RESEARCH ARTICLE

Aroma Treatment of Wool Fabric with Microencapsulated Vetiver Essential Oil

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ABSTRACT

The current 'green' trend is favoring usages of natural ingredients. There is increasing interest in the health and wellness benefits of herbal products as they offer a natural safeguard against the development of certain conditions and treatment for some diseases. Some essential oils can be used to infuse textiles with aroma with added biological properties that can also be useful for healthcare textile applications. To achieve the objectives of the study, vetiver essential oil microcapsules were prepared using complex coacervation technique and applied on wool fabric through pad-dry-cure method by optimizing various variables of aroma treatment. Aroma treatment was given to wool fabric using optimized concentrations of padding bath components i.e. 60 g/l microcapsule gel, 2 g/l softener and 10 g/l binder maintaining M:L ratio 1:20 for 30 minutes at 35oC treatment temperature as the fabric treated at these optimized conditions exhibited good wash durability and improved fabric properties. The 70oC drying temperature with 4 minutes drying time and 100oC curing temperature with 60 seconds curing duration were optimized on the basis of presence of higher number of microcapsules, retention of aroma for longer duration and improvement in fabric properties of treated fabric.

Keywords: *Vetiver oil microcapsules, wool fabric, standardization, pad-dry-cure method, aroma treatment*

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INTRODUCTION

In present decade, the consumers' needs, demands and expectations for a healthier and more comfortable life are increasing everyday even when it comes to clothing. After fabricating the mansions of fashion and comfort, textiles are now moving towards high-tech era of performance, which has brought up diversification and expansion of technologies. The recent interest in bio-functional textiles is mainly directed to the use of specific textiles in medical therapy and prevention of deficiencies. With advent of new eco-technologies, the growing needs of the consumers in the wake of health and hygiene can be fulfilled without compromising the issues related to safety, human health and environment [1-2].

Buyers always expect a high degree of wearing comfort and finishing plays an important role in achieving it. Fragrance finishing of textile material increases the value of the product by adding beneficial factors and such factors affect moods of the wearer. Aromatherapy is the art and science of using naturally extracted aromatic plant essential oils to balance, calm, cure infections and promote the health of body, mind and soul [3-4]. Essential oils are extracted from varied parts of the plant *viz.* root, seed, trunk, leaf, fruit and flower. These oils are so potent and concentrated that they work on pressure points and rejuvenate and make the surroundings free from disease, bacteria, virus and fungus [5-6]. Vetiver is a grass native to India that is used both for its fragrant oil and as a traditional medicine since ancient times. Vetiver essential oil, also known as the *Khus* Oil or 'Oil of Tranquillity', is extracted from the aromatic roots of *Vetiveria zizanioides*. Its versatile antibacterial, antiviral, anti-inflammatory nature along with immune booster with hormonal, glandular, emotional, circulatory, calming effect, memory and alertness enhancer is well documented by many scientists [7-8].

Textile materials are treated with pleasant odour producing essential oils and aromatic compounds to impart aroma finish so that the wearer gets some valuable effects. Due to their highly volatile nature, these are ineffective to utilize for profitable applications in textile. But microencapsulation technology locks essential oils with fibre in a stable manner however lots of affecting factors need to be considered in order to obtain high performance microcapsules which can serve specific applications [9]. Microencapsulation is defined as a process in which tiny particles or droplets of the active ingredient(s) are surrounded by a coating or embedded in a homogeneous or heterogeneous matrix to give small capsules that may range from sub-microns to several millimeters in size with many useful properties [10].

As being the close friends of humans, textiles can make aromatherapy easy wherever they are needed. All fabrics take up oil and aroma differently and protein fibres are considered excellent media to transfer fragrance and to retain it for longer time. Wool is natural protein fibre and polymer system of wool fibre consists of salt linkage and hydrogen bonding. Hydrogen bonds are very weak bonds which are formed between the hydrogen and nitrogen atom that breaks by water or any other substance like aroma oil and enter into the fibre polymer system [11]. Wool is hygroscopic in nature and it has more amorphous areas. The scaly structure of wool makes it partially water repellent but once water or other substances such as oil and aroma penetrate the fibre surface it get absorbed quickly and has good retention for a longer time. Hence, the present study was planned in order to standardize the aroma treatment for preparation of aroma wool fabric.

MATERIAL AND METHODS

Materials

Pure griege woven wool fabric was purchased from market of Ludhiana city of Punjab, India. The fabric specifications were: 59 ends/inch (EPI), 49 picks/inch (PPI), 162 g/m^2 basis weight having 0.3 mm thickness. Vetiver essential oil was procured from Emmbros Overseas Lifestyle Pvt. Ltd., Haryana, India. Wall materials (gum acacia and gelatin), softener (silicon) and binder (βeta-cyclodextrin) were provided by chemical suppliers of Haryana, India. Other materials used in the study were acetic acid, formalin, sodium hydroxide and wetting agent (Ultravon JU).

Preparation of Fabric

The woven wool fabric was initially weighted and pre-wetted in plain water for 10-15 minutes. It was then entered into scouring bath containing required amount of neutral soap (2 g/l) keeping material to liquor ratio 1:20 and pH 7. The temperature of the bath was gradually raised to 60^{o}C and fabric was treated for 60 minutes with occasional stirring. The scoured fabric was then rinsed with water and dried at ambient temperature.

Preparation of Vetiver Oil Microcapsules

Complex coacervation technique of microencapsulation was used for preparing microcapsules. Experiments were conducted to optimize various variables of microcapsule gel formation i.e. ratios of essential oil:gum:gelatin, temperature and pH to obtain the desired results. The microencapsulation process was optimized on the basis of visual evaluation through inverted microscope on three parameters i.e. size of microcapsules, uniformity in size and distribution and walls of microcapsules. 16 g of gelatin was weighed and dissolved in 25 ml warm water and stirred using a high speed stirrer for 10 minutes. 4 g of vetiver oil was added to the solution at 45^{o}C. 16 g of gum acacia was weighed and dissolved in 25 ml warm water separately. The gum acacia solution was added to the gelatin solution and the temperature of the solution was maintained at 45^{o}C. The pH of the solution was decreased to 4.5 by adding dilute acetic acid and stirred at high speed for 20 minutes. The pH of the solution was increased to 8.5 using sodium hydroxide solution to form microcapsule gel. For stabilization, 1 ml of 17 percent alcoholic formalin was added to the formed capsules [12].

Standardization of Aroma Treatment for Wool Fabric

For aroma treatment of wool fabric, pad-dry-cure method was used. The padding bath components (microcapsule gel, softener and binder) and other variables i.e. material to liquor ratio, treatment temperature and time, drying temperature and time, curing temperature and time were optimized for application of microencapsulated essential oil on wool fabric.

Optimization of padding bath components

The padding bath was prepared using microcapsule gel, softener and binder. The concentration of padding bath components were optimized on the basis of presence of microcapsules on the fabric as examined under stereo zoom microscope.

i. Optimization of microcapsule gel concentration:

To determine optimum concentration of microcapsule gel, four padding bath of different concentrations of

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microcapsule gel i.e. 30, 40, 50 and 60 g/l were taken. For the application of essential oil by pad-dry-cure method, the wool fabric samples were immersed in the solutions of four different concentrations of microcapsule gel with 5 g/l binder and 1 g/l softener at MLR 1:20 maintaining a temperature of 35°C for 30 minutes with occasional stirring. After that fabric and solution were transferred to the trough of padding mangle and the fabric was passed between the squeezing rollers of the padding mangle at pneumatic pressure of 2 kg/cm^2 with two dips and nips having 80-90 percent wet pick-up. As the fabric left the padding mangle, it was dried at 80°C for 5 minutes and cured at 110°C for 1 minute [14-15]. The treated fabrics were examined under stereo zoom microscope and optimum concentration of microcapsule gel was selected on the basis of microscopic assessment for presence of microcapsules on fabric, wash durability of aroma treatment and improvement in properties i.e. bending length, flexural rigidity and crease recovery angle of aroma treated fabric.

ii. Optimization of softener concentration:

For determination of optimum concentration of softener, four different concentrations of softener i.e. 1, 2, 3 and 4 g/l were taken with optimized concentration of microcapsule gel while all other variables were kept constant. Padding, drying and curing was carried out and optimization of softener concentration was done as explained in section 2.4.1.i.

iii. Optimization of binder concentration:

Four different concentration of binder i.e. 5, 10, 15, and 20 g/l were taken to optimize the concentration of binder with optimized concentrations of microcapsule gel and softener keeping all other variables constant. Padding, drying and curing was carried out and optimized concentration of binder was selected as mentioned under section 2.4.1.i.

Optimization of material to liquor ratio:

For optimization of material to liquor ratio (MLR) of padding bath, four different material to liquor ratios i.e. 1:20, 1:30, 1:40 and 1:50 were taken using optimum concentrations of microcapsule gel, softener and binder while other variables were kept constant. On the basis of presence of microcapsules, wash durability and improvement in fabric properties in terms of bending length, flexural rigidity and crease recovery angle, M:L ratio was optimized for aroma treatment of wool fabric.

Optimization of treatment temperature:

The treatments were carried out at four different temperatures i.e. 25, 35, 45 and 55°C with optimized concentrations of microcapsule gel, softener and binder keeping optimized M:L ratio while other variables of pad-dry-cure method were kept constant. The padding, drying and curing of the fabric was carried out and the temperature giving best results was selected as optimum treatment temperature.

Optimization of treatment time:

The aroma treatment was given to wool fabric for four different time durations i.e. 20, 30, 40 and 50 minutes using optimized concentrations (microcapsule gel, softener and binder) and conditions (M:L ratio and treatment temperature). The fabrics were kept in the padding solution for given time duration and then passed through the rollers of padding mangle. The treated fabrics were dried subsequently at 80°C for 5 minutes and cured at 110°C for 1 minute time duration. The optimum treatment time was selected on the basis of presence of microcapsules, wash durability and improvement in properties of treated fabric i.e. bending length, flexural rigidity and crease recovery angle.

Optimization of drying temperature:

To determine optimum drying temperature, fabric samples were treated using optimum concentrations of padding bath components, M:L ratio, treatment temperature and treatment time. Then, the fabric was passed through the squeezing rollers of padding mangle at pneumatic pressure of 2 kg/cm^2. Drying of treated fabric samples was carried out at four different temperatures i.e. 60, 70, 80 and 90°C for 5 minutes and then subsequently cured at 110°C for 1 minute. Optimization of drying temperature was done as explained in section 2.4.1.i.

Optimization of drying time:

For optimizing drying time, samples were immersed in treatment bath consisting of optimized concentrations of microcapsule gel, softener and binder under the optimized conditions (M:L ratio, treatment temperature) for optimum time of treatment. The drying of treated samples was carried out for four different time durations i.e. 2, 3, 4 and 5 minutes at optimum drying temperature keeping curing temperature and time constant i.e. 110°C for 1 minute. The drying time exhibiting best results was selected as optimum drying time.

Optimization of curing temperature:

For the optimization of curing temperature, fabric samples were immersed in treatment bath consisting of optimized concentrations of microcapsule gel, softener and binder using optimized M:L ratio under

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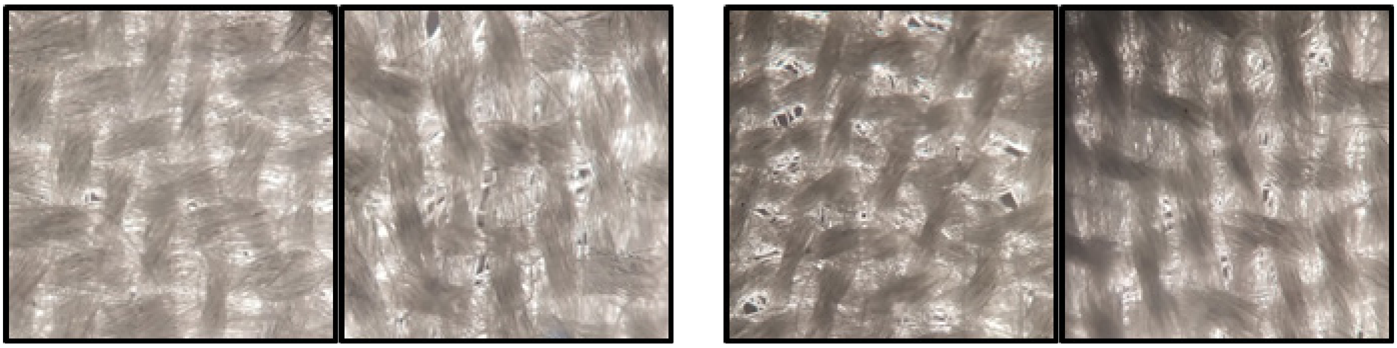
Table1: Optimization of microcapsule gel concentration

Concentration of microcapsules gel (g/l)	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycles)						Average bending length(cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
30	Few	√	√	×	×	×	×	3.37	16.53	111.00	IV
40	Average	√	√	√	×	×	×	3.27	15.79	113.16	III
50	Many	√	√	√	√	×	×	3.24	15.29	115.33	II
60	**Many**	√	√	√	√	×	×	**2.99**	**13.36**	**116.83**	**I**

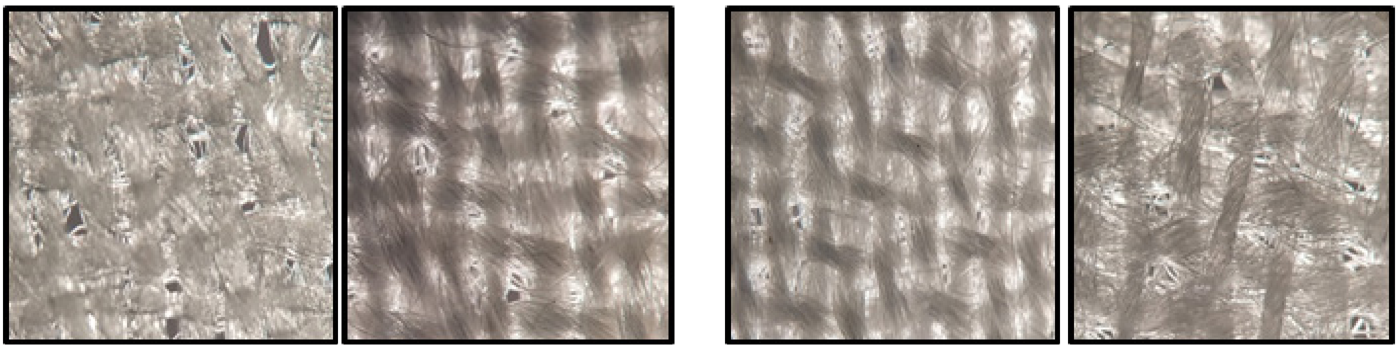


30 g/l (Rank- IV) 40 g/l (Rank- III) 50 g/l (Rank- II) 60 g/l (Rank- I)

Image 1: Stereo zoom microscopic images of treated fabric at different concentrations of microcapsule gel

Table2: Optimization of softener concentration

Concentration of softener (g/l)	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycles)						Average bending length(cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
01	Few	√	√	×	×	×	×	3.26	15.83	110.66	IV
02	**Many**	√	√	√	√	×	×	**2.97**	**13.19**	**114.83**	**I**
03	Many	√	√	√	√	×	×	3.20	14.75	112.49	II
04	Average	√	√	√	×	×	×	3.22	14.84	111.49	III



1.0 g/l (Rank- IV) 2.0 g/l (Rank- I) 3.0 g/l (Rank- II) 4.0 g/l (Rank- III)

Image 2: Stereo zoom microscopic images of treated fabric at different concentrations of softener

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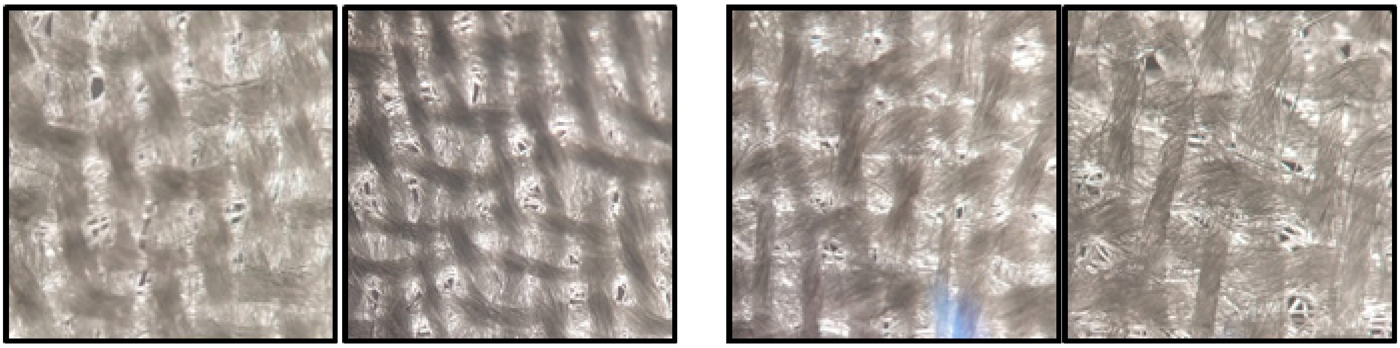
Table3: Optimization of binder concentration

Concentration of binder (g/l)	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycles)						Average bending length(cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
05	Average	√	√	√	×	×	×	3.09	13.77	112.66	II
10	**Too many**	√	√	√	√	√	×	**2.89**	**12.19**	**113.99**	**I**
15	Many	√	√	√	√	×	×	3.20	14.83	112.33	III
20	Many	√	√	√	√	×	×	3.28	15.64	111.33	IV

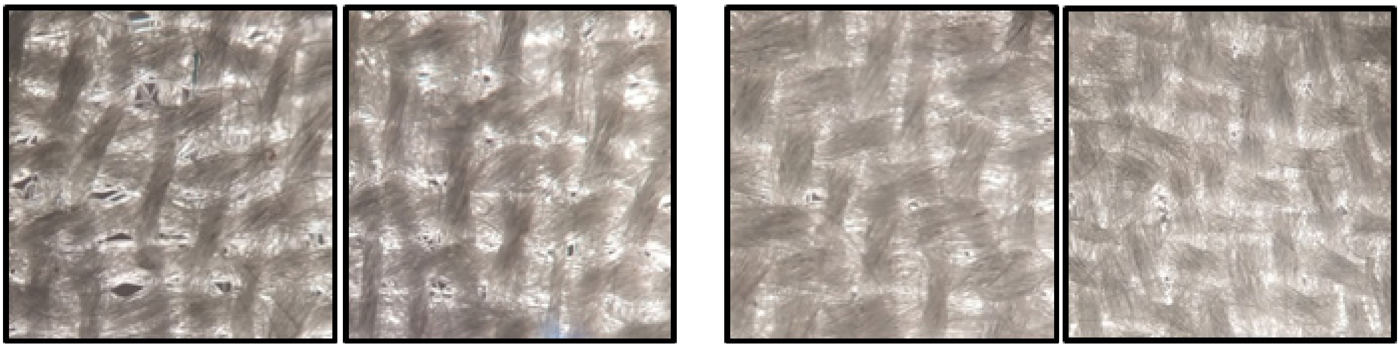


5 g/l (Rank- II) 10 g/l (Rank- I) 15 g/l (Rank- III) 20 g/l (Rank- IV)

Image 3: Stereo zoom microscopic images of treated fabric at different concentrations of binder

Table 4: Optimization of MLR of aroma treatment

MLR	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycles)						Average bending length(cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
1:20	**Too many**	√	√	√	√	√	×	**2.97**	**12.78**	**115.83**	**I**
1:30	Many	√	√	√	√	×	×	3.15	14.45	114.83	II
1:40	Few	√	√	√	×	×	×	3.18	14.52	112.49	III
1:50	Few	√	√	√	×	×	×	3.29	15.48	112.33	IV



1:20 (Rank- I) 1:30 (Rank- II) 1:40 (Rank- III) 1:50 (Rank- IV)

Image 4: Stereo zoom microscopic images of treated fabric at different MLR

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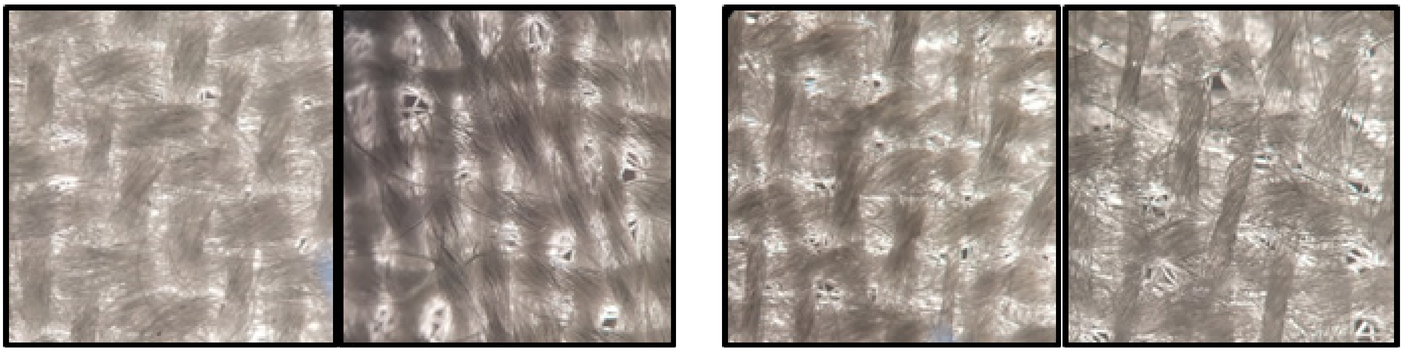
Table 5: Optimization of temperature of aroma treatment

Treatment temperature (0C)	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycles)						Average bending length(cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
25	Average	√	√	√	×	×	×	3.20	15.05	113.16	IV
35	**Too many**	√	√	√	√	√	×	**2.99**	**13.05**	**115.16**	**I**
45	Many	√	√	√	√	×	×	3.12	14.41	113.66	II
55	Few	√	√	×	×	×	×	3.20	15.02	112.66	III

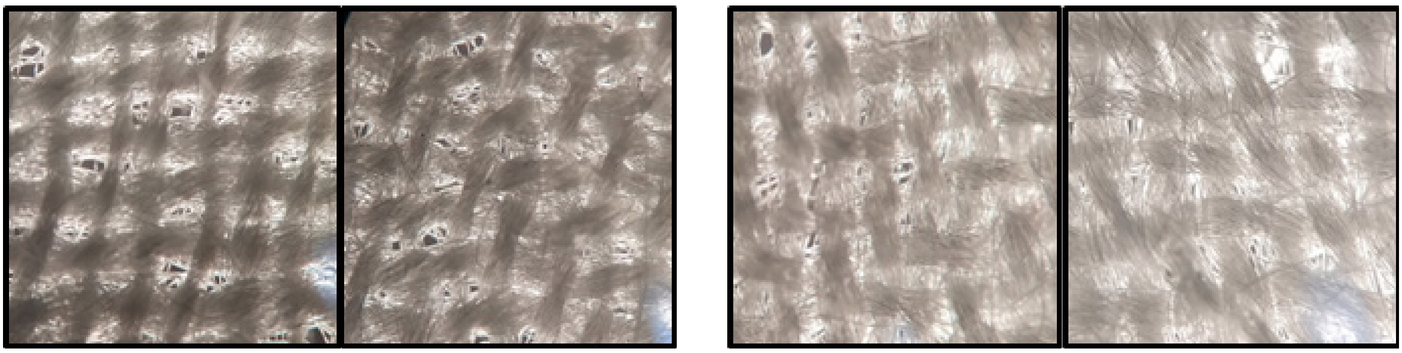


25°C (Rank- IV) 35°C (Rank- I) 45°C (Rank- II) 55°C (Rank- III)

Image 5: Stereo zoom microscopic images of treated fabric at different treatment temperatures

Table 6: Optimization of time of aroma treatment

Treatment time (minutes)	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycles)						Average bending length(cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
20	Too Many	√	√	√	√	√	√	3.10	13.80	113.83	II
30	**Too Many**	√	√	√	√	√	√	**3.01**	**12.96**	**115.00**	**I**
40	Average	√	√	√	√	×	×	3.15	14.08	113.66	III
50	Few	√	√	√	×	×	×	3.19	14.78	112.99	IV



20 min (Rank- II) 30 min (Rank- I) 40 min (Rank- III) 50 min (Rank- IV)

Image 6: Stereo zoom microscopic images of treated fabric at different treatment times

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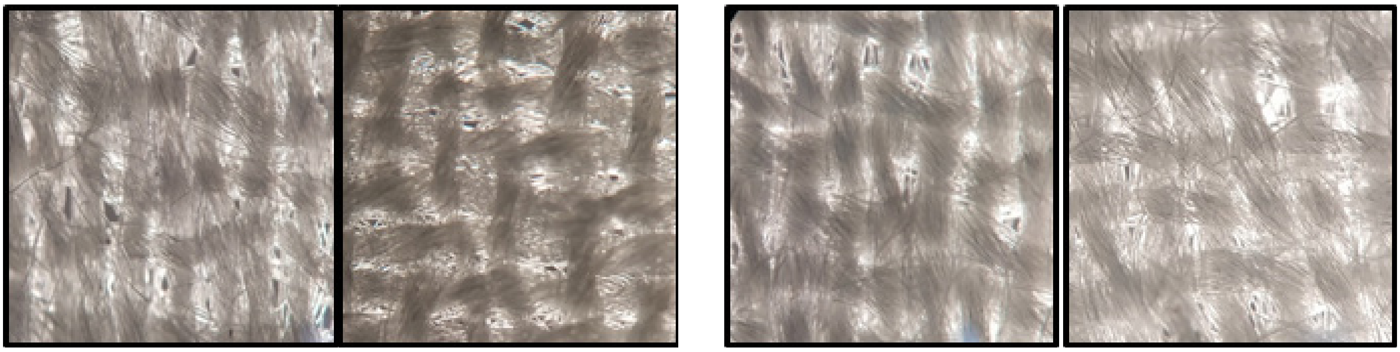
Table 7: Optimization of drying temperature for aroma treatment

Drying temperature (0C)	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycles)						Average bending length(cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
60	Many	√	√	√	√	√	×	3.24	15.06	112.49	III
70	**Too Many**	√	√	√	√	√	√	**3.07**	**13.65**	**114.99**	**I**
80	Many	√	√	√	√	√	×	3.22	14.51	113.83	II
90	Few	√	√	√	×	×	×	3.28	15.64	111.49	IV

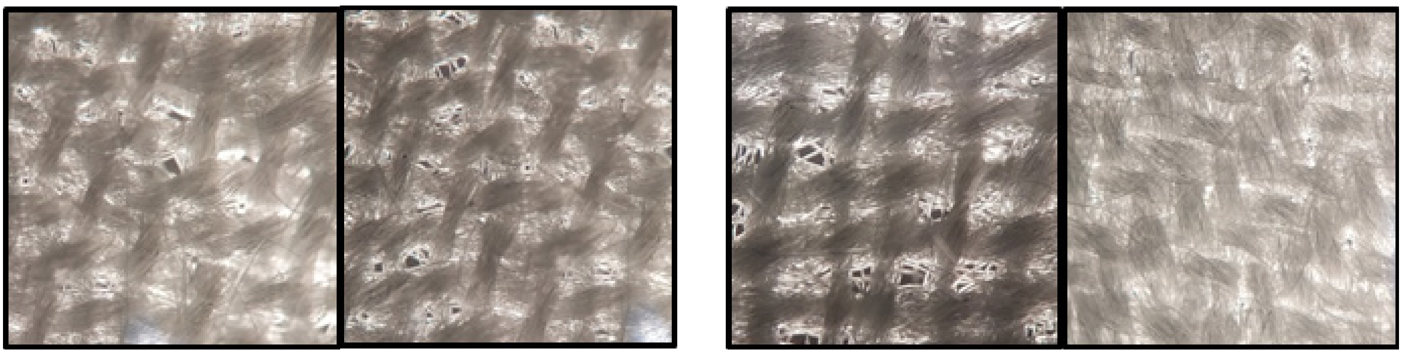


60°C (Rank- III) 70°C (Rank- I) 80°C (Rank- II) 90°C (Rank- IV)

Image 7: Stereo zoom microscopic images of treated fabric at different drying temperatures

Table 8: Optimization of drying time for aroma treatment

Drying time (minutes)	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycles)						Average bending length(cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
02	Many	√	√	√	√	√	×	3.16	14.35	112.99	III
03	Many	√	√	√	√	√	×	3.11	14.06	113.33	II
04	**Too many**	√	√	√	√	√	√	**3.01**	**12.97**	**114.16**	**I**
05	Average	√	√	√	×	×	×	3.29	15.57	111.50	IV



2 min (Rank- III) 3 min (Rank- II) 4 min (Rank- I) 5 min (Rank- IV)

Image 8: Stereo zoom microscopic images of treated fabric at different drying times

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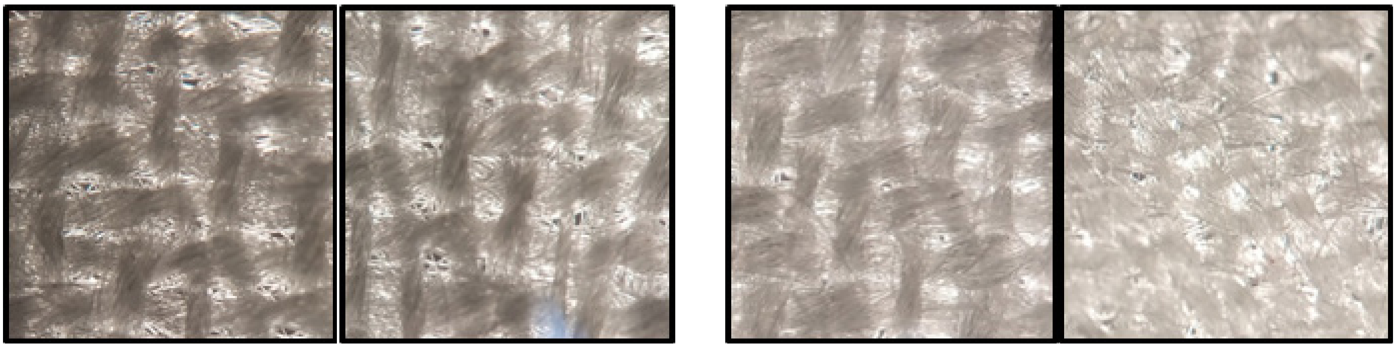
Table 9: Optimization of curing temperature for aroma treatment

Curing tempera-ture (oC)	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycles)						Average bending length(cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
100	**Too Many**	√	√	√	√	√	√	**3.15**	**14.24**	**114.33**	**I**
110	Many	√	√	√	√	√	×	3.27	15.50	112.49	II
120	Few	√	√	√	×	×	×	3.32	15.84	110.99	III
130	Very few	√	√	×	×	×	×	3.35	16.44	110.16	IV

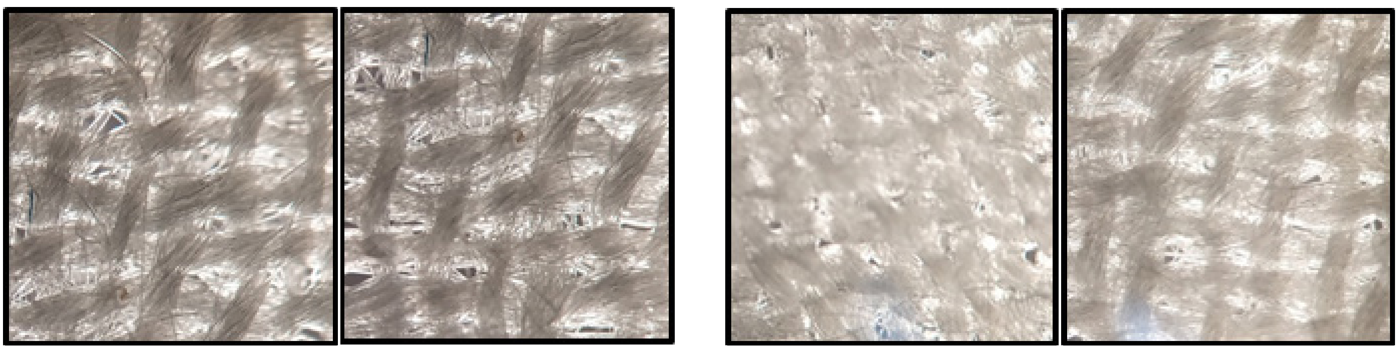


100°C (Rank- I) 110°C (Rank- II) 120°C (Rank- III) 130°C (Rank- IV)

Image 9: Stereo zoom microscopic images of treated fabric at different curing temperatures

Table 10: Optimization of curing time for aroma treatment

Curing time (seconds)	Parameters										Ranks
	Presence of microcapsules on fabric	Wash durability (Wash cycles)						Average bending length(cm)	Flexural rigidity (mg-cm)	Average crease recovery (Degree)	
		5	10	15	20	25	30				
30	Too many	√	√	√	√	√	√	3.19	14.60	113.49	II
60	**Too many**	√	√	√	√	√	√	**3.02**	**13.10**	**114.33**	**I**
90	Few	√	√	√	√	×	×	3.33	15.92	112.83	III
120	Very few	√	√	√	×	×	×	3.34	16.06	111.16	IV



30 sec (Rank- II) 60 sec (Rank- I) 90 sec (Rank- III) 120 sec (Rank- IV)

Image 10: Stereo zoom microscopic images of treated fabric at different curing times

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optimized conditions (treatment temperature and time). The impregnated fabric samples were passed between the rollers of padding mangle. Drying of treated samples was carried out at optimum drying temperature and time and curing treatment was carried out at four different temperature ranges i.e. 100, 110, 120 and 130°C keeping curing time constant i.e. 1 minute. On the basis of presence of microcapsules, wash durability and improved properties of aroma treated fabric in terms of bending length, flexural rigidity and crease recovery angle, curing temperature was optimized.

Optimization of curing time:

Fabric samples were treated using the optimized concentrations of padding bath components under the optimized conditions of M:L ratio, treatment temperature and time. After application of aroma treatment, the padded samples were dried at optimum temperature and time and cured at optimum temperature for four different durations of curing time i.e. 30, 60, 90 and 120 seconds. Optimization of curing time was done as mentioned under section 2.4.1.i.

RESULTS AND DISCUSSION

Optimization of Padding Bath Components

Padding bath for aroma treatment of wool fabric was prepared using microcapsule gel of vetiver essential oil, softener and binder. The concentrations of padding bath components i.e. microcapsule gel, softener and binder were optimized on the basis of presence of microcapsules on the treated wool fabric, wash durability, improvement in softness and crease recovery of the treated wool fabric.

i. Optimization of microcapsule gel concentration:

It is obvious from the Table 1 and microscopic evaluation (Image 1) of the vetiver essential oil treated wool fabric that 50 and 60 g/l concentrations of microcapsule gel showed presence of many microcapsules on the fabric surface with wash durability of aroma treatment lasted till 20 wash cycles. It was found that 60 g/l concentration of microcapsule gel exhibited improvement in softness as indicated by decreased average bending length (2.99 cm) and flexural rigidity (13.36 mg-cm). Also increased crease recovery angle, 116.83° was recorded as compared to 50 g/l concentration which had increased average bending length (3.24 cm), flexural rigidity (15.29 mg-cm) and decreased crease recovery angle (115.33°). At 30 and 40 g/l concentrations of microcapsule gel, few to average number of microcapsules were present on the treated fabric with poor wash durability. It was further observed that with higher concentration of microcapsule gel more number of microcapsules were deposited on the wool fabric with good wash durability whereas with lower concentration of microcapsule gel presence of less number of microcapsules with poor wash durability were observed.

Thus, the 60 g/l concentration of microcapsule gel was selected as optimum concentration for further experimental work as it showed presence of too many microcapsules with good wash durability and improved properties of treated wool fabric. Similar research outcomes have been noted by [16-18] that with lower concentration of microcapsule gel less number of microcapsules were attached on the fabric surface and wash durability also decreased.

ii. Optimization of softener concentration:

The data in the Table 2 and microscopic assessment of the aroma treated fabric indicate that when 2 and 3 g/l concentrations of softener were used, many microcapsules were present on surface of the fabric and their wash durability lasted till 20 wash cycles. At 3 g/l concentration of softener, bending length (3.20 cm) and flexural rigidity (14.75 mg-cm) were observed more and degree of crease recovery angle was less (112.49°) as analyzed and compared with 2 g/l concentration of softener which had decreased bending length (2.97 cm) and flexural rigidity (13.19 mg-cm) and increased crease recovery angle (114.83°) (Image 2). At 1 and 4 g/l concentrations of softener, presence of few to average number of microcapsules was seen on the fabric surface with low aroma retention to washing.

It is obvious from the table that more number of microcapsules were present at 2 g/l concentration of softener with good wash durability, improvement in softness and good resistance to creasing. Therefore, 2 g/l concentration of softener was chosen as the optimum concentration in the padding bath to obtain soft aroma treated wool fabric. [19-20] also suggested that some amount of silicon softener must be added to padding bath when aroma treatment to fabric was given using microencapsulated essential oils to control the stiffness.

iii. Optimization of binder concentration:

The data presented in Table 3 and microscopic analysis (Image 3) of aroma treated wool fabric reveal that 10 g/l concentration of binder displayed presence of too many microcapsules on the fabric surface and wash durability lasted till 25 wash cycles. It was found that 10 g/l concentration showed improvement in fabric properties as indicated by decreased average bending length (2.89 cm) and flexural rigidity (12.19 mg-cm). Also increase in crease recovery angle (113.99^0) was noted as compared to other concentrations of binder i.e. 5, 15 and 20 g/l.

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It was further observed that with increase in binder concentration, more number of microcapsules were present on the surface of fabric and that was also responsible for the stiffness of the fabric. It might be due to deposition of more number of microcapsules on the surface of the fabric which led to increased stiffness of fabric, therefore higher concentration of binder was not used. Therefore, on the basis of presence of too many microcapsules on the fabric, good aroma retention to washing and improved fabric properties i.e. bending length, flexural rigidity and crease recovery angle, 10 g/l binder concentration was selected and used for carrying out further research work. These findings are in consistent with [21-22] that the role of binder is to fix the capsules onto the fabric and to hold them in place during wear and washing as it can be chemically bonded to or permanently fixed to fabrics.

Optimization of material to liquor ratio:

It is evident from the Table 4 and microscopic visualization of treated wool fabric that too many microcapsules were observed on the fabric surface at MLR 1:20 and wash durability lasted till 25 wash cycles with 2.97 cm average bending length, 12.78 mg-cm flexural rigidity and 115.83^{o} crease recovery angle (Image 4). With further increase of MLR in the padding bath i.e. 1:30, 1:40, 1:50 decrease in the presence of number of microcapsules on the fabric surface, wash durability and crease recovery angle were noticed whereas bending length and flexural rigidity were found to be increased. It might be due to the reason that the fabric when dipped in the padding bath with higher MLR, it could not absorb all the contents hence a lower MLR gave better results.

It is apparent from the table that higher number of microcapsules, good wash durability, improved softness and good resistance to creasing was found at MLR 1:20, hence this was taken as optimum M:L ratio for application of aroma treatment on wool fabric. The results of the present study are in agreement with [23-24] that the maximum number of microcapsules were present on the fabric at MLR 1:20 with good wash durability and with increase in MLR, deposition of number of microcapsules and wash durability decreased.

Optimization of treatment temperature:

The data shown in the Table 5 and microscopic evaluation (Image 5) of aroma treated wool fabric indicate that at 35 and 45^{o}C treatment temperatures, many to too many microcapsules were present on the fabric, wash durability lasted till 25 to 20 wash cycles with increased average bending length from 2.99 to 3.12 cm, flexural rigidity from 13.05 to 14.41 mg-cm and decreased crease recovery angle115.16 to 113.66^{o}. Treatment temperatures 25 and 55^{o}C showed presence of average to little number of microcapsules with low wash durability, increased average bending length, flexural rigidity and decreased crease recovery angle. Further it was observed that microcapsules were not be able to withstand both lower and higher temperature and got ruptured.

Thus, on the basis of presence of microcapsules, wash durability and improvement in fabric properties, 35^{o}C temperature was chosen as optimum temperature for aroma treatment of wool fabric with microencapsulated vetiver essential oil. The results are in line with the findings [13] that increase in treatment temperature allowed more microcapsules to be deposited on the fabric surface but when temperature raised above 60^{0} C, the effect was not significantly noticeable. Therefore temperature should be kept lower otherwise active product could be damaged.

Optimization of treatment time:

It is apparent from the Table 6 and microscopic assessment (Image 6) of treated fabrics that at 20 and 30 minutes treatment duration, too many microcapsules were present and wash durability lasted till 30 wash cycles. But at 30 minutes treatment time, average bending length (3.01 cm) and flexural rigidity (12.96 mg-cm) of the treated fabric was less and crease recovery angle (115.00^{o}) was more as compared with the fabric treated for 20 minutes treatment time having 3.10 cm average bending length and 13.80 mg-cm flexural rigidity with 113.83^{o} crease recovery angle. It was further observed that when the treatment time was increased to 40 and 50 minutes, only little number of microcapsules was seen on the fabric with low wash durability i.e. up to 15 and 20 wash cycles, respectively. It might be due to the reason that the saturation point for absorption of essential oil microcapsules was 30 minutes. After that no further absorption of microcapsules took place and the microcapsules started diffusing into the treatment bath.

Hence, for carrying out further padding process, 30 minutes treatment time was optimized as it displayed presence of more number of microcapsules with good aroma retention to washing and improved fabric properties in terms of softness and resistance to creasing. The results of the study are in agreement with [24-25].

Optimization of drying temperature:

It can be inferred from Table 7 and microscopic analysis (Image 7) of aroma treated fabric that drying temperature 70^{o}C exhibited presence of too many microcapsules on the surface of the fabric with wash

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durability that lasted till 30 wash cycles having 3.07 cm average bending length and 13.65 mg-cm flexural rigidity with 114.99° crease recovery angle. At 60 and 80°C temperatures, many microcapsules were seen on the fabric and wash durability lasting upto 25 wash cycles. At 80°C temperature, 3.22 cm average bending length, 14.51 mg-cm flexural rigidity and 113.83° crease recovery angle was noticed whereas 3.24 cm average bending length, 15.06 mg-cm flexural rigidity with 112.49° crease recovery angle were observed at 60°C drying temperature. However, at 90°C drying temperature, only few microcapsules were observed with decreased wash durability (upto15 wash cycles) and crease recovery angle (111.49°) and increased average bending length (3.28 cm) and flexural rigidity (15.64 mg-cm). It was also noticed that drying at higher temperature for longer duration might cause rupturing of microcapsules and yellowing of fabrics and led to increase in bending length and flexural rigidity and decrease in crease recovery.

It is deduced from data in the table that higher number of microcapsules, good wash durability, improved softness and good resistance to creasing was found at 70°C drying temperature. So, this temperature was selected as optimum drying temperature for aroma treatment of wool fabric. The results of the study were in corroboration with [22][13].

Optimization of drying time:

It is clear from the Table 8 and through visualization of vetiver oil treated fabric samples under stereo zoom microscope that many microcapsules were present with wash durability lasting till 25 wash cycles at 2 and 3 minutes drying time having 3.16 and 3.11 cm average bending length, 14.35 and 14.06 mg-cm flexural rigidity and 112.99 and 113.33° crease recovery angle, respectively. At 4 minutes drying time, too many microcapsules were seen on the fabric surface with 3.01 cm average bending length, 12.97 mg-cm flexural rigidity and 114.16° crease recovery angle having wash durability lasting upto 30 washes (Image 8). Whereas, at 5 minutes drying time, average number of microcapsules were found present on the fabric with wash durability lasting till 15 wash cycles having increased average bending length (3.29 cm) and flexural rigidity (15.57 mg-cm) and decreased crease recovery angle (111.50°).

It is thus concluded that at 4 minutes drying time soft fabric was obtained with more number of microcapsules as compared to other time durations. Therefore, 4 minutes was taken as optimum time for drying of aroma treated fabric. [23] also noticed that higher drying temperature for longer duration cause rupturing of microcapsules and yellowing of fabrics.

Optimization of curing temperature:

The data in the Table 9 and microscopic images of aroma treated wool fabrics indicate that with increase in curing temperature, too many to very few microcapsules were seen on the surface of the fabric with decreased wash durability and crease recovery angle whereas average bending length and flexural rigidity increased. At 100°C curing temperature, too many microcapsules were observed with good wash durability lasting till 30 wash cycles. It was found that 100°C temperature displayed improved softness and resistance to creasing as indicated by decreased average bending length (3.15 cm) and flexural rigidity (14.24 mg-cm) and increased crease recovery angle (114.33°) in comparison to other curing temperatures i.e. 110, 120 and 130°C where increased average bending length (3.27, 3.32 and 3.35 cm), flexural rigidity (15.50, 15.84 and 16.44 mg-cm) with decreased crease recovery angle (112.49, 110.99 and 110.16°) of aroma treated wool fabrics were noticed (Image 9).

Hence, 100°C was chosen as optimum temperature for curing of vetiver essential oil treated fabric as better results in terms of enhanced fabric properties with higher number of durable aroma capsules were obtained at this curing temperature.

Optimization of curing time:

The perusal of the Table 10 and indicates that microencapsulated vetiver essential oil treated fabrics had average bending length of 3.19, 3.02, 3.33 and 3.34 cm, flexural rigidity of 14.60, 13.10, 15.92 and 16.06 mg-cm and crease recovery angle of 113.49, 114.33, 112.83, 111.16 degree when cured for 30, 60, 90 and 120 seconds, respectively. It is further deduced from the table and microscopic visualization (Image 10) of the microcapsules that too many microcapsules were present on the fabric at curing times 30 and 60 seconds having wash durability lasting upto 30 wash cycles whereas at curing times 90 and 120 seconds few to very few microcapsules were observed with wash durability that lasted till 15 to 20 wash cycles. With the increase in curing temperature and time, number of microcapsules present on fabric and wash durability decreased and the walls of formed microcapsules also started rupturing.

Thus, upon comparison of results of different curing times on different parameters i.e. of microscopic evaluation of the treated fabrics for presence of microcapsules, wash durability, bending length, flexural rigidity and crease recovery angle, 60 seconds time was optimized for curing of aroma treated wool fabric. Similar results were noticed by [7][9][23].

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CONCLUSION

Optimized variables for aroma treatment were 60 g/l microcapsule gel, 2 g/l softener and 10 g/l binder concentration, 1:20 material to liquor ratio, 35°C temperature and 30 minutes treatment time as at these conditions too many microcapsules were present on the fabric surface having good wash durability, decreased bending length and flexural rigidity with increased crease recovery angle. Aroma treated wool fabric when dried at 70°C temperature for 4 minutes and cured at 100°C temperature for 60 seconds exhibited more number of microcapsules, longer wash durability and better fabric properties, hence optimized for drying and curing of microencapsulated vetiver essential oil padded fabric. Thus, these optimized variables can be effectively used for application of microencapsulated vetiver oil through pad-dry-cure method on wool fabric for the development of fragrant textiles for its wider application as per end use.

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