STUDIES ON SUSTAINABLE PRETREATMENT IN COTTON TEXTILE WET PROCESSING

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INDIAN INSTITUTE OF TECHNOLOGY DELHI
DECEMBER 2023

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by

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Submitted

In fulfilment of requirements for the awards of the degree of Doctor of Philosophy to the

Indian Institute of Technology Delhi
December 2023

Dedicated Gratefully

To

My Late Parents,

My Gurus,

My wife, Both Daughters (Rajshree & Roopshree),

&

Friends

Certificate

This is to certify that the thesis entitled **"Studies on Sustainable Pretreatment in Cotton Textile Wet Processing"** submitted by **Mr. Sanjay Kumar Bhikari Charan Panda** to the **Indian Institute of Technology Delhi** for the award of the degree of **Doctor of Philosophy** in the **Department of Textile and Fibre Engineering,** is a record of bonafide research work carried out by him. **Mr. Sanjay Kumar Bhikari Charan Panda** has worked under our guidance and supervision.

The results contained in this thesis are original and have not been submitted, in partial or complete, to any other university or institute for the award of any degree or diploma.

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Acknowledgements

The research work presented in the current thesis would be impossible without the support of numerous individuals. I take this prospect to recognise them and extend my genuine appreciation for assisting me in crafting this PhD thesis a likelihood.

Firstly, I sincerely thank Prof. Samrat Mukhopadhyay and Prof. Kushal Sen for their valuable time, insights, and unconditional and unceasing support. I am indebted to their contribution as supervisors and will always behold them in high regard. I thank them for introducing me to this exciting field of “studies on sustainable pretreatment in cotton textile wet processing”. Apart from technical inputs, they have taught me life lessons and bestowed me with their kindness in difficult times, enabling me to climb the hill and overcome the bumps to reach the current PhD stage.

I want to express profound appreciation towards Prof. Deepti Gupta, Prof. Abhijit Mazumdar, and Prof. A. Ramanan for being on the research review committee and providing an appropriate recommendation duration for research.

I am indebted to Mr. S.K. Ojha (Vardhman Industries) for assisting fabric and industrial-grade chemicals from his renowned working organization. I would also like to thank Mr. Satish Kadam for helping in the follow-up for the above materials.

I sincerely appreciate the knowledge and skills of Mr. Dharmendra Bhadoi in fabricating the UV-C processing chamber.

I want to thank all the lab assistants, IIT Delhi, Mr. Veerender Sharma, Mr. Sandeep Kaswan, Mr. Surender Kumar, Mr. Bhabagrahi Bishwal, Mr. Shiv Upadhyay, Mr. Rohit Kumar, Mr. Rajinder Khattar, Mr. Vikas, Mr. Mahafuj Ali, Mr. Manoranjan Kundu, Mr. Manjeet Singh, and Mr. Rajkumar Tejania for their support in accessing the lab facilities.

I acknowledge my fellow lab mates Chandra Jeet, Ankur, Sujan, Rahul, Nagender, Indrajeet, Prasun, Ankit, Manisha, Preeti, Mayuri, and Shashi for our shared time, having stirred technical deliberations and toiling hard until the wee hours to accomplish the research objectives. Apart from the lab mates, I am grateful to all in IIT Delhi for being benevolent friends. I sincerely appreciate their appropriate help and treasure the goodwill shown by them.

With the heavenly blessings of my late parents, the intangible love conferred upon me by my wife, the patience shown, the sacrifices made, and moral support by my both daughters made it possible and will stimulate further life progress.

I gratefully acknowledge the financial support the Department of Textile and Fibre Engineering provides through the Institute assistantship at IIT Delhi.

SANJAY KUMAR BHIKARI CHARAN PANDA

Abstract

The textile sector stands out as one of the largest consumers of water. Its significant usage of natural resources, energy, and water - particularly in wet processing - has deleterious effects on the environment. Desizing, scouring, bleaching, and mercerising are the essential processes in textile pretreatment that consume vast amounts of water and energy. This investigation delves into the viability of pretreating cotton grey fabrics utilising ultraviolet-C (UV-C) radiation to mitigate the industry's ecological footprint. A UV-C processing chamber is designed to control exposing energy and temperature on the fabric. Firstly, a sustainable process has been developed using UV-C for PVA-based textile desizing. Bleached cotton fabric is padded with industrial-grade PVA solution and dried to obtain a nominal add-on of 10%. With the help of UV-C irradiation, the cotton fabric desizing is accomplished at a lower temperature to save approximately 67% water, 68% time, and 83% energy compared to the conventional process without compromising the quality. The treated fabric has been characterised by FTIR and WAXD and shows no significant change in the structure of the cotton. Life cycle analysis confirms that the new technique is sustainable. Secondly, a UV-C-assisted desizing method of starch-sized cotton fabric has been developed to lower the utility consumption in desizing. The UV-C exposure time is optimised concerning the desizing efficiency. The UV-C exposed-sized fabric is washed at different times and temperatures to optimise the process. The alkali consumption in washing is reduced by 75%, and desizing efficiency improved to 95%. Applying oxidising agents like $NaNO_2$, $K_2S_2O_8$, and $NaBO_3.4H_2O$ during sizing further reduces the washing temperature and washing time of desizing with 100% desizing efficiency. The novel desizing process has the potential to save approximately 60% water, 90% energy, and more than 70% of time. Life cycle analysis has also been done. The photocatalytic desizing processes can reduce the impact on human health by more than 86% and approximately

69% on mineral resources scarcity than the conventional technique. Thirdly, a novel photocatalytic technique reduces the time, water, and energy consumption in a combined desizing and scouring process. The grey cotton fabric is padded with an oxidising agent and exposed under UV-C, followed by a low-temperature washing. Then, the pretreated fabric is dyed with reactive dyes, and the dyeability is compared with the conventional process. The UV-C process reduces process time by 80% of the conventional process. The fabric dyeability is also found to be superior to the conventional process. UV-C processes save about 71% water and 72% energy compared to conventional methods. Life cycle analysis also confirms the UV-C-assisted process is more sustainable than the conventional process. Finally, an efficient ultraviolet-C-assisted single-step process has been developed, combining desizing, scouring, and bleaching. The grey cotton fabric is padded with a bleaching solution and exposed under Ultraviolet-C followed by a low-temperature washing. The process parameters like exposure time under Ultraviolet-C, the concentration of hydrogen peroxide, the pH of the bleaching solution, and the temperature and duration of washing are optimised. The pretreated fabric is characterised by absorbency time, whiteness, strength, FTIR, WAXD, and SEM. The analysis of fabric structure using Fourier transform infrared spectroscopy and Wide-angle X-ray diffraction indicates no significant alterations in the parent structure of the fabric. The combined process saves 73% water, 75% time, and 76% energy from the conventional technique without compromising the quality of the fabric. The dyeability test reveals that the combined pretreatment has a 42% higher dye uptake than the conventionally pretreated fabric. The life cycle analysis of the innovative one-step combined pretreatment reveals that it potentially reduces over 60% of the environmental impacts associated with conventional processes, thereby promoting sustainability. Furthermore, since minimal modifications to existing setups are necessary, implementing this process within the textile industry is highly feasible.

सार

वस्त्र उद्योग पानी के सबसे बड़े उपभोक्ताओं में से एक है। प्राकृतिक संसाधनों, ऊर्जा और पानी के महत्वपूर्ण उपयोग का (विशेष रूप से गीले प्रौद्योगिकी में) पर्यावरण पर हानिकारक प्रभाव पड़ता है। वस्त्र की गीले प्रौद्योगिकी का पूर्व उपचार में डिसाइजिंग, स्कोअरिंग, ब्लीचिंग और मर्सराइजिंग आवश्यक प्रक्रियाएं हैं जो भारी मात्रा में पानी और ऊर्जा की खपत करती हैं। यह जांच उद्योग के पारिस्थितिक पदचिह्न को कम करने के लिए पराबैंगनी-सी विकिरण का उपयोग करके अनुपचारित सूती कपड़ों का पूर्व-उपचार करने की व्यवहार्यता की जांच करती है। एक पराबैंगनी-सी प्रसंस्करण कक्ष को कपड़े पर विकिरण होने वाली ऊर्जा और तापमान पर नियंत्रण के साथ डिज़ाइन किया गया है। सबसे पहले, पीवीए-आधारित कपड़ा डिसाइजिंग के लिए पराबैंगनी-सी का उपयोग करके एक टिकाऊ प्रक्रिया विकसित की गई है। प्रक्षालित सूती कपड़े को औद्योगिक-ग्रेड पीवीए-घोल के साथ लपेटा जाता है और १०% का अंकित अतिरिक्त भार प्राप्त करने के लिए सुखाया जाता है। पराबैंगनी-सी विकिरण की मदद से, गुणवत्ता से समझौता किए बिना पारंपरिक प्रक्रिया की तुलना में लगभग ६७% पानी, ६८% समय और ८३% ऊर्जा बचाने के लिए कम तापमान पर सूती कपड़े का डिसाइजिंग पूरा किया जाता है। उपचारित कपड़े की एफटीआईआर और एक्सआरडी सहायता से लक्षण वर्णन की अवधि में यह दिखाता है की कपास संरचना में कोई महत्वपूर्ण परिवर्तन नहीं है। जीवन चक्र विश्लेषण पुष्टि करता है कि नई तकनीक टिकाऊ है। दूसरे, कपड़ा पूर्व-उपचार में उपयोगिता खपत को कम करने के लिए स्टार्च-आधारित सूती कपड़े की एक पराबैंगनी-सी-सहायता प्राप्त डिसाइज़िंग विधि विकसित की गई है। डिसाइजिंग दक्षता के संबंध में पराबैंगनी-सी विकिरण समय को अनुकूलित किया गया है। डिसाइज़िंग प्रक्रिया को अनुकूलित करने के लिए पराबैंगनी-सी उजागर स्टार्च-आधारित कपड़े को अलग-अलग समय और तापमान पर धोया जाता है। धुलाई में क्षार की खपत ७५% कम हो जाती है, और डिसाइज़िंग दक्षता में ९५% तक सुधार होता है। साइज़िंग के दौरान सोडियम नाइट्राइट, पोटेशियम परसल्फेट, और सोडियम पेरबोरेट ट्ट्राहाइड्रेट जैसे ऑक्सीकरण-रसायन को लगाने से १००% डिसाइज़िंग की दक्षता के साथ धोने का तापमान और समय कम हो जाता है। यह नवीन डिसाइज़िंग प्रक्रिया में लगभग ६०% पानी, ९०% ऊर्जा और ७०% से अधिक समय बचाने की क्षमता है। जीवन चक्र का विश्लेषण भी किया गया है। पारंपरिक तकनीक की तुलना में फोटोकैटलिटिक डिसाइजिंग प्रक्रियाएं मानव स्वास्थ्य पर प्रभाव को ८६% से अधिक और खनिज

संसाधनों की कमी पर लगभग ६९% तक कम करती हैं। तीसरा, एक नवीन फोटोकैटलिटिक तकनीक का उपयोग करते हुए संयुक्त डिजाइनिंग और स्कोअरिंग प्रक्रिया में समय,पानी और ऊर्जा की खपत को कम करती है। अनुपचारित सूती कपड़े को ऑक्सीकरण-रसायन के साथ लपेटा जाता है और पराबैंगनी-सी से विकिरणित किया जाता है, जिसके बाद कम तापमान पर धोया जाता है। फिर, पहले से उपचारित कपड़े को प्रतिक्रियाशील रंगों से रंगा जाता है, और रंगाई क्षमता की तुलना पारंपरिक प्रक्रिया से की जाती है। पराबैंगनी-सी के प्रक्रिया पारंपरिक प्रक्रिया की तुलना में समय को ८०% तक कम करती है। कपड़े की रंगाई क्षमता भी पारंपरिक प्रक्रिया से बेहतर पाई गई है। पराबैंगनी-सी प्रक्रियाएं पारंपरिक तरीकों की तुलना में लगभग ७१% पानी और ७२% ऊर्जा बचाती हैं। जीवन चक्र विश्लेषण यह भी पुष्टि करता है कि पराबैंगनी-सी-सहायता वाली प्रक्रिया पारंपरिक प्रक्रिया की तुलना में अधिक टिकाऊ है। अंत में, एक कुशल पराबैंगनी-सी-सहायता वाली एक-चरणीय प्रक्रिया विकसित की गई है, जिसमें डिसाइज़िंग, स्कोअरिंग और ब्लीचिंग का संयोजन किया गया है। अनुपचारित सूती कपड़े को ब्लीचिंग घोल से लपेटा जाता है और पराबैंगनी-सी के से विकिरणित किया जाता है , जिसके बाद कम तापमान पर धोया जाता है। पराबैंगनी-सी के विकिरणित समय, हाइड्रोजन पेरोक्साइड की सघनता, ब्लीचिंग घोल का पीएच, और तापमान और धोने की समय जैसे प्राचल अनुकूलित किए गए हैं। उपचारित कपड़े का परीक्षण अवशोषण समय, सफेदी, मजबूती, एफटीआईआर, एक्सआरडी और एसईएम के सहायता से किया गया है। फूरियर ट्रांसफॉर्म इंफ्रारेड स्पेक्ट्रोस्कोपी और वाइड-एंगल एक्स-रे विवर्तन का उपयोग करके कपड़े की संरचना का विश्लेषण दर्शाता है, कपड़े की मूल संरचना में कोई महत्वपूर्ण परिवर्तन नहीं है। यह संयुक्त प्रक्रिया से कपड़े की गुणवत्ता से समझौता किए बिना पारंपरिक तकनीक से ७३% पानी, ७५% समय और ७६% ऊर्जा की बचत होती है। रंगाई योग्यता परीक्षण से पता चलता है कि संयुक्त पूर्व-उपचार में पारंपरिक रूप से पूर्व-उपचारित कपड़े की तुलना में ४२% अधिक रंग ग्रहण होता है। नवोन्मेषी एक-चरणीय संयुक्त पूर्व-उपचार प्रक्रिया के जीवन चक्र विश्लेषण से पता चलता है कि यह संभावित रूप से पारंपरिक प्रक्रियाओं से जुड़े ६०% से अधिक पर्यावरणीय प्रभावों को कम करता है, जिससे वहनीयता को बढ़ावा मिलता है। इसके अलावा, कपड़ा उद्योग के भीतर इस प्रक्रिया को लागू करना अत्यधिक संभव है,क्योंकि मौजूदा उद्योग में इस विधि के अनुप्रयोग के लिए न्यूनतम संशोधन की आवश्यक है।

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Abbreviation and Symbols

kg	Kilogram
g	Gram
mg	Milligram
L	Litre
ml	Millilitre
dL	Decilitre
m	Metre
cm	Centimetre
mm	Millimetre
µm	Micrometre
nm	Nanometre
ft	Feet
h	Hour
min	Minute
s	Second
%	Percentage
L d^{-1}	Litre per day
L m^{-1}	Litre per minute
L h^{-1}	Litre per hour
m^{3} d^{-1}	Cubic metre per day
G h^{-1}	Gram per hour
€ m^{-3}	Euro per cubic metre
mmol L^{-1}	Milli mol per litre
g L^{-1}	Gram per litre
ml L^{-1}	Millilitre per litre
g dL^{-1}	Gram per deciliter
dL g^{-1}	Decilitre per gram
W	Watt
kW	Kilowatt
kWh	Kilowatt hour
mJ kg^{-1}	Millijoule per kilogram
kJ kg^{-1}K^{-1}	Kilojoule per kilogram per kelvin
mWcm^{-2}	Milliwatt per square centimetre
°C	Degree Celsius
rpm	Revolutions per minute
m min^{-1}	Metre per minute
g cm^{-2}	Gram per square centimetre

w/v	Weight by volume
kcal mol^{-1}	Kilocalorie per mole
N	Neuton
R.H.	Relative humidity
EPI	Ends per inch
PPI	Picks per inch
UV	Ultraviolet
LCA	Life cycle analysis
EU	European union
PVA	Polyvinyl alcohol
FPMF	Fine particulate matter formation -
FRS	Fossil resource scarcity
FECT	Freshwater ecotoxicity
FETP	Freshwater eutrophication
GWFW	Global warming, Freshwater
GWHH	Global warming, Human health
GWTE	Global warming, Terrestrial
HCT	Human carcinogenic toxicity
HNCT	Human non-carcinogenic toxicity
IR	Ionising radiation
LU	Land use
MECT	Marine ecotoxicity
METP	Marine eutrophication
MRS	Mineral resource scarcity
OFHH	Ozone formation, Human health
OFTE	Ozone formation, Terrestrial ecosystems
SOD	Stratospheric ozone depletion
TACF	Terrestrial acidification
TECT	Terrestrial ecotoxicity
WCAE	Water consumption, Aquatic ecosystems
WCHH	Water consumption, Human health
WCTE	Water consumption, Terrestrial ecosystem
TA	Terrestrial acidification