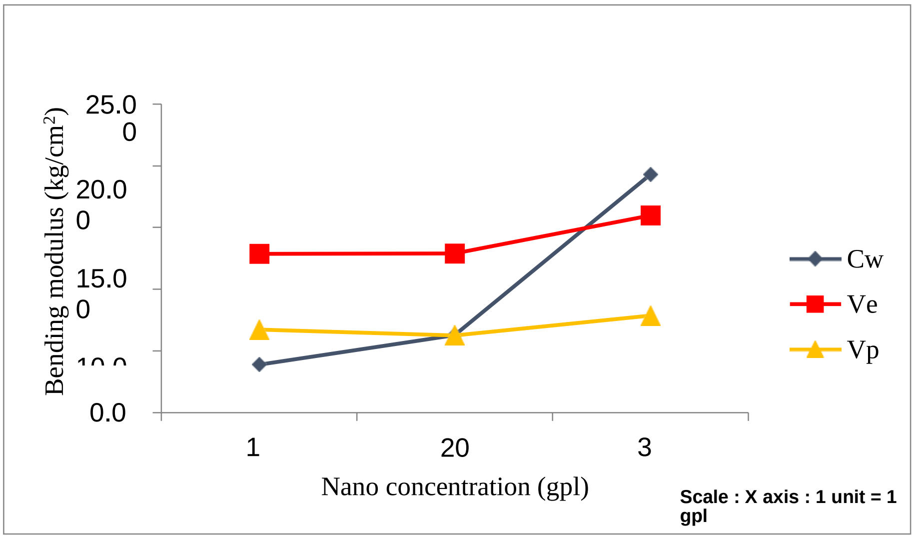

Fig. 4.36 Effect of nano cellulose concentration with 10 gpl cross-linking agent on bending modulus in machine direction

4.5.2 Bending modulus in cross machine direction

The bending modulus in cross machine direction of fabric coated using nano cellulose solution having various concentrations have been given in Table 4.13. The effect of concentration of cross-linking agent in cellulose solution of different concentration has been shown in Fig. 4.37, Fig. 4.38 and Fig. 4.39. Similar to bending modulus of machine direction, the woven fabric samples show low bending modulus, while nonwoven fabrics comparatively exhibits higher bending modulus. This behaviour of the fabric can be attributed to the fabric structure.

Table 4.13 Bending modulus in cross m/c direction at different concentration of cellulose solution (kg/cm^2)

Type of Fabric	Nano cellulose 10gpl			Nano cellulose 20gpl			Nano cellulose 30gpl		
	Cross-linking agent (gpl)			Cross-linking agent (gpl)			Cross-linking agent (gpl)		
	0	5	10	0	5	10	0	5	10
Cw	1.29	7.85	5.72	8.16	6.42	13.44	26.02	16.75	32.04
Ve	19.22	16.55	17.51	23.38	18.23	12.35	15.48	19.99	21.53
Vp	2.88	24.60	25.87	33.69	21.82	21.70	24.01	24.22	30.91

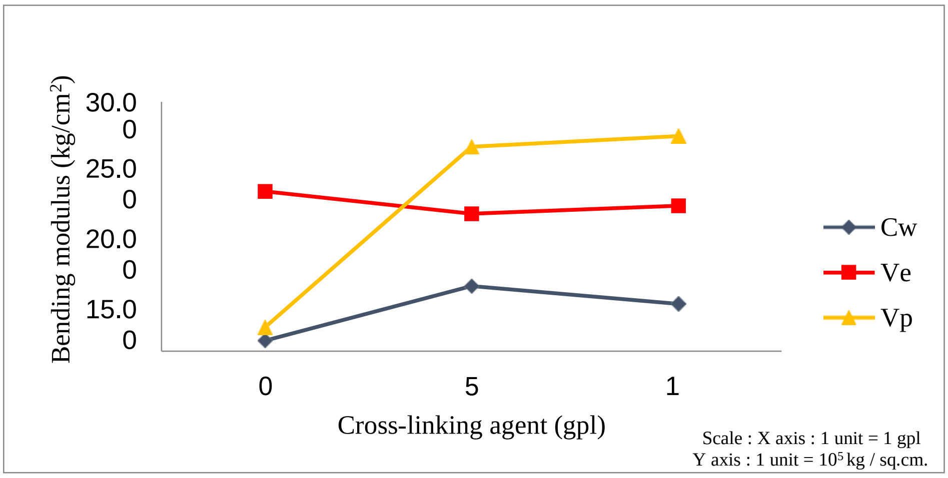

Fig. 4.37Effect of cross-linking agent concentration with 10gpl cellulose concentration on bending modulus in cross machine direction

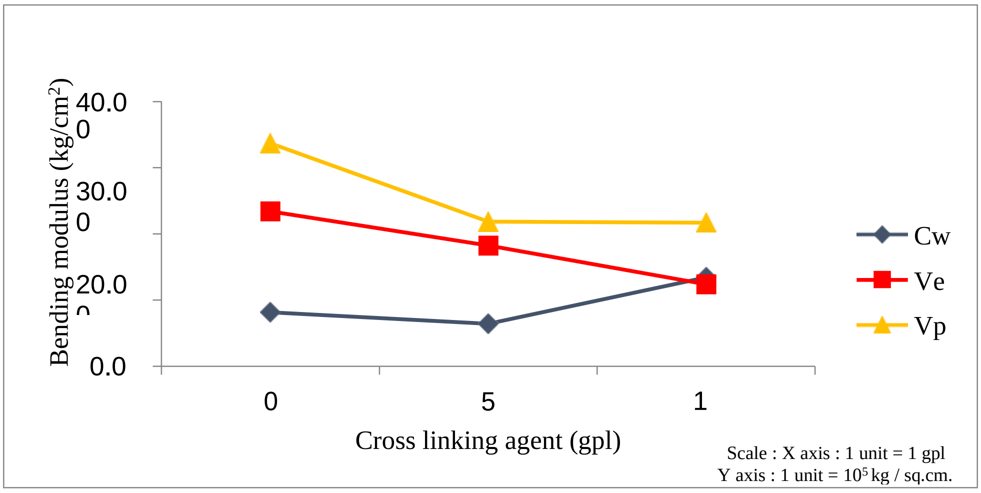

Fig. 4.38 Effect of cross-linking agent concentration with 20gpl cellulose concentration on bending modulus in cross machine direction

In case of woven structure nano particles cannot penetrate in yarn bodies whereas spun laced nonwoven fabrics structure is highly porous providing room for nano cellulose particles to be deposited in the inner layers and on the surface as well. Therefore in case of non-woven viscose fabric samples, the nano cellulose particles penetrate well and again, they also stick to the fabric sample surface due to its unevenness.

It can be seen that the bending modulus is low at 10gpl cellulose concentration as compared to that of 30gpl. This can be attributed to the concentration of nano cellulose. The 10gpl concentration of nano cellulose offers less nano particles to be adhered to the fabric surface and at 30gpl concentration, more nano cellulose particles are present to adhere to the fabric.

The bending modulus of fabric coated using different concentrations of cross-linking agents have been given in and Table 4.14. The effect of cellulose concentration without cross-linking agent and addition of cross linking agent in the cellulose solution has been shown in Fig. 4.40, Fig. 4.41 and Fig 4.42.

In the absence of cross-linking agent, nano cellulose particles adhere to the fabric surface and also settle in the pores of the fabric sample. But, presence of cross-linking agent, binds them very well to the fabric and hence at 10gpl concentration, after conditioning of the samples, they become stiffer and their bending modulus increases.

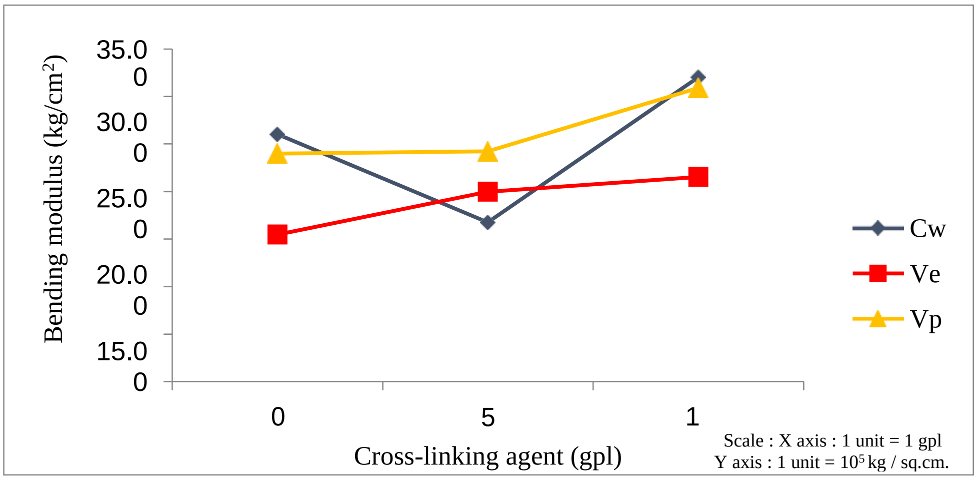

Fig. 4.39 Effect of cross-linking agent concentration with 30gpl cellulose concentration on bending modulus in cross machine direction

Table 4.14 Bending modulus in cross m/c direction at different cross-linking agent concentrations (kg/cm^2)

Type of Fabric	Without cross-linking Agent			Cross-linking agent 5gpl			Cross-linking agent 10gpl		
	Nano cellulose (gpl)			Nano cellulose (gpl)			Nano cellulose (gpl)		
	10	20	30	10	20	30	10	20	30
Cw	1.29	8.16	26.02	7.85	6.42	16.75	5.72	13.44	32.04
Ve	19.22	23.38	15.48	16.55	18.23	19.99	17.51	12.35	21.53
Vp	2.88	33.69	24.01	24.60	21.82	24.22	25.87	21.70	30.91

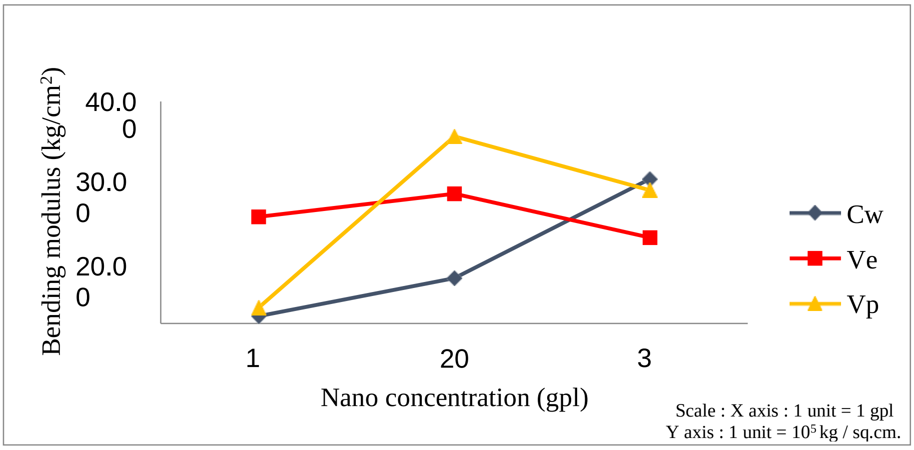

Fig. 4.40 Effect of nano cellulose concentration without cross-linking agent on bending modulus in cross machine direction

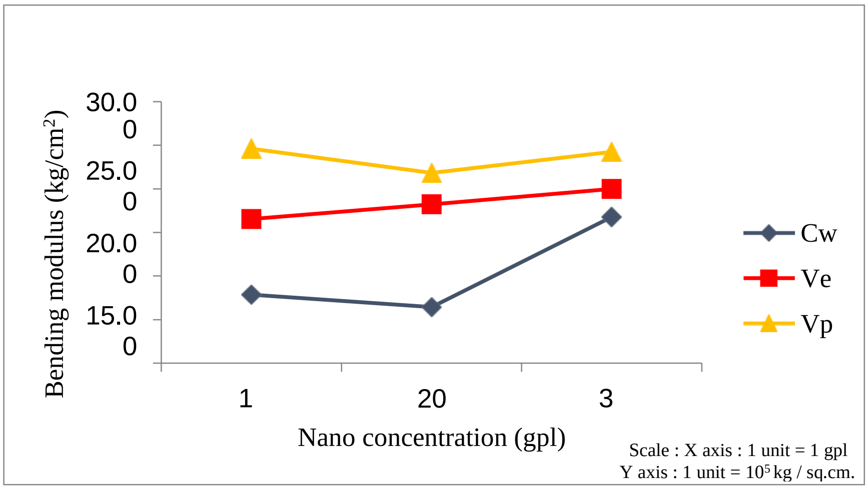

Fig. 4.41 Effect of nano cellulose concentration with 5gpl cross-linking agent on bending modulus in cross machine direction

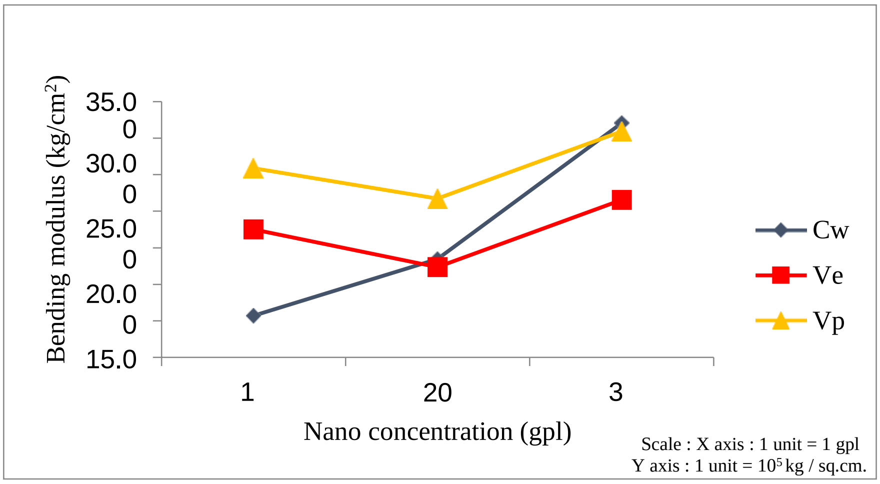

Fig. 4.42 Effect of nano cellulose concentration with 10gpl cross-linking agent on bending modulus in cross machine direction

4.6 Anti-bacterial property

Neem seed oil solution has been used as an antibacterial agent in the present work. Fabric strips of selected samples have been treated with neem seed oil solution to improve anti-bacterial property of the fabric. It has been observed that all the treated samples have been found with some improvement in antibacterial property. The control, mentioned as “C” or “untreated” is a sample strip, which is a sample on which antibacterial treatment is not carried out. In all the cases, these samples are affected by colonies of bacteria, on and around the control sample. The development of bacterial colonies indicates that there are cent per cent chances of development of bacteria, if these untreated fabrics are used to produce surgical gowns. Hence there are chances of infections also.

Plain viscose fabric treated samples have been observed without such bacterial colonies’ development. This indicates that if the surgical gown or fabric is treated, the gown or fabric will not allow bacteria to generate colonies. Such surgical gown is safe for the surgeon or the patient in operation theatre. Fig.4.43 to Fig.4.57 shows effect of neem seed oil solution on fabric samples. It has been observed that all control samples have developed the colonies of bacteria, whether bacteria are Gram positive or Gram negative. In treated samples of cotton, the development of bacterial colonies has been observed. Only plain viscose non-woven fabric, treated with 30gpl nano cellulose solution with10gpl cross-linking agent has been observed without the developments of bacterial colonies for Gram positive and Gram-negative bacteria.

The reason for the same is the difference in fabric structure of woven and nonwoven fabric samples. Cotton woven fabric sample does not have smooth surface like viscose nonwoven plain fabric sample. So, coating of nano cellulose on cotton fabric is not uniform and continuous. Hence the application of neem seed oil solution on cotton sample is also not uniform. Viscose nonwoven fabric has a plain smooth surface. Hence nano cellulose coating is even on the surface of the viscose fabric. So, neem seed oil solution treatment on the sample is also even on the fabric surface. This evenness of layering resists the development of bacterial colonies around the treated sample. In this case 10gpl cross-linking agent has been used during nano cellulose coating. This higher concentration of cross-linking agent also binds the nano cellulose particles on the regular surface of viscose plain nonwoven sample. Hence this fabric offers excellent resistance against the development of bacterial colonies.

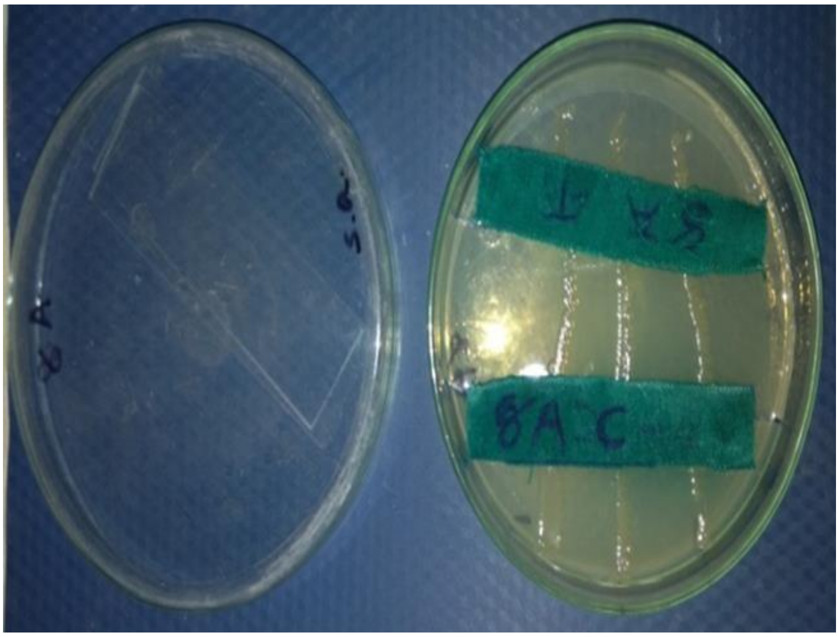

Fig 4.43 Sample 8A, Bacteria S. A

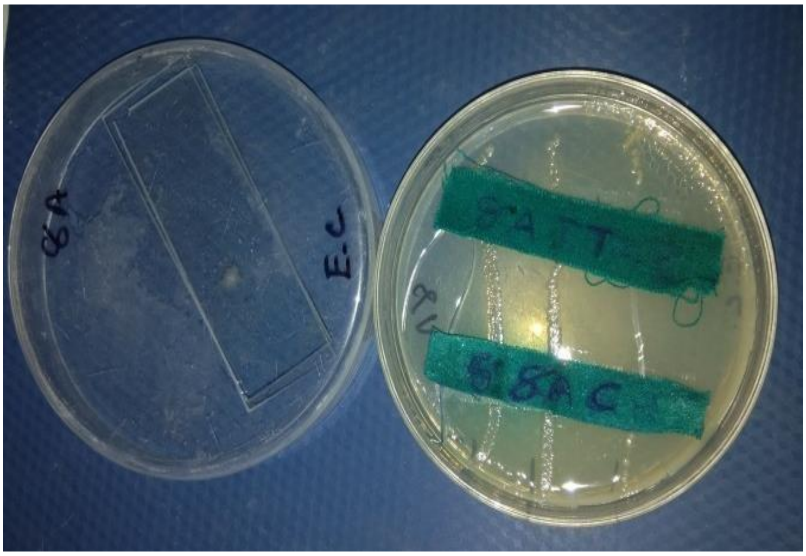

Fig 4.44 Sample 8A, Bacteria E. C.

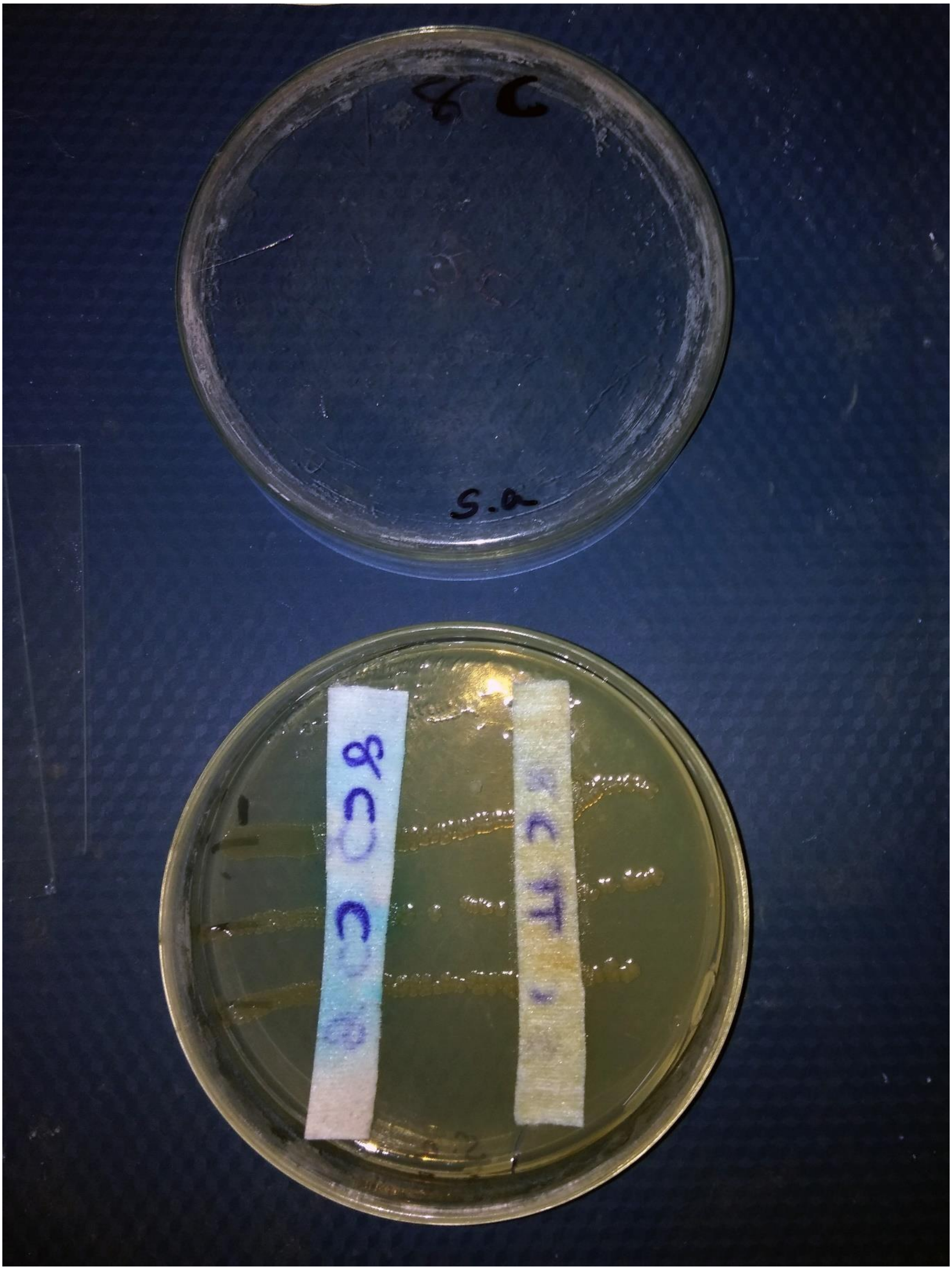

Fig 4.45 Sample 8C, Bacteria S. A.

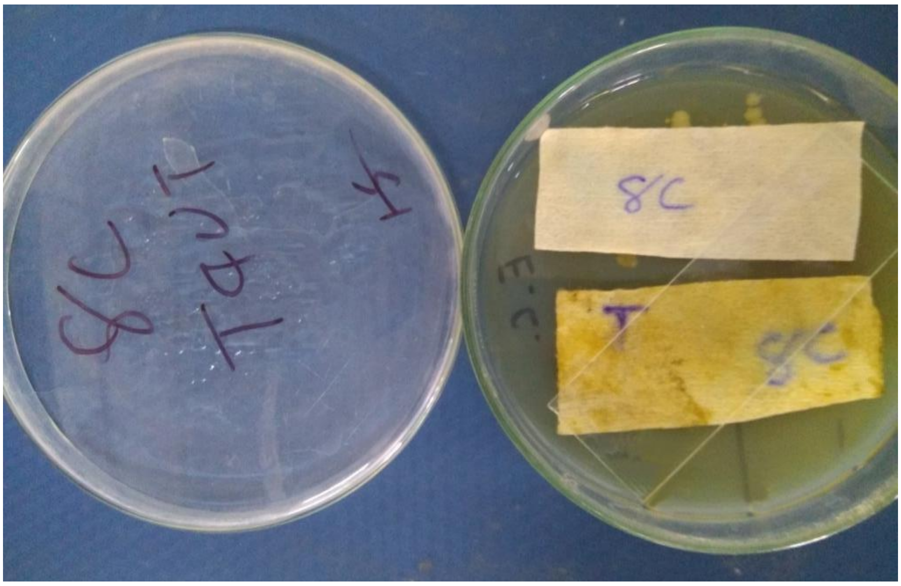

Fig 4.46 Sample 8 C, Bacteria E. C.

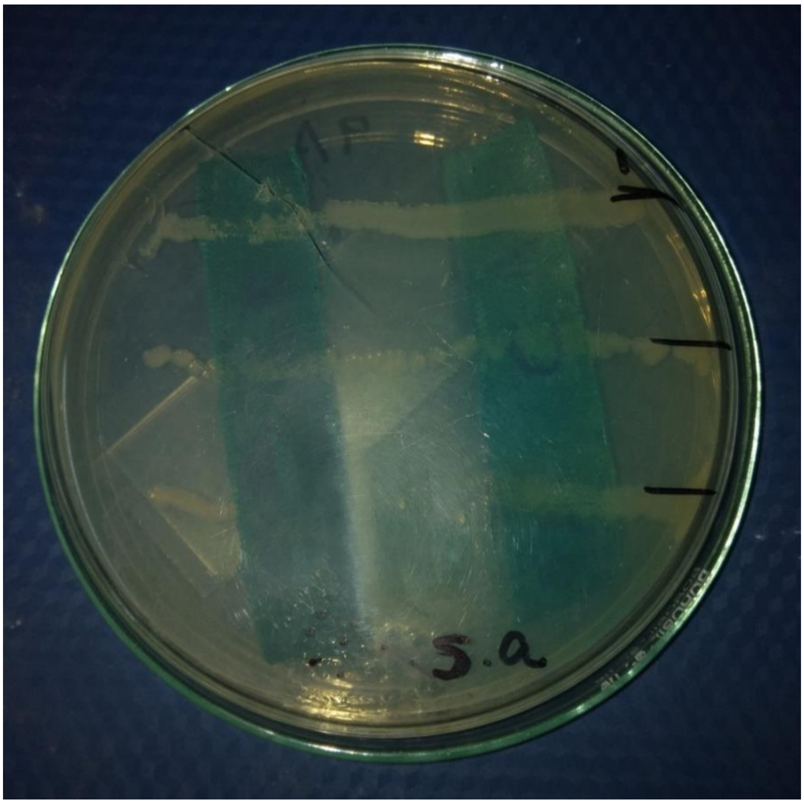

Fig 4.47 Sample 9 A, Bacteria S. A.

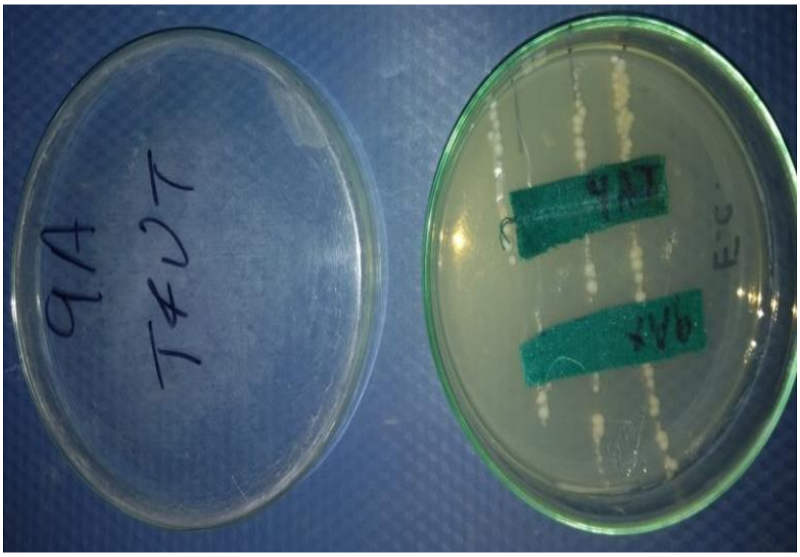

Fig 4.48 Sample 9 A, Bacteria E. C.

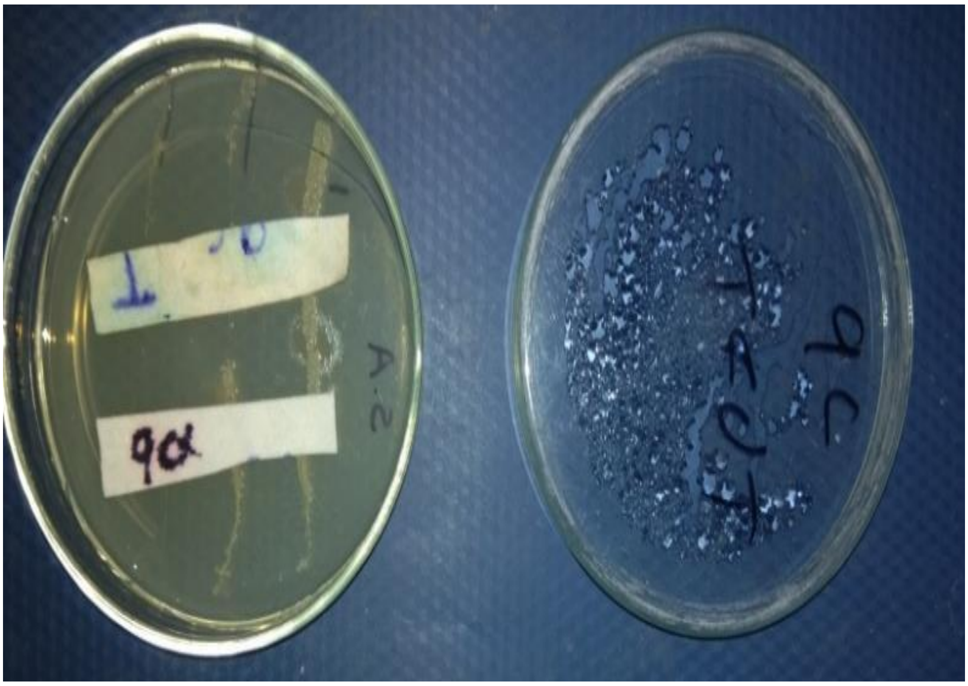

Fig 4.49 Sample 9 C, Bacteria S. A.

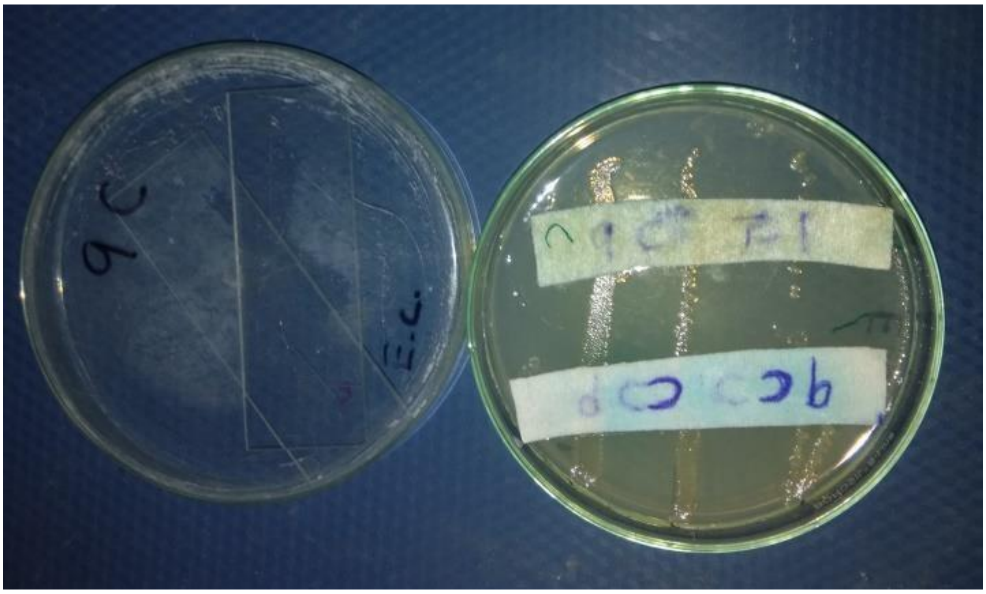

Fig 4.50 Sample 9 C, Bacteria E. C.