ENZYME AND POLYMER MEDIATED PRE-TREATMENT OF CELLULOSIC TEXTILES TO RATIONALIZE WATER CONSUMPTION VIS-À-VIS REDUCTION IN EFFLUENT LOADING

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BRIEF RESEARCH METHODOLOGY:

Rapid industrialization transformed the world's terrain in the previous century. The chemicals employed in various production operations greatly contaminated the air, land, and water. The traditional practice of "How to walk with nature" was harmed by urban industrial culture. The enlightened populace emphasizes sustainable development and sees this as a darker aspect of the changes. When dyes are made, both the intermediates and the finished product are extremely poisonous, not biodegradable, and completely recalcitrant. Some synthetic fabrics, like plastics, have seriously harmed the environment.

Ecologically friendly processing will take into account issues with wastewater discharge, health considerations when handling, storing, and applying chemicals, and the choice of ecologically appropriate substances throughout processing. Despite the world's current information explosion, senior managers, technicians, and chemical producers are not sufficiently aware of these important issues.

A significant amount of environmental contamination is caused by the numerous procedures employed in the textile processing sector. The wet processing of textiles typically produces a significant amount of complex and varied effluents, both in terms of quantity and properties. It is well known that the effluent from the textile sector is intensely coloured, contains a lot of suspended particulates, has a pH that fluctuates a lot, is hot, and has a high chemical oxygen demand (COD). The psychological impact of colour on water contamination is equally significant. In addition to being unsightly, the discharge of highly coloured garbage disrupts biological processes, interferes with light transmission, and may even directly cause the death of aquatic species in the receiving stream. The pollutant load is reduced in a number of ways.

In light of this, the suggested research and work plan will centre on the following topics:

- Developing an appropriate process formulation for cellulosic textiles such low GSM cotton and viscose that require pretreatment. to create desizing and scouring solutions using polymers, enzymes, soda, etc. At the conclusion of each stage of the pretreatment of cellulosic textiles, the formulation will be standardized and its performance optimized.
- Examining the effects of pretreatment on the characteristics of textiles.
- A study of water use during the initial production of cellulosic textiles.
- A number of preparation activities necessitate the quantitative and qualitative examination of water in terms of COD, BOD, and TDS.

The study's thesis, "Enzyme and Polymer mediated Six chapters make up "Pre-treatment of cellulosic textiles to rationalize water consumption vis-à-vis Reduction in effluent loading."

It has become popular to consider "Eco-designing" products from start to finish. It is necessary to take the ecological element of the entire production process into account, from the fibre to the finished product, including its fabrication, but also its packaging, labelling, and recycling at the end of its useful life. These advancements in chemical textile processing will create new possibilities.

Maintaining high standards, being economical, having enhanced performance, creating less waste, requiring little to no chemical or water consumption, and overall being environmentally friendly

The traditionally thought of traditional industry of textile wet processing is coming under more pressure from the global market. There is a general consensus that the textile industries need to move towards more advanced and high-quality products and that using outdated processing techniques may not be sufficient to maintain a profitable operation. New materials and technologies have led to the development of high-tech textiles, which are distinguished by previously unheard-of functions and effects.

Generally, different types of products are used for pretreatment of Cotton and Viscose rayon like Wetting agents, Enzymes, Salts, Alkalis, Acid, Bleaching agent, Stabilizers, Defoaming agents, chelating agents, etc. Out of these products, the present studies focus on modifying wetting agent and desizing agent. Several, formulations with different permutation & combinations have been studied and finalized Enzymatic desizing agent (EDA) & Polymeric wetting agent (PWA).

This project was divided in three phases. First study phase considered as making formulation and testing of desizing agent and wetting agent for cellulosic namely Cotton and Viscose rayon. The second study phase is application of that desizing and wetting agent on Cotton (woven & knitted) and Viscose rayon woven on lab scale to optimizing all parameters and developed optimistic process called as modifying pretreatment process. The third phase of study is purely industrial trial based where compared modified pretreatment process with current pretreatment process on Cotton and Viscose rayon. I have divided 3 main sections to this thesis' organisation:

First section: Theoretical reflections on the Introduction, literature review, classification of fibres, and Chapters 1 and 2's list of pretreatment products for cotton and viscose rayon.

Second part: Chapters 3 and 4 of this portion provide innovative desizing and wetting agent formulations, materials, and experimental techniques employed for pretreatment of cotton and viscose rayon in woven and knitted form, as well as the findings gained and pertinent remarks.

Third section: Chapters 5 general discussion, conclusions, and outlook

KEY FINDINGS / CONCLUSIONS:

1. **Particle size distribution and Zeta potential**

The particle size and size distribution of EDA and PWA were analyzed on the Malvern instrument. Figure 1 and 2. shows the intensity size distribution of EDA and PWA dispersed in water. The first peak of EDA at around 1558 nm arises from the dispersion.

The particle size and the size distribution graph as shown in the corresponding figure 1 for EDA, shows that the Z-average size of the dispersed particles is 2455 with Pdi value of 0.419. Two peaks for the size and size distribution in EDA solution is seen, indicats the solution is in polydisperse condition.

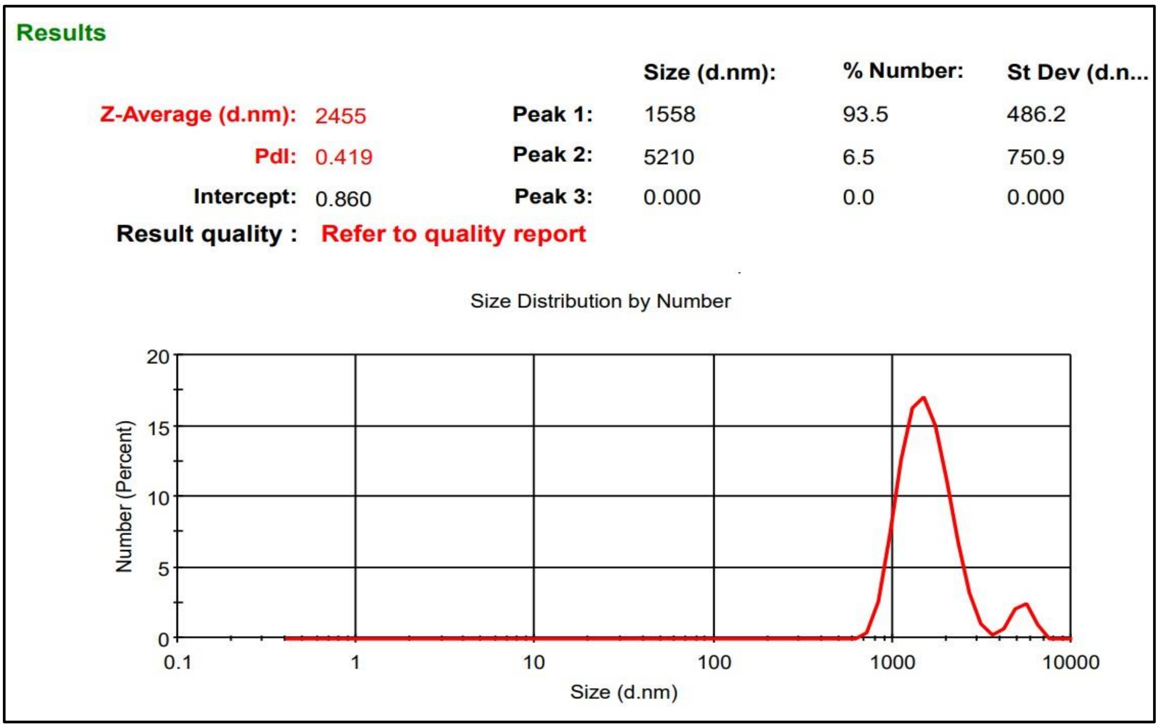

Figure 1 Particle size and size distribution of EDA

The particle size and the size distribution graph as shown in the corresponding figure 4.10 for PWA, shows that the Z-average size of the dispersed particles is 2607 with Pdi value of 0.362. This indicates that the size distribution is in very narrow range. The uniform size and narrow range of size distribution may responsible for the higher stability of the PWA product.

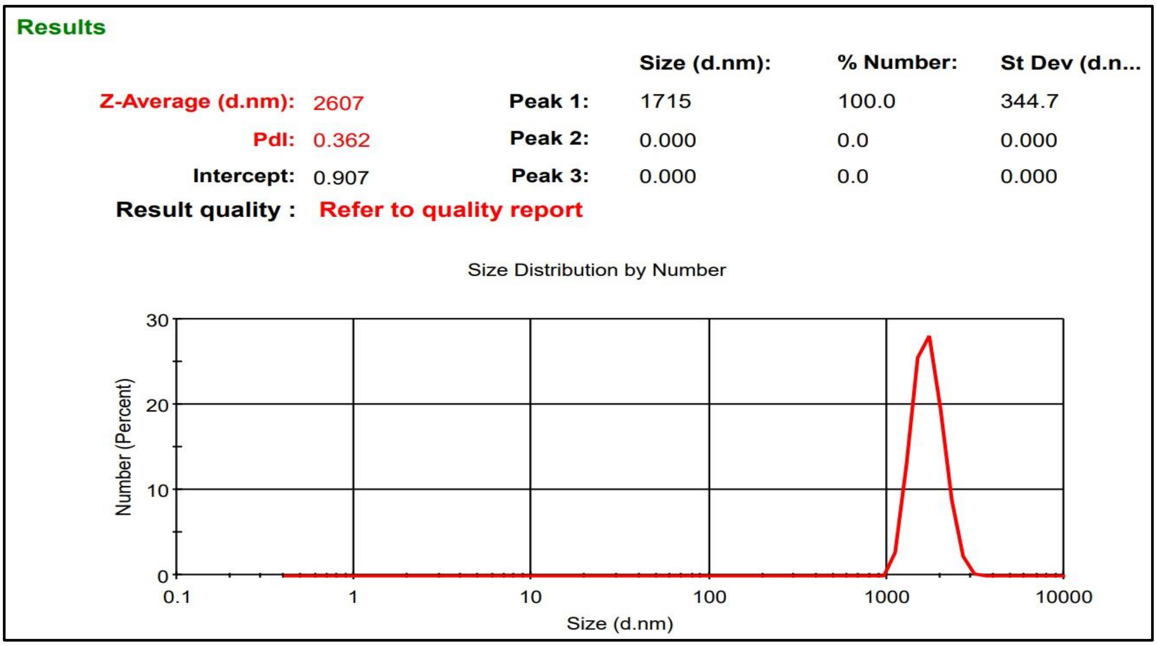

Figure 2 Particle size and size distribution of PWA

2. **Analysis of optimized parameters for desizing process of cotton woven**

Good desizing depends on different processing parameters which results in good tegawa rating. Graphs shown in Figure 3 to 7 point up that the best Tegawa rating (8-9 Tegawa) achieved by optimizing dosage of EDA, pH of desize bath, dwell time of process, temperature of desize bath and water qulity used to processing.

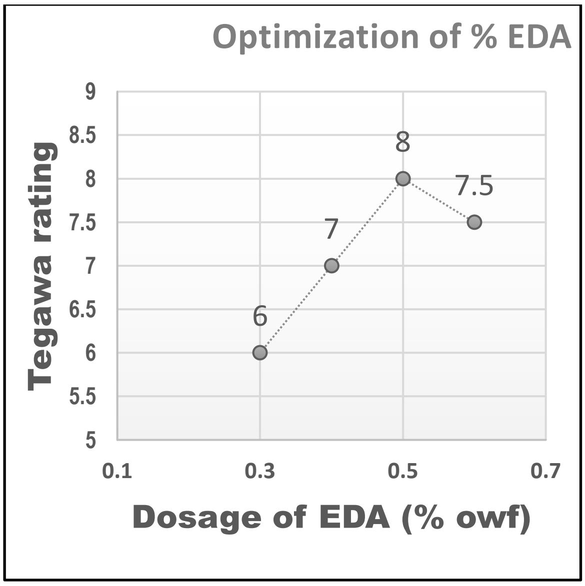

Figure 3 Optimization concentration of EDA in cotton woven desizing

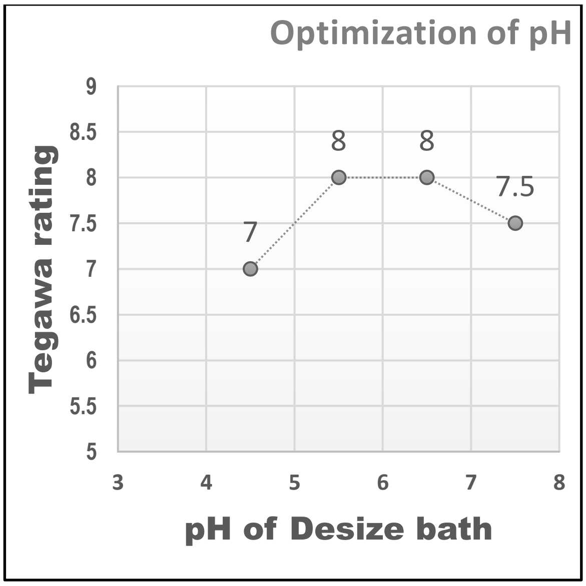

Figure 4 Optimization of pH in cotton woven desizing

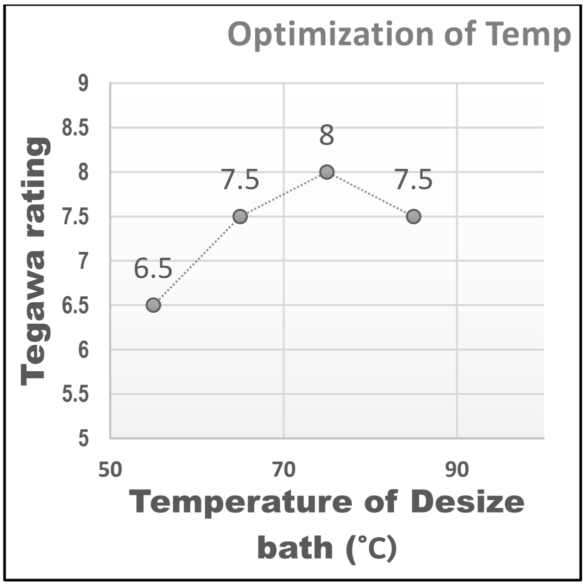

Figure 5 Optimization of bath Temperature in cotton woven desizing

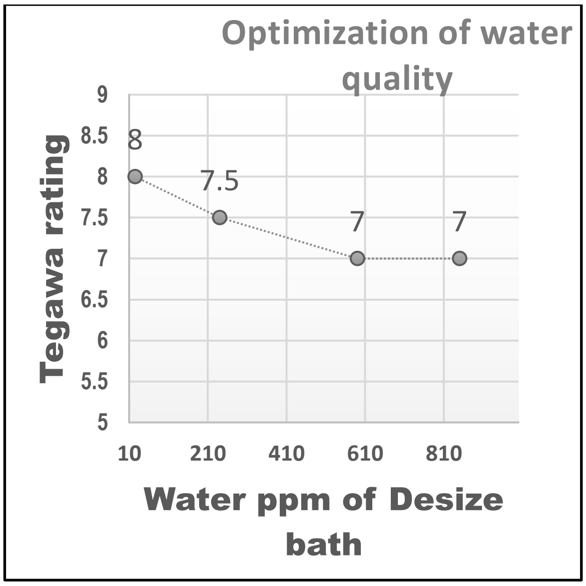

Figure 7 Optimization of quality of water in cotton woven Desizing

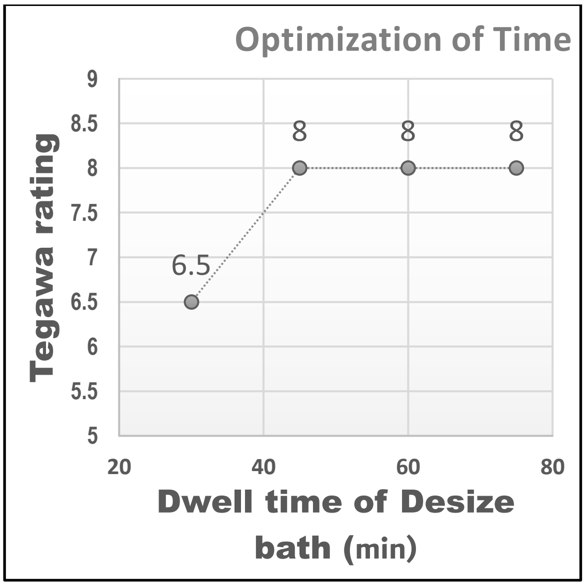

Figure 6 Optimization of dwell time in Cotton woven Desizing

3. Whiteness and Yellowness Index

The fabrics were analyzed in terms of any change in appearance using CCM. The results in terms of whiteness and yellowness index are given in Table 1. Results shows that there is only a negligible change in the whiteness and yellowness index of all three fabrics after both types of current and modified pretreatment.

Table 1 Whiteness and yellowness index of fabrics after current and modified pretreatment

Sr.No.	Fabric	Pretreatment	Whiteness Index	Yellowness index
1	Cotton woven	Current	60.05	10.60
		Modified	59.18	9.97
2	Viscose woven	Current	57.66	12.79
		Modified	59.86	11.85
3	Cotton knitted	Current	62.02	8.07
		Modified	60.51	9.91

4. Core pH of fabrics

The core pH of fabric depends on the alkali present in the core, which was not neutralized properly during the neutralization process. Generally, the core pH of fabric is more alkaline when more alkali is used in the pretreatment process followed by washing & neutralization is not done enough. Cotton woven and knitted fabrics showed more alkaline core pH because NaOH was used but viscose was near to neutral pH where no alkali was used. The current pretreatment process had used almost double the dosage of alkali compared to the modified process which shows that higher core pH in the current processed compared to the modified processed fabric as per table 2.

Table 2 Core pH of fabrics after current and modified pretreatment

Sr.No.	Fabric	Pretreatment	Core pH of the fabric
1	Cotton woven	Current	8.45
		Modified	8.02
2	Viscose woven	Current	7.40
		Modified	7.55
3	Cotton knitted	Current	8.61
		Modified	8.21

5. Tensile strength of fabrics

The results for tensile strength (dry) and elongation at break of current as well as modified pretreatment are given in Table 3.

Table 3 Tensile strength of current and modified pretreated fabrics

Sr.No.	Fabric	Pretreatment	Lengthwise/	Load (kgf)	Percentage Strain

Widthwise					
1	Cotton woven	Current	Warp	18.57	19.35
			Weft	11.28	5.14
		Modified	Warp	19.15	19.85
			Weft	11.55	5.25
2	Viscose woven	Current	Warp	23.16	8.92
			Weft	19.50	8.42
		Modified	Warp	24.50	9.47
			Weft	22.85	9.10
3	Cotton knitted	Current	Course	38.44	81.44
			Wale	22.74	78.44
		Modified	Course	40.05	83.08
			Wale	22.50	79.89

From the results, it can be visualized that the modified treatment marginally improves the tensile strength of all the fabrics most probably due to the lower concentration of auxiliaries and lower washing cycle. It is clear from the corresponding figures that the modified treatment leads to a slight improvement in the tensile strength as well as elongation at break. The improvement in the tensile and elongation of fabric attributed due to the lesser washing cycle was done in a modified process which led to lesser thermal energy usage and lesser abrasion on the cellulose chain. However, the change in improvement in values of TS and % strain varies for cotton woven to viscose woven to the cotton knitted fabric. Such differences in the values of tensile strengths in warp and weft direction could be associated with variations in the class of fiber.

6. Result and Discussion of effluent testing of current v/s modified pre-treatment process

Table 4 Approximate quantity of effluent generated after pretreatment of cotton and viscose process

Sr.No.	Fabrics	Quantity of fabric (kg)	Machine used for pretreatment	Effluent generated in liters	
				Current process	Modified process
1	Cotton woven	200	Jigger	4200	3000

2	Viscose woven	250	Soft flow	5000	3000
3	Cotton knitted	250	Soft flow	5000	4000

The effluent generated in the current and modified pretreatment process of three types of fabric was measured in industry. Here table 4 shows the amount of effluent generated in all processes.

Washing effluent parameters like BOD, COD, and TDS for current and modified process samples were evaluated by standard methods and reported in Table 4.

Table 5 Pretreatment effluent testing of cotton woven fabric by current and modified process

Sr. No.	Effluent testing parameters	Current process	Modified process
1	TDS (in PPM)	14500	9580
2	BOD for 3 days	3680	3792
3	COD	18255	14622
4	pH	8.55	7.50

Table 6 Pretreatment effluent testing of viscose woven fabric by current and modified process

Sr. No.	Effluent testing parameters	Current process	Modified process
1	TDS (in PPM)	952	1177
2	BOD for 3 days	3020	3193
3	COD	12520	11856
4	pH	7.75	7.59

Table 7 Pretreatment effluent testing of cotton knitted fabric by current and modified process

Sr. No.	Effluent testing parameters	Current process	Modified process
1	TDS (in PPM)	17500	14900
2	BOD for 3 days	3325	3218
3	COD	16525	12953
4	pH	9.23	8.58

Today, biodegradable products are used all over the world, and significant research is being done to create new synthetic processes that will enhance their application qualities. However, increasing the amount of alkalis might have serious negative environmental effects on the effluent. Table 5 to 7 makes it evident that, in contrast to the current washing effluent of the sample with higher alkali, the washing effluent with the proposed treatment does not increase the BOD, COD, TDS, or pH. It is acceptable to assume that polymer can safely deliver high durability of the intended textile functionalities based on the lower values of TDS.

The pretreatment and cleaning of textiles constitute the initial stage of textile wet processing. Begin wet processing with an environmentally friendly desizing procedure using an enzyme. The formulation of a desizing agent with various auxiliaries for a one-shot product was done in the current inquiry using the same principle. The Zydex lab and industrial trial created, examined, and standardized this one-shot EDA, which demonstrates the following product attributes:

- The pretreatment of viscose can be completed with just the addition of EDA in a single bath operation, which saves both water and energy.
- Viscose does not need to be pretreated with soda.
- A quicker grey wetting property that allows enzymes to more easily reach the fabric's core and speed up the processing process.
- **Very high detergency and emulsifying action,** which dissolves and suspends oily and greasy contaminants as well as size and soil particles.
- **Very low foaming,** making it appropriate for extended liquor exhaust processes in high shear machines.
- **APEO free eco-friendly product**
- **Feel after pre-treatment is excellent**
- **Fabric cleanliness** is good compared to other emulsifiers.

In the second step of wet processing, scouring and bleaching, lowering the pollution load and saving money on utilities like water, steam, chemicals, and auxiliaries are also crucial. A polymeric-based wetting agent, a one-shot product, was created. The results of the experiments show that the created product lowers the concentration or dose of NaOH and soda ash used for scouring. Sodium hydroxide quickly degrades when it is introduced into the effluent and interacts with other chemicals. In the process of dissolving in water, sodium hydroxide separates into sodium cations (positively charged sodium atoms) and hydroxide anions (negatively charged oxygen and hydrogen atoms), thereby lowering the acidity of the water. The list of PWA product characteristics is as follows:

- Outstanding performance by **micro cleaning** of wax on cotton and oils & greasy material for polyesters.
- It **does not provide temporary wetting** like low mol. weight scouring agent
- It is important to distinguish the scouring effect of this product by observing **the solidity of dyeing** rather than the absorbency of scour fabric.
- Artificial wetting after scouring will go away after 2-3 times washing but PWA shows **good wettability throughout washing**.
- **Eliminate total soda concentration** in the scouring bath by adding PWA.
- Fabric **cleanliness in terms of kitties, dirt, and dust is good** compared to other scouring formulations.
- **Very low foaming** and hence suitable for high shear machines.
- **Very high detergency** and emulsifying action which **removes & suspends oils, grease, and natural wax impurities as well as size material and soil particles**.

Both products were evaluated in the lab for stability, viscosity, solid content, dispersibility, particle size distribution, zeta potential, and other factors and passed; they then began to be produced in large quantities on an industrial scale. The lab conducted a number of laboratory tests on various cotton and viscose rayon fabrics, including determining the ideal pH, temperature, time, doses of auxiliaries, etc. for each fabric. Set the optimal 0.5% EDA dosages, 5.5 pH, 75 °C temperature, 45 minutes for the desizing of cotton and viscose woven fabric in Recipes 1 and 3, and the optimal 0.5% PWA, 0.8% NaOH, 3% $H2O2$ dosage, 90 °C temperature, 45 minutes for the scouring and bleaching of cotton woven and knitted fabric in Recipes 2 and 4, respectively.

Wet processing industries conducted the bulk trials for the same against the current procedure used by the relevant industry. The results of the bulk testing of the new modified method were encouraging in comparison to the conventional pretreatment procedure.

Current and modified processed all fabrics were taken from the industry and evaluated in the lab showing that most of the properties like weight loss (3-3.5% on Cotton woven; 5.25% in the current process and 3.5% in the modified process), Tegawa rating (6-7 rating on cotton woven and 8-9 rating on Viscose woven), Absorbency (Avg 1-3 seconds on all fabric), Sinking time(Avg 2-3 seconds on all fabric), Whiteness and Yellowness index (Avg WI of fabrics are 60 ± 2)and Yellowness index (Avg YI of fabrics are 10 ± 2), core pH of fabric (viscose is near to neutral whereas 0.4 pH higher seen in current pretreatment of cotton woven and knitted fabric compared to modified), a colour strength of the pretreated fabric, Tensile and Tear strength of fabric were almost same or negligible difference but feel of the fabric was improved in the modified process due to good cleaning, lesser caustic used and polymer deposition on fabric.

The effluent generated in the modified process of Cotton woven, Cotton knitted, and viscose rayon fabric by 20 -40% lower compared to the current process. Also TDS, COD, and pH were showing lower values in the modified process of Cotton woven and knitted fabric but slightly increase all values in the viscose woven modified process.

Reduced processing time, temperature, and water and steam usage are all signs of the modified process. So, from per economy point of view, 550 - 580 Rs/ 200-250 kg batch save which converts to large savings on monthly and yearly bases in water, Steam, and auxiliaries using all types of fabrics. Also, the time of processing per batch was reduced which increases production by 25% in cotton knitted, 40% in cotton woven and 60% in viscose woven fabric.

The world will utilise more cotton as a result of its comfort, affordability, and environmental friendliness. The textile industry must deal with challenges related to effluent and waste disposal. Additionally, the red-listed substances and prohibited hues are very dangerous or carcinogenic. The amount of contaminants in the final product is what causes health problems for people. On the other hand, as people's awareness of the quality of the environment increases, environmental regulations are becoming more stringent all over the world every day.

RECOMMENDATIONS/ SUGGESTIONS:

- The same study can be done by further optimizing medium and higher GSM cotton and viscose rayon fabric.
- Can use of different alkalis to reduce the effluent load in the pretreatment of Cotton.
- Further study can be extended in blended textiles like P/V, P/C, C/P and many more fabrics.
- Also can study in sizing process for less size or modified starch/ size application on Cotton, Viscose, and blended textiles for easy desizing.
- Reuse Desizing, Scouring and bleaching bath after filtration and top-up of required chemicals.

BIBLIOGRAPHY/ WEBLIOGRAPHY:

1. Achwal, W. 2001. "Ecoprotection technologies in the Dutch Textile industry." *Colourage* 43.
2. Agarval, B., Patel, B. 2001. "Ink-jet printing technology to the fore." *The Indian Textile Journal* 9-16.
3. Ameram. 2019. "Hydroxide, Chemical composition in sugarcane bagasse: Delignification with sodium." *Malaysian Journal of Fundamental and Applied Sciences* 15 (2): 232-236.
4. Amorim, A. M., Gasques, M. D. G., Andreaus, J., Scharf, M. 2002. "The application of catalase for the elimination of hydrogen peroxide residues after bleaching of cotton fabrics." 74 (3): 433-436.
5. Amorim, M., Gasques, D., Andreaus, J., Scharf, M. 2002. "The application of Catalase for the elimination of H2O2." *Annals of the Brazilion academy of Sciences* 741 (3): 433-436.
6. Ananthashankar, R., Ghaly, A.,. 2013. "Production, Characterization and Treatment of Textile Effluents: A Critical Review." *Journal of Chem ical Engineering & Process Technology* 5 (1).
7. Arya, D., Kolhi, P. 2009. "Environmental Impact of Textile Wet Processing." *fibre2fashion.*
8. 2022. *bartleby.* 10 5. https://www.bartleby.com/?isBot=NewRelicSynthetics.
9. Belkheiri, A., Forouhar, A., Ursu, A. V., Dubessay, P., Pierre, G., Delattre, C., Djelveh, G., Abdelkafi, S., Hamdami, N., Michaud, P. 2021. "Extraction, characterization, and applications of pectins from plant by-products." *Applied Sciences* 11 (14).
10. Benninger, AG. 2009. "Process-integrated Resource Management for Textile finishing." *New cloth market* 13-20.
11. Bhargava, A., Barhanpurkar, S., Roy, P., Singh, V. 2011. "Ecofriendly dyeing of cotton with madder and lac mixture by Various mordents." *Asian Dyer* 29-34.
12. Britannica, T. 2023. *polymer.* Edited by Encyclopaedia. 5 15. Accessed 5 17, 2023. https://www.britannica.com/science/polymer.
13. Bumiller, M., *Review, ISO 13099 colloidal systems Methods of Zeta potential determination.* Accessed 12 6, 2020.

https://static.horiba.com/fileadmin/Horiba/Products/Scientific/Particle_Characterization/Webinars/Slides/TE019.pdf.

14. Cavaco, A.,Gübitz, G. 2003. In *Textile Processing with enzymes*, 123-131. Woodhead.
15. Cegarra, J. 1996. "The state of the art in textile biotechnology." *Journal of Society of Dyers and Colourists* 112: 326-329.
16. Chakrabarti, R., Vignesh, A. "Natural Dyes: Application, Identification and Standardization." *fibre2fashion.*
17. Chakraborty, J. Chap. 32 in *Fundamentals and practices in coloration of Textiles*, 381-408.
18. Chavan, R., Chattopadhyay, D., Sharma. 2000. "Peracetic acid – An ecofrindly bleaching agent." *Colourage* 1: 15-20.
19. *Chelating agent.* Accessed 2 10, 2020. https://en.wikipedia.org/wiki/Chelation.
20. Chinta, S., Wasif, A., Doshi, B. 1993. "Role of Speciality Chemicals and Auxiliaries in Textile Wet Processing-A Review." *Textile Dyer and Printer* 7: 25-34.
21. Clariant Ltd. *Eco-friendly products.* Accessed 6 10, 2018. https://www.clariant.com.
22. CPCB. 2005. *Performance Status of Common Effluent Treatment Plants in India Central Pollution Control Board.* Accessed 11 4, 2021. https://cpcb.nic.in/publication.
23. Dalal, A. 1993. "Environment and Safety Aspects in Indian Dyestuff Industry."
24. Das, S., singh, S.,. 2000. "Enzyme application in textile." *Indian textile journal* 27-32.
25. Demir, A. G., Oliveira, F. R., Gulumser, T., & Souto, A. P. 2018. "New Possibilities of Raw Cotton Pre-treatment before reactive dyeing." *IOP Conference Series: Materials Science and Engineering* 460 (1).
26. Deopura, B., Alagirusamy, R., Gupta, B., Joshi. M. 2008. "Fibrous materials: Polyesters and polyamides." (Woodhead Publishing Ltd and CRC Press).
27. Dong Yang, X., Hou, H., Stanfield, J., He, J., Vijay, K., & Bae, J. 2001. "Environmentally Benign Preparatory Processes-Introducing a Closed-Loop System." C99-A07.
28. Doshi, R.,. 2002. "Impact of biotechnology on the textile industry." *Asian textile journal* 76-78.

29. Eklahare. S, 2012. "Eco-friendly chemical processing of textile and Environmental management." Kolhapur: D.K.T.E., 1 1.
30. "Ecotex- next generation engineering." Accessed 12 3, 2022. http://www.sahaiecotex.com/.
31. Feitkenhauer, Heiko, Ulrich M. 2003. "Anaerobic Microbial Cultures in Cotton Desizang: Efficient Combination of Fabric and Wastewater Treatment." *Textile Research Journal* 73 (2): 93-97.
32. Forte Tavčer, P. *Biotechnology in Textiles-an Opportunity of Saving Water.* Accessed 5 1, 2020. www.intechopen.com.
33. GPCB. *Sectoral Guidance Manual Series Environmental Management Centre LLP Gujarat Cleaner Production Centre Cleaner Production in the Dyes and Dye Intermediate Industries.* Accessed 11 4, 2020. http://www.gcpcgujarat.org.in.
34. *Gujarat Pollution Control Board; Effluent Standard.* Accessed 1 10, 2008. https://gpcb.gujarat.gov.in/.
35. Harane, Rachana, S., Ravindra,V. 2017. "Sustainable Processes for Pre-Treatment of Cotton Fabric." *Textiles and Clothing Sustainability* 2 (1).
36. Hauser, P., Schindler, W. "Textile Chemical Finishing." Chap. 17, 181-188.
37. I Abd El-Thalouth, Kantouch, F., Hennawi, H.El. 2008. "Ecofriendly discharge printing using laccase enzyme." *Indian Journal of Fiber and Textile Research* 33: 52-57.
38. Institute, Textiles. *Properties of cotton - Physical/chemical/uses.* Accessed 10 5, 2022. https://textilesschool.com/properties-of-cotton/.
39. *Introduction to polymers.* Accessed 3 10, 2023. https://irimee.indianrailways.gov.in/instt/uploads/files/1435551295008-POLYMER-%20L-1.pdf.
40. Islam, M. T., Rahman, Md. M., & Mazumder, N. 2020. "Polymers for Textile Production." *Frontiers of Textile Materials* 13-59.
41. Jadhav, A. 2010. "Eco-friendly substitution in textile." *fibre2fashion (E-jouranal).*
42. Jain, C. 2007. "Textiles, An Introduction to Eco." *Eco conference; Singapore Fashion Week.* Singapore.
43. Joshi, M., Bhattacharyya, A., Wazed, A.,. 2008. "Characterization techniques for nanotechnology applications in textiles." *Indian Journal of Fibre and Textile Research* 33 (3): 304-317.

44. Kanimozhi, M. 2011. "Textile Effluent Treatment- An Eco-friendly Approach." *fibre2fashion.*
45. Karimah, A., Ridho, M. R., Munawar, S. S.D. S., Ismadi, Damayanti, R., Subiyanto, B., Fatriasari, W., & Fudholi, A. 2021. "A review on natural fibers for development of eco-friendly bio-composite: characteristics, and utilizations." *Journal of Materials research and technology* 2442-2458.
46. Karmakar, S. Chap. 15 in *Chemical technology in the Pretreatment processes of Textiles*, 418-431.
47. Kazakevičiūtė, Gailutė, Vitalija, V. ,Aušra A. 2001. "Printing: New ways to achieve higher quality and efficiency." *Environmental Research, Engineering and Management* 40-47.
48. Keshk, M., Gouda, M.,. 2017. "Natural biodegradable medical polymers: Cellulose." In *Science and Principles of Biodegradable and Bioresorbable Medical Polymers Materials and Properties*, 279-294. Elsevier.
49. Khot, A., Lende, C. "E-control-The Eco-friendly Process." *fibre2fashion.*
50. Kirk, O., Borchert, T. V., & Fuglsang, C. C. 2002. "Industrial enzyme applications." *Current opinion in biotechnology* 345-351.
51. Kiron, M., Hasan, R., Amin, M., Rana, M.,. 2021. "Study on Different Chemical Finished Treatment on Knitted Fabric."
52. koushik, C., Josico, A. "Chemical processing of tetiles." 364-380.
53. Koushik, C., Josico, A. "Chemical processing of textiles." Chap. 9, 364-380.
54. Kumar, D., Garje, A., Desai, K., Gupta, D. 2010. "Dyeing without Water." *Journal of the Textile Association* 71 (4).
55. Kumar, D., Srivastava, A., Vifhyarthi, R. "Herbal Textiles: Green Business, Green Earth!!!" *fibre2fashion.*
56. Li, Y., Hardin, I. 1997. "Enzymatic scouring of cotton: Effects on Structure and Properties." *Textile Chemist and Colorist* 29 (8): 71-76.
57. Manickam, M., Prasad, J.,. 2006. "Application of biotechnology in textiles." *Asian dyer* 67-73.
58. Manjrekar, S.,. 1999. "Application of enzyme in wet processing-An overview." *Journal of textile association* 79-86.

59. Marialma Blog. 2020. *Sustainability: The Cellulose Fiber – From Nature to your Skin.* 6 15. Accessed 6 1, 2021. https://marialma.com/blog/sustainability-the-cellulose-fiber-from-nature-to-your-skin/.
60. Mazharul, K.,. 2012. *Jigger Dyeing Machine: Objectives, Dyeing Process, Advantages and Disadvantages.* 3 2. Accessed 12 25, 2022. https://textilelearner.net/jigger-dyeing-machine-objectives-dyeing-process/.
61. Menezes, E. "Eco-friendly Chemicals, Enzymes and Dyes." *New cloth market.*
62. 2012. "Microfibrillated cellulose: Energy-efficient preparation techniques and key properties Mikael Ankerfors - Licentiate Thesis." Accessed 12 3, 2022. https://www.diva-portal.org/smash/get/diva2:557668/FULLTEXT01.pdf.
63. Miles, W. "Textile printing." Chap. 9, 301-330.
64. Mishra, A., Rani, A. 2007. "Enzymes and textile sector." *Asian Dyer* 31-39.
65. Mohamed, A., Hassabo, A.,. Chap. 10 in *Flame Retardant of Cellulosic Materials and Their Composites*, 255.
66. Molen, J. "Treatability studies on the wastewater from a dye manufacturing industry." Chap. 1,2, 1-5.
67. Mostafa, M. 2015. "Waste Water Treatment in Textile Industries-the Concept and Current Removal Technologies." *Journal of Biodiversity and Environmental Sciences* 7 (1): 501-525.
68. Mulimani, V. H., & Lalitha, J. A Rapid and Inexpensive Procedure for the Determination of Amylase Activity. Patent PIh S0307-4412(96)00093-3.
69. Nair, V. K. *BASIC CONCEPTS OF POLYMERS.* Accessed 5 12, 2023. http://gnindia.dronacharya.info/APS/Downloads/SubjectInformation/Chemistry/Unit2/Lecture_1_13022019.pdf.
70. Naser, M., Ahsanul H., Abu, Azharul I. 2015. "Optimization of Bleaching Parameters By Whiteness Index And Bursting Strength Of Knitted Cotton Fabric." *International journal of scientific & technology research* 4 (4).
71. Ouederni, M. 2020. "Polymers in textiles." *Polymer Science and Innovative Applications* 331-363.
72. Panda, S. K. B. C., Sen, K., Mukhopadhyay, S. 2021. "Sustainable pretreatments in textile wet processing." *Journal of Cleaner Production* 329.
73. Patel, K.J., Patel, B.H., Patel, A.I. 2004. "Eco- friendly Wet processing of Cotton." *Asian Textile Journal* 13 (8): 89-93.

74. Prabhakaran, S., Mugunthraj, V.,. 2008. "Enzymes in textile industry – An Overview." *Textile review* 12-16.
75. Rahman, Mahfuzur, M., Morsaline, B., Dieu, H., Alam, A.,. 2020. "The Use of Biotechnologies in Textile Processing and Environmental Sustainability: An Emerging Market Context." *Technological Forecasting and Social Change* 159: 120-204.
76. Ramachandran, T.,. 2004. "Application of Genetic Engineering and Enzymes in Textiles." 84.
77. Rehman, A. 2016. "Optimization of amylase activity in the presence of various metal ions and surfactants in aqueous system Surface modification of textile fabrics View project comfort View project." *Journal of Biochem Tech* 7 (1): 1058-1062.
78. Rekha, R.,. 2002. "Role of enzyme in textile wet processing." *Manmade textile in India* 308-401.
79. Renfrew, H. Chap. 5,6,7 in *Reactive Dyes for Textile*, 105-167.
80. Rensburg, J., Vander Walt, Van, J. "Low-Liquor Dyeing and Finishing." *Textile Progress* 14 (2): 1-35.
81. Scheyer, L., Rai, V., Chiweshe, A. 2000. "Compensation for Hydrolysis in the Reuse of Reactive dyes." *Textile Research journal* 70 (1): 59-63.
82. Sekar, N. 1999. "Bleaching of cellulosic materials." *Colourage* 25-28.
83. Selvakumar, N., Thiagarajan. P. 2008. "Cotton, pectinolytic enzymes and enzymatic scouring of cotton." *Colourage* 51-57.
84. Shah, S. 2014. "Chemistry and application of cellulase in textile wet processing." *Research Journal of Engineering Sciences* 3 (2): 1-5.
85. Shukla, S. 2006. "Developments in textile auxiliary chemicals." *Colourage Annual* 175-180.
86. Sivaramakrishnan, C. 2012. "Environmental Concerns In Textile Processing." *Journal of Textile Association* 73 (2): 105-106.
87. Subramanian, M. N. "Basics of Polymers Fabrication and Processing Technology." In *PLASTICS AND POLYMERS COLLECTION*.
88. Subramanian, S., Phalgumani, G.R. 1995. "Processing of Eco-friendly Textiles." *International Norms, A Bilateral Symposium on Eco-Friendly Textile processing.* IIT Delhi. Accessed 11 6, 2020.
89. Taylor, J. 2000. "Recent developments in Reactive dyes." *Coloration* 30: 93-107.

90. *The Manufacturing Process for Viscose Rayon.* Accessed 12 3, 2022. http://plastiquarian.com/?page_id=14338.
91. Tissura. 2018. *Tissura brand.* Accessed 12 10, 2022. https;//tissura.com.
92. Trivedi, S., Vaidya, A.,"Textile Auxiliaries and Finishing chemicals." Chap. 2,4, 5-52, 88-152.
93. U.S. EPA group/SEMARNAP Section-3. 2010. "Pollution prevention in the Textile industry." Chap. 2, 7-65.
94. *UNIT-II-Polymers.* Accessed 5 5, 2023. https://aits-tpt.edu.in/wp-content/uploads/2018/08/UNIT-II-Polymers.pdf.
95. Verma, N., Nishkam, A.,. 2003. "Enzymes in wet processing." *Indian textile journal* 37-41.
96. Vigneswaran, C., Ananthasubramanian, M., & Anbumani, N. 2012. "Neural Network Approach for Optimizing the Bioscouring Performance of Organic Cotton Fabric through Aerodynamic System. In Article Designation." *Journal of Textile, Apparal and Management* 7 (3).
97. Vigneswaran, C., Ananthasubramanian, M., Anbumani, N. 2013. "Effect of sonication on bioscouring of organic cotton through mixed enzymatic system-Neural network approach." *Indian Journal of Fibre & Textile Research* 38.
98. Weeks, R.,. 2007. "Soft jammed materials." 6 12. Accessed 2020. https://physics.emory.edu/faculty/weeks/lab/papers/sendai2007.pdf.
99. Accessed 12 3, 2022. https://www.onlinetextileacademy.com/viscose-rayon-fibre-manufacturing-process-summary/.