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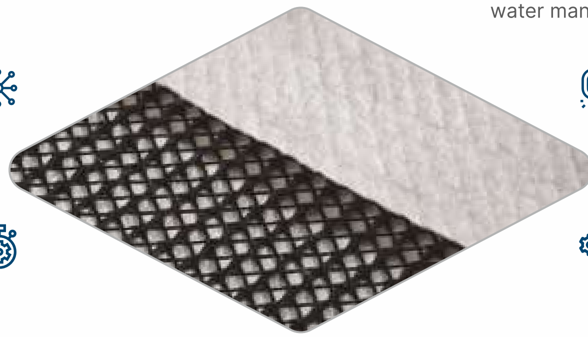

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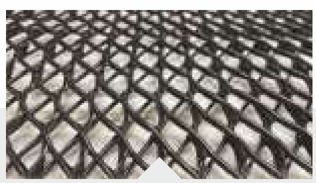

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EDITOR'S DESK

Dear Readers,

Greetings!!

Research with persistent and focused efforts lead to a positive result. Fostering research and providing a platform to publish quality research papers and related articles has been a continuous effort of BTRA Scan. We are working hard to help the journal in climbing up the ranking ladder. In continuation to this effort, I am delighted to present to our readers the 2nd issue of 54th Edition of BTRA SCAN.

This issue has 3 papers from the different domains such as a study on utility & cost comparison involved during wet processing of regenerated cellulosic fabric, radiation processing of municipal dry sewage sludge, development of sustainable hygiene products from sugarcane bagasse. Now we are open for authors from outside so researchers can send their original articles, case studies, research reviews or empirical contributions for publication in our journal.

I thank my entire publishing team for all their support. Together we would work towards making the journal a truly influential publication. Comments and suggestions are always welcome.

Our sincere thanks to all the reader and contributors for their support and interest.

T V Sreekumar, PhD
Director, BTRA

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A STUDY ON UTILITY & COST COMPARISON INVOLVED DURING WET PROCESSING OF REGENERATED CELLULOSIC FABRIC

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Abstract

The wet processing of regenerated cellulosic fabrics involves a complex interplay of chemical treatments, process control parameters, utility consumption, and associated costs. This review provides a comparative study of different regenerated cellulosic fabrics - such as viscose, lyocell, modal and Bamboo by evaluating the chemical recipes used, process control parameters employed, utility consumption patterns, and the cost per kg of fabric during the wet processing phase. The review aims to offer insights into the optimization of wet processing operations, contributing to reduced resource consumption, cost efficiency, and sustainability in the textile industry.

Keywords

wet processing, regenerated cellulosic fabric, chemical recipes

Citation

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1.0 Introduction:

Regenerated cellulosic fibresderived from natural cellulose sources, are an important segment in the textile industry, offering diverse characteristics and applications. Wet processing of these fabrics includes various stages such as scouring, bleaching, dyeing, and finishing, which are necessary to enhance the fibre properties and prepare them for end-use. This study compares the wet processing parameters, chemical recipes, and utility consumption of different regenerated cellulosic fabrics (viscose, lyocell, and modal) to assess their environmental impact, energy requirements, and economic viability.

2. Manufacturing process of regenerated cellulose fibres

The manufacturing process of viscose, modal, lyocell and baboo fibres is as below,

Viscose Process

Wood Pulp → Alkali Treatment (NaOH) → Aging → Xanthation (CS_2) → Dissolution in NaOH (Viscose Dope) → Filtration & Degassing → Wet Spinning (Acid Bath) → Regeneration → Washing & Cutting → Finishing

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Modal Process

Beechwood Pulp → Alkali Treatment (NaOH) → Short Aging → Mild Xanthation → Dissolution (Modal Dope) → Filtration & Stretching → Wet Spinning (Acid Bath) → Regeneration → Washing & Cutting → Finishing

Lyocell Process

Wood Pulp (Eucalyptus, etc.) → Dissolution in NMMO Solvent → Filtration → Dry-Jet Wet Spinning → Water Coagulation Bath → Washing & Solvent Recovery → Drying → Cutting & Finishing

Bamboo Process

Bamboo Plant → Crushing & Cooking to Bamboo Pulp → Alkali Treatment (NaOH) → Aging → Xanthation (CS_2) → Dissolution (Viscose Dope) → Wet Spinning (Acid Bath) → Regeneration → Washing & Cutting → Finishing

3. Properties that specifically influence wet processing of fabric

TheProperties that specifically influence wet processing of viscose, modal, lyocell and baboo fabric is as below,

Properties	Viscose	Modal	*Lyocell (TENCEL™)*	*Bamboo*
Water Absorbency	Very high	Very high	High	Very high
Moisture Regain	~11–13%	~12–14%	~11–13%	~11–13%
Swelling in Water	Significant (high swelling)	Moderate	Controlled swelling (less fibrillation)	Significant
Wet Strength	Poor (strength drops 40–50%)	Better than viscose	Very good wet strength	Poor
Alkali Resistance	Poor (damaged by strong alkalis)	Slightly better	Good resistance	Poor
Colour Uptake / Dye Affinity	High	Very high	High (but requires fibrillation control)	High
Dye Penetration Uniformity	Excellent	Excellent	Needs care to avoid surface fibrils	Good
Bleaching Sensitivity	Sensitive to strong bleaching agents	Slightly better	Tolerates eco-friendly bleaching	Sensitive
Fibrillation Tendency	Low	Low	High (needs enzyme/desizing control)	Low
Shrinkage During Processing	High	Low to moderate	Very low	Moderate
Drying Behaviour	May shrink, needs controlled drying	Improved dimensional stability	Very stable, fast drying	May shrink, soft feel retained
Softness Retention After Wash	Decreases	Retains softness	Retains smooth hand feel	Retains softness
Pilling Tendency	Moderate	Lower than viscose	Can pill if fibrillation untreated	Moderate
Finish Compatibility	Accepts softeners and finishes well	Good response to softeners	Needs anti-fibrillation/enzymes	Good
Fabric Handle Post Processing	Soft, but weaker	Softer and stronger	Smooth, stable, premium	Soft, plush

4. Overview of Wet Processing Stages

Wet processing refers to a series of treatments that fabric undergoes to achieve the desired appearance and functionality. These treatments typically include:

- Desizing: Removal of size (Woven Only)
- Scouring: Removing natural impurities.
- Bleaching: Whitening or lightening the fabric.
- Dyeing: Imparting colour to the fabric.
- Soaping/ Washing:
- Finishing: Final treatments for fabric texture and performance (e.g., softening, water-repellent finishes).

5. Details of process route for viscose, modal, lyocell and bamboo:

Viscose (100%)	Modal (100%)	Lyocell (100%)	Bamboo (100%)
Desizing (woven only) ↓ Scouring (5-6 gpl Soda ash, wetting agent) ↓ Peroxide Bleaching (1.5–2% H_2O_2, stabilizer) ↓ Neutralization (Acetic acid) ↓ Reactive Dyeing (Salt 40–60 gpl, Soda 15–20 gpl, 60–80°C) ↓ Soaping (Non-ionic detergent, 70–80°C) ↓ Acid Rinse (pH 5–6) ↓ Softening (Cationic or Silicone)	(Desizing if needed – Enzymatic) ↓ Mild Scouring (4-5 gpl Soda ash or Enzymatic) ↓ Mild Bleaching (1–1.5% H_2O_2) ↓ Neutralization (Acid rinse) ↓ Reactive Dyeing (Salt 30–50 gpl, Soda 10–15 gpl, 60–80°C) ↓ Soaping (High-temp, non-ionic) ↓ Acid Rinse (pH 5–6) ↓ Softening (Silicone preferred)	Bio-Scouring (Enzymatic – pectinase, 55°C) ↓ Optional Mild Bleaching (0.5–1% H_2O_2, stabilizer) ↓ Neutralization (Acid rinse) ↓ Reactive Dyeing (Cold brand dyes, Salt 20–30 gpl, Soda 10 gpl, Max 60°C) ↓ Anti-Fibrillation Enzyme Treatment (Cellulase, 50–55°C) ↓ Soaping (50–60°C) ↓ Acid Rinse (pH 5) ↓ Softening (Low-cure, fibrillation control)	Mild Scouring (4-5 gpl soda ash, wetting agent) ↓ Bleaching (1–1.5% H_2O_2, stabilizer) ↓ Neutralization (Acetic acid rinse) ↓ Reactive Dyeing (Salt 40–50 gpl, Soda 15–20 gpl, 60–70°C) ↓ Soaping (Non-ionic detergent, 70–75°C) ↓ Acid Rinse (pH 5–6) ↓ Softening (Cationic softener)

6. Details of chemicals used and process control parameters maintained:
**** All doses are in g/L, and M: L = 1:10 (standard for winch, soft flow)**

Process	Fabric Type	Chemicals	Dosage	Purpose / Notes	Temp / Time
Desizing	Viscose (Woven)	α-amylase enzyme	1.5–2.0	For starch removal	60–70°C / 20–30 min
		Wetting agent	0.5–1.0	Helps enzyme penetration	
		Soda ash (Na_2CO_3)	0.5	Mild pH (~7–8) support	
	Modal(Knits or Woven)			Desizing if needed – Enzymatic	
	Lyocell / Bamboo (Knits or Woven)	—	—	Usually not required (not sized)	—
Scouring	Viscose (Woven)	Soda ash	5–6	Removes oils, waxes	90°C / 30–40 min
		Wetting agent	0.5–1.0	Surface tension reduction	
		Sequestering agent (EDTA)	1.0	Controls hardness	
	Modal (Woven)	Soda ash	4–5	Softer alkali to retain strength	85°C / 30 min
		Anti-creasing agent (if rope form)	1.0	Prevents creases	
	Lyocell (Knit)	Bio-Scouring (Enzymatic – pectinase, 55°C)	2-3	Lower alkali to prevent fibrillation	80°C / 25–30 min
		Anti-creasing + Wetting agent	1.0 + 0.5	Essential for loop/rope process	
	Bamboo (Knit)	Soda ash	4–5	Similar to viscose	85°C / 30 min
		Wetting agent	0.5–1.0	Surface tension reduction	

Table continue...

Process	Fabric Type	Chemicals	Dosage	Purpose / Notes	Temp / Time
Bleaching	Viscose/Modal/ Bamboo	Hydrogen peroxide (35%)	1.5-2%		
	Lyocell	Hydrogen peroxide (35%)	0.5-1%	Decolorization	85–90°C / 30–45 min
		Soda ash	3–5	pH 10.5–11.0 for safe activation	
		Peroxide stabilizer	0.5–1.0	Prevents catalytic breakdown	
		Sequestering agent	0.5–1.0	Controls metals (Fe, Cu)	
Neutralization	All	Acetic acid	0.5–1.0	Final pH ~6.5–7.0	40–50°C / 10 min
Dyeing	Viscose	Reactive dye (HE or ME brand)	X% owf	Based on shade depth	60°C -80 °C / 45–60 min
		Common salt / Glauber's salt	40- 60	Salt addition in 2 steps	
		Soda ash	15–20	pH 10–11 for fixation (2-step addition)	
	Modal	Reactive dye (hot brand)	X% owf	Stronger fiber, tolerates standard recipe	60°C -80 °C / 45 min
		Common salt / Glauber's salt	30-50	Salt addition in 2 steps	
		Soda ash	15–20	pH 10–11 for fixation (2-step addition)	
	Lyocell	Reactive dye (cold or medium temp)	X% owf	Use soft liquor flow, low agitation	40–50°C / 45 min
		Common salt / Glauber's salt	20-30	Salt addition in 2 steps	
		Soda ash	10–15	Avoid high pH to limit fibrillation	
	Bamboo (Knit)	Reactive dye (cold/hot brand)	X% owf	Similar to viscose	60°C-70°C / 45 min
		Common salt / Glauber's salt	40-50	Salt addition in 2 steps	
		Soda ash	15-20	Avoid high pH to limit fibrillation	
Soaping	All	Soaping agent	1–2	Removes unfixed dye	75–80°C / 15 min

Notes:
- Lyocell requires the gentlest treatment due to fibrillation risk — always use low pH, low agitation, and anti-creasing agents.
- Modal behaves similar to cotton but needs moderate alkali strength.
- Bamboo performs like standard viscose.
- Always use soda ash instead of caustic soda to protect cellulosic fibre integrity in these regenerated fibres.

7. Comparison of utility consumption:

	Viscose		Modal		Lyocell		Bamboo	
	(Batch)	(Continuous)	(Batch)	(Continuous)	(Batch)	(Continuous)	(Batch)	(Continuous)
Water (L/kg)	60	40	55	38	50	30	70	45
Steam(kg/kg)	1-1.5 kg/kg		0.8-1.2 kg/kg		0.5-1 kg/kg		1-1.5 kg/kg	
Electricity (kWh/kg)	0.5-1 kWh/kg		0.6-1 kWh/kg		0.4-0.8 kWh/kg		0.5-1 kWh/kg	
Wastewater (L/kg)	50	30	45	28	35	20	55	35

8. Comparison of wet processing cost (Rs. /kg)

	Viscose		Modal		Lyocell		Bamboo	
	Batch Processing (Rs/kg)	Continuous Processing (Rs/kg)	Batch Processing (Rs/kg)	Continuous Processing (Rs/kg)	Batch Processing (Rs/kg)	Continuous Processing (Rs/kg)	Batch Processing (Rs/kg)	Continuous Processing (Rs/kg)
Chemical Costs	45-50	35-45	50-60	40-50	60-75	50-65	55-70	45-60
Water Consumption	20-30	15-20	20-30	15-20	25-35	20-30	20-30	15-20
Energy Consumption	15-25	10-15	15-20	10-15	20-30	15-20	15-25	10-15
Labour and Maintenance	10-15	5-10	10-15	5-10	15-20	10-15	10-15	5-10
Total Cost	**90-125**	**65-90**	**95-130**	**70-95**	**120-160**	**95-130**	**100-140**	**75-105**

* Note: Above tables are meant to serve as a general guideline and may vary depending on the specific setup of a textile processing plant.

9. Benefits to the textile industry:

Stakeholder	Key Benefits
Production/Processing	- Helps select optimal process parameters for different fibres- Reduces processing errors and rework- Informs choice of auxiliaries and chemicals
Cost Management	- Enables better budgeting by comparing chemical, water, and energy consumption - Supports decision-making on most economical fibre choice
Quality Assurance	- Improves consistency and dyeing quality- Helps troubleshoot defects like fibrillation, shade variation, etc.
Technical Teams (R&D)	- Identifygaps and process improvement opportunities- Aids in developing new recipes or machinery settings
Sustainability / EHS	- Allows comparison of environmental impact (e.g., water, alkali, temp) - Supports implementation of cleaner and safer processes

10. Conclusion

The comparative study of cost, utility requirements, and process parameters across different regenerated fibres viz., viscose, modal, lyocell, and Bamboo providescritical operational and strategic insights to the textile industry and its associated stakeholders. Overall, it helps in knowledge-based decision making, risk mitigation, better resource utilization, higher customer satisfaction, greater innovation and compliance

In conclusion, manufacturers seeking to optimize their wet processing operations should consider the trade-offs between chemical usage, water and energy consumption, and overall cost. Further innovations in chemical recipes and process control technologies may further enhance the environmental and economic viability of regenerated cellulosic fabrics.

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Radiation Processing of Municipal Dry Sewage Sludge for Hygienisation and Agricultural Applications

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Abstract

According to CPCB the status of sewage sludge treatment in India is currently inadequate, with most sludge generated being disposed of in dumpsites due to a lack of proper treatment facilities. Despite recent improvements in overall sewage treatment capacity; only a small percentage of generated sludge is actually treated, highlighting a significant gap in management practices across the country. Radiation Technology provides an excellent route to safely and effectively recycling and agronomically use of sewage sludge. Exposure to Gamma radiation effectively kills microorganisms, weeds and degrade chemicals and reduce smell in the sewage sludge. Two such facilities at Ahmedabad and Indore have been recently established. Incorporation of treated sewage sludge (Biosolids) in Fertilizer Control Order (FCO) would facilitate and make available a safe, effective organic manure/soil conditioner to farmers. The government can save some subsidy on chemical fertilizers and environment is largely benefited w.r.t to disposal of sewage sludge and cleaner water bodies. Besides other associated benefits, one ton per hectare use of treated Biosolids with Bio NPK reduces use of chemical fertilizer to the extent of 20% and provide much needed organic carbon to soil. Use of Biosolids provides a few billions of dollar business (2 to 5) in the US, Europe, Australia and part of Asia. India at present does not have any specific regulations for use of sewage sludge in agriculture and other applications.

Key words:

Gamma Radiation,radiation processing, sewage sludge, hygienisation, pathogen, radiation dose, FCO, bio fertilizer, heavy metals, agriculture

Citation

Lalit Varshney - "Radiation Processing of Municipal Dry Sewage Sludge for Hygienisation and Agricultural Applications", *BTRA Scan* - Vol. LIV No.2, April 2025, Page no. 10-17, DOI: 10.70225/404067whtkmf

1.0 Introduction:

Disposal of municipal sewage sludge, especially in large metropolitan cities is an emerging serious problem for urban authorities as sludge contains a high load of potentially infectious microorganisms that can be a serious threat to public health. The present sludge disposal methods have their own limitations. For example, disposal in to sea is site specific, incineration is an extremely energy intensive process and land filling involves transporting the sludge to faraway places because of nonavailability of land in urban areas.

On the other hand, sludge is an important source of macro and micro nutrients such as C, N, P, K, & Zn, Fe, Cu etc respectively. Interest in the use of sludge for application in agriculture has increased among the farming community as well as among the sewage treatment plant (STP) operators. The farming community has realized that the excessive use of chemical fertilizers is not sustainable for long term agriculture and Biosolids can be beneficially utilized for supplying nutrients to the crop, improving soil physical properties and above all increasing the soil organic matter. This can result in increased crop productivity as well as restoration of soil fertility. For STP operators it may offer a way of generating a value added by product from waste whose disposal otherwise is a matter of environmental concerns and economic loss to the nation. Therefore, recycling of the sewage sludge for agriculture application can emerge as an important outlet provided it is carried out in a manner that protects human and animal health as well environment at large (1).

The sludge after conventional treatment processes still contains a heavy pathogenic microbial load and needs to be Hygienised before it is applied to agricultural land. This necessitates development of technologies that can hygienise the sludge in a reliable, efficient and cost-effective manner. Bhabha Atomic Research Centre came out with an interesting technology which can hygienise sewage sludge on large scale (Biosolids) and has set up two facilities at Ahmedabad and Indore in collaboration with the local Municipal Corporations in 2019 and 2023 respectively.

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The high energy Gamma radiation has the unique ability of inactivating microorganisms present in sewage sludge in an efficient and reliable manner. The ionizing radiation emitted by radiation source such as Co-60 interact with the critical molecules like DNA, proteins, fats, carbohydrate and water present in the cell resulting in the inactivation of pathogens. Thus, radiation technology is emerging as an important application in the area of public health. The technology is available locally and Cobalt-60 source is available from Board of Radiation and Isotope Technology (BRIT), Department of Atomic Energy. The facilities can be indigenously constructed under regulation of Atomic Energy Regulatory Board.

2.0 Discussions:

The end product of a standard STP is dried sludge which contain about 75-80% solid and 20-25% water. For land applications It should meet the specified limits for the following characteristics:

1. The presence of pollutants (Arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium and zinc). Domestic sewage is not expected to have high concentration of these metals. Ministry of Urban Development has described limits which are similar to norms of United States Environmental Protection Agency (2)

2. The presence of pathogens (e.g. bacteria, viruses, parasites)

3. he sewage sludge attractiveness to vectors such as rodents, flies, mosquitoes, birds etc. which could transfer pathogens to other places and human. .

Table 1. Typical pathogens present in the Fecal sludge and their concentration

Microorganisms	Conc. /100 ml
Coliforms	10^5–10^7
Fecal Coliforms	10^4–10^6
Fecal streptococci	10^4–10^5
Salmonella	1-100

2. Radiation Technology

The advancements in applications of radioisotopes and radiation technologies in various areas like healthcare, industry, agriculture, environment and research have improved the quality of life in many spheres. Radiation sterilization of health care products and food preservation by irradiation are two important applications of radiation technology now playing an important role for the benefit of the mankind. Radiation sterilization using gamma radiation from Cobalt – 60 source is a well-established industrial process in India. Dry sludge can be Hygienised using the same technology and in a similar process. Irradiation plant can be integrated to STP or could be located at different place to serve as a central facility for other STP'S in the region (1).

The Process

The pathogens present in the dried sewage sludge can be effectively inactivated/killed by exposing it to high energy radiation in a fully automatic process as shown in Table 2 and process flow sheet diagram in Figure 1(1). Due to its high penetration property, the bulk sludge can be uniformly treated in large containers or bags. No residues are left and no pollution is created. Therefore, the whole treatment process is environment friendly. Typical irradiation facility features are given in Table 3.

Table 2. Reduction in microorganism number on Irradiation

S.N.	Dosimeter Position.	Radiation Dose (kGy)	Coliform/g	B. Pumilus Spores
1	Control	0	11.5 x 10^6	1 x 10^6
2	Minimum	6.85	NIL	0.96 x 10^2
	Maximum	9.03	NIL	0.3 x 10^2
3	Minimum	7.07	NIL	0.42 x 10^2
	Maximum	9.15	NIL	0.16 x 10^2
4.	Minimum	6.81	NIL	0.85 x 10^2
	Maximum	9.04	NIL	0.10 x 10^2

Figure 1. Process flow sheet diagram for 100 tons/day facility

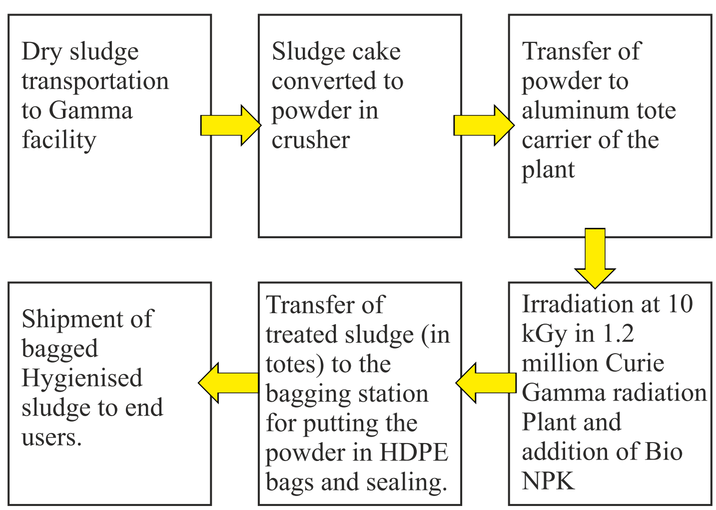

Table 3. Salient Features of Dry Sludge Gamma Irradiation Plant(1)

SR. NO	FEATURE	DESCRIPTION
1	Category of Irradiator	Panoramic wet source storage. Category IV (Ref AERB-SS-6, REV-1, 2008)
2	Products	Dry Sludge (75-80%) solid and 20-25% water
3	Maximum source strength	1.5 MCi (Cobalt-60 Source) of BC188/W31 Pencils.
4	Mode of operation	Product overlap geometry with shuffling outside the cell, with Continuous mode of operation
5	Radiation source Geometry	Rectangular stainless steel source frame with max designed capacity of 3.0 MCi.
6	Source movement system	Hydraulic cylinder with SS wire rope system with requisite safety interlocks.
7	Maximum designed throughput.	5.9 Metric tons / hr. (at 1 gms/cc density) @ 1.5 MCi
8	Radiation dose	10 kGy (Average Dose)
9	Major Sub-systems	• Product Handling System for cell and labyrinth with shuffling feature • Conveyors for loading and unloading area. • Automated crushing & bagging system. • Source Rack with Hydraulic source raise system. • Electrical hoist for source cask handling. • DM plant and pool water conditioning and monitoring. • Irradiation cell Ventilation. • PLC based control and safety systems with SCADA and HMI interface • In cell firefighting. • Pool water chilling system (optional). • Auxiliary conveyor system for sample irradiation (Optional) • Foot print: 4500 m^2 [Cell Area Approx. 400 m^2]
10	Processing (Irradiation cost only)	Rs 1.5/kg in bag of 50 kg, based on 100 tons processed per day.

3. Value addition to Biosolids by addition of bio NPK

On irradiation, bacterial load is significantly reduced. Addition of useful bacterial culture to the Biosolid makes it a useful product increasing it potential to add nutritional value to soil. Due to lower competition, the added bacterial culture shows enhanced growth as shown in Table 4. The slow release of Phosphate and potash in the Biosolid is enhanced due to the presence of corresponding mobilizing bacterial culture. The improved Nitrogen fixation also helps in increase in quality parameter of the treated Biosolid. Increased carbon, micronutrients and soil conditioning results in increase of soil fertility. The proposed specifications for treated Biosolids is given in Table 5.

Table 4. Typical Growth Pattern of useful bacteria in the dry sludge (1)

Useful Bacteria	Inoculated in non-irradiated sludge (CFU/gram)	Inoculated in Irradiated Sludge (CFU/gram)
Phosphate solubilizing bacteria	$3x\ 10^9$	$5x\ 10^{11}$
Rhizobium	2.5×10^8	2.5×10^{11}
Azotobacter	4×10^9	2.5×10^{12}

Since there are large variations expected in pollutant levels and Nutritional components in Biosolids, minimum values have been chosen for N, P, K and organic carbon so that a reproducible, well characterized product is made. The specifications are similar to bio compost (FCO) except heavy metal levels (7).

Table 5. Proposed General specifications for Biosolids

Parameters	Specifications
Moisture, percent by weight (Gravimetrically)	Maximum 25
Particle size	Minimum 90% material should pass through 4.0 mm IS sieve
Bulk density (g/cm^3)	<1.0
Total organic carbon as percent by weight	Minimum 12
Total Nitrogen (as N), Phosphate as P_2O_5 and Potash as K_2O, per cent by weight.	Minimum 1.2
C:N ratio#	<20
pH	6.0 – 7.5

Table 5 continue.....

Parameters	Specifications
Conductivity (as dsm^{-1}), not more than	5
Pathogens including Helminths Ova	Not Detectable
***Heavy Metals (Maximum)** Arsenic (As) Cadmium(cd) Chromium (Cr) Copper (Cu) Mercury (Hg) Nickel (Ni) Lead (Pb) Zinc (Zn) *US EPA 40 CFR part 503 for EQ sludge, #Due to variation in sludge	(mg/kg) 41 39 1200 1500 17 420 300 2800
PGPB not less than	**10^7**spores or cyst per g of dry sludge at ambient temp. at the time of production.

4. Outcome of the Radiation Hygienisation process:

The results of radiation processing of dry sewage sludge results in Biosolids which are effective and safe to use (1,2,46,8) and recycled in environmentally friendly manner.

- An average radiation dose of 8-10 kGy has been observed to hygienise dried/solar dried sludge. as recommended for Class "A" Biosolids". The Hygienised sludge in bagged form can be distributed and can be stored for longer time. The quality of sludge processed is equivalent to United States Environmental Protection Agency (2) Exceptional Quality Biosolids which does not require further regulation for use in agriculture applications.

- Sludge treated by radiation processing therefore will not add to the pathogen load of the environment and will not present any risk to the human, animal or crop health. Efficacy of the process is shown by killing of radiation resistant Bacillus Pumilus spores. No smell and weeds are the added advantage.

- Due to reduction in microbial counts, the Hygienised sludge can be inoculated with useful bacteria to give value added biofertilizer.

- It can be blended with other chemical fertilizers and bioproducts and distributed in bags.

The pollutants level in Biosolids is regulated/tested before radiation processing, Due to use of limited quantity of EQ sludge and dilution in the soil, the concern of pollutants is minimized. The use of Biosolids in advanced countries at much higher scale based on their standards evidences its safety and use.

5. Why Radiation Processed Biosolids should be included in FCO (Fertilizer Control Order) for agriculture applications.

The major concerns of the authorities for not including it in FCO are:

1. Presence of pathogens
2. Presence of heavy metals
3. Presence of organic pollutants like drugs, pesticides, poly chloro-flouro compounds, microplastics, nano materials etc.

World over more than 50% of treated sewage sludge (Biosolids) are utilized on land applications. Its use is commercialized in developed countries. Some of those countries include USA, Australia, 27 countries in European Union, UK, Japan, China, South Africa etc. (Table 6). The use of sewage sludge is regulated as per the countries norms most of which are similar to USEPA 40 CFR 503 as shown. For unknown reasons, there are no specific regulatory standards for use of Biosolids in India. Biosolids use is also not included in FCO which could provide much needed organic carbon to soil. It is also an environmental concern if not disposed/recycled properly. India generates about 52644 MLD of sewage with a potential of generating 1.5 lakh tons of sludge per day (5). The sewage treatment present capacity is only 31886 MLD which is growing with coming years. More than 65% of sludge is unused and remaining is used on land applications, biochar and others. Sewage sludge is known to contain significant quantity of organic carbon, micronutrients, Nitrogen, Potassium, Phosphorous and soil conditioning properties. Practically no technology is being used in India to recycle sewage sludge. Lot of research has been done in India and abroad on the subject and many countries have formulated their standards. India has yet to come out with standards.

Table 6 gives the standards formulated by various pollution control agencies including that of India I. It is observed that there are specific regulations for using sewage sludge in agriculture applications. The studies carried out in India clearly demonstrate that:

1. Only dewatered sludge classified as Biosolids s A or B should be used. The heavy metals concentration and pathogens in the sludge should meet regulatory requirement. Class A Biosolids from Sewage Treatment Plants are suitable for organic farming and have fertilizing potential. Such sewage sludge could be used for commercial purpose (6).

2. Most of the regulations are based on USEPA 40 CFR 503. Standard stipulate not only quality but quantity of biosolid use is regulated based on the pollutant load. Sludge crossing ceiling concentration of pollutants should not be used on land application.

3. There is no regulation in FCO over use of compost or organic manure in terms of quantity. In general, 5 tons per hectare of compost is recommended for agriculture applications. Organic bio compost cost about 30-50 Rs/kg.

4. India used about 35 million tons of Urea in agriculture in 2022-23. The Urea subsidy for 2024-25 stands at Rs 1.22 trillion which is about Rs. 35 per kg. Use of Biosolids could save some subsidy and recycle sludge in the safest manner, reduce use of chemical fertilizer and increase productivity. Due to dilution factor in soil, the concern of pollutants would be minimized without effecting the yield as demonstrated by research in India.

5. India has a sludge generation capacity of approx. 7.3 kg/capita/year on dry basis. With 1.4 billion people, the sludge generation per year is about 10 million tons. Taking example of Delhi, with 330 million population process about 2000 MLD of sewage every day leading to generation of about 500 tons dry sludge each day or 182500 tons /year Using one ton per hectare of biosolid comes out to be equivalent to cultivation of 182500 hectare of land per year (9). Urea at 120 kg of per hectare would require about 21900 tons. Saving of 20% Urea means about 4380 tons of urea which is equivalent to government subsidy of about (35x 5600000) 15 crores a year from Delhi alone. Environment cost, health cost and increased productivity cannot be calculated. Since treated Biosolids are good biofertilizer would have commercial value. Otherwise, disposal cost would be much higher along with the health risk. The chances that the untreated sludge going back to water bodies are high.

   In spite of established success of the technology, the availability of Biosolids (treated sludge) to farmers is limited due to non-inclusion in FCO. Inclusion in FCO would increase awareness and channels to sell the product in market and help in recycling of safe sewage sludge. Other available options are not environment friendly. Using the treated sludge could provide great benefits to all including farmers, STP operators, health and environment.

It can be seen from Table 6 that Fecal coliform, salmonella and helminths ova are serious health concern. Irradiation kills all of them with high reliability. Also, Foul smell is reduced, weeds inactivated and persistent organic pollutant degraded to some extent. It may be noted that sewage sludge drying process itself drastically reduces volatile organic compounds.

Table 6. Various regulations followed by pollution control agencies

Country	Microbiologial class	Application/ Reuse	Salmonella	Helminth Ova	Faecal Coliform	E.coli
India (MoUD 2013, CEPT 2015) (Adapted from US EPA, Class A biosolids, WHO 2006)	Dewatered sludge to be used as fertilizer or soil conditioner in agriculture as per MoUD 2016, USEPA and WHO 2006.	Fertilizer or soil conditioner in agriculture.	<3 MPN/4 gram of total dry solid	<1 /gram of total dry solid	<1000 MPN/ gram of total dry solid	<1000 / gram of total dry solid
India (CPHEED 20135, Adapted from US EPA criteria of class A Biosolid).	Dewatered septage/sludge to be used as fertilizer in agriculture	Reuse in agriculture	<3 MPN /4 gram of total dry solid		<1000 MPN/ gram of total dry solid	
WHO 2006	Faecal sludge	Reuse in agriculture		<1 /gram of total dry solid		<1000 MPN/4 gram of total dry solid
US EPA	Pathogen Class A (Ceiling concentration for all biosolids applied to land)	For all biosolids applied on all land types, agriculture, forest, reclamation sites, lawns and home gardens.	3 MPN /4 gram of total dry solid	<1 / 4gram of total dry solid	<1000 MPN/ gram of total dry solid	
US EPA	Pathogen Class A or B (Ceiling concentration limits for EQ and PC biosolids)	For applications in agriculture land, forest and reclamation sites	3 MPN /4 gram of total dry solid		1000 MPN/ gram of total dry solid(A) or 2x 10^6 MPN/CFU per gram dry solid(B)	
South Africa	Unrestricted use qualifies for agriculture	Can be used for all types of crops		1 ova/ 4gram of dry solid	<1000 CFU/ gram of total dry solid(5 log reduction)	

Table 7. Toxic metals limits in Biosolids as per US EPA/ MoUD and in dry sludge samples

Pollutant	Ceiling Concentration limits* (mg/kg)	Annual pollutant loading rate Limits per 365-day period (kg/hectare)	EQ Sludge Heavy Metal Load (mg/kg)	Delhi (Okhla, 560 MLD STP) Sludge Heavy Metal Load (mg/kg)	Indore Smart City STP sludge (mg/kg)
Arsenic	75	20	41	22.4	BLQ
Cadmium	85	1.9	39	BQL	BLQ
Chromium	3000	150	1200	28	BLQ
Copper	4300	75	1500	148	40.3
Lead	840	15	300	30	8.37
Mercury	57	0.85	17	0.05	
Molybdenum	75	--	--		-
Nickel	420	21	420	15	BLQ
Selenium	100	5.0	36		
Zinc	7500	140	2800	368	110.9
Applies to:	All biosolids that are land applied	Bulk and Bagged biosolids	Bulk and Bagged Biosolids		

As per US, EPA, if limit for any one or all exceeds then Sludge cannot be applied on land. EQ sludge as per can be land applied without any further regulation and can be distributed in bags: MoUD Ministry of Urban Development, CPHEED: Central Public Health and Environmental Engineering. BLQ: Below Limit of Quantification

There are large variations in the maximum and minimum values of studied heavy metal loads in various samples of sludge. These variations are expected. As such heavy metal load and other pollutants should be minimum in domestic sewage sludge. However, industrial units and other routes contaminate sewer lines to which government need to regulate and control. To have minimum adverse effects of the biosolids (treated sludge) in the soil and utilizing their agronomical values, one can consider: -

1. Not to use sludge as replacement of chemical fertilizers. Use of 80 % chemical fertilizers and one ton per hectare Biosolids per crop would be useful for long term use of Biosolids. No significant changes in heavy metal loads have been observed even at 5 tons/ hectare (10)

2. Use of Bio NPK increases its agronomical value and mobilizes slow releasing nutrients.

3. For example, for wheat crop 80 kg, 40kg, 40 kg of N.P, K respectively can be replaced with 64 kg,32 kg, 32 kg of NPK and one metric ton of Bio NPK Biosolids. Due to large variations of NPK in Biosolids it could be impossible to know exact values every time of its use. Use of Biosolids increases soil fertility, organic carbon, micro macronutrients, soil structure, retention of chemical fertilizer and microbiological activity and consequently increasing crop yield as observed in many research studies.

4. Use of limited quantities of treated Biosolids addresses the concern of pollutants and benefits, farmers, government and environment.

Table 8. shows the results of study carried out by Centre for Science and Environment on 46 STPs of India in different states. The mean values, minimum and maximum values show large variations from sample to sample as the material is not based on some fixed formulation of its constituents (8). Some values are higher than FCO values but much lower to US EPA values and European Directives. The values in USEPA and European directives for heavy metals are much higher but sludge are permitted there for agriculture/land applications. Certainly, the limits are based on several studies in those countries and ill effects of use of such sludge is not observed. Similarly, evidences are not available for ill effects of persistent pollutants either including microplastics in soil crops.

Table 8. Average heavy metal load in biosolids of 46 STPS in India

Metal	Average mg/kg	Maximum mg/kg	Minimum mg/kg	Limit For Organic Manure by FCO mg/kg	US EPA EQ Sludge mg/kg	EU Directive 86/278/EEC (11)
Hg	1.5	5.9	0.0	0.15	17	16-25
As	1.0	4.7	0.0	10	41	-
Cd	2.8	5.4	0.1	5	39	20-40
Cr	7.6	443	10.4	50	1200	-
Cu	236.4	47	23.2	300	1500	1000-1750
Ni	30.9	68.8	7.6	50	420	300-400
Pb	36.5	104.9	4.6	100	300	750-1200
Zn	140.4	5658	48.6	1000	2800	2500-4000

Using a ton of biosolid per hectare as per USEPA (EQ sludge) along with chemical fertilizer not only would improve soil fertility but also the concern of pollutants in the sludge are significantly reduced due to dilution in soil. The actual pollutants level in Indian Biosolids are observed to have much lower concentration of pollutants than stipulated by USEPA. Using USEPA norms absolves the concern of observed variations in the biosolid for its practical use (Table 8).

Therefore, FCO should consider adopting USEPA norms for Biosolids for agriculture use. The results and discussions in the present manuscript indicates that radiation technology process for treatment of Sewage Sludge is ;-

- Simple, economic, effective, reproducible and scalable .
- Easy to integrate with conventional process in the existing sewage treatment facility and can also be used as central facility for other STP's in the region.
- Total indigenous technology to design, commission and operate the plant, fully automatic to avoid manual handling of contaminated sludge.
- Based on the process of radiation sterilization which is well established world over and in India.
- Hygienised sludge is a potentially useful organic manure as well as good substrate to produce bio-fertilizer to the required standards thus offering the much-desired micronutrients and carbon to the agricultural soil.
- Recycles the waste material to ergonomically useful product in an environmentally friendly way.

The use of Bio NPK Biosolids would ;

- Increased crop yield
- Improved soil conditions – soil conservation & restoration.
- Reduced health risks to farmer associated with sludge.
- Reduced demand of water thus making this valuable resource available for irrigation.
- The nutrient rich sludge which otherwise is wastefully discarded can be gainfully recycled for economic gain by farmers.

Overall, the benefits outweigh the risks and financial costs in treating and utilizing the bio solids.

Conclusion:

Radiation Hygienised Biosolids with Bio NPK provides safe and effective manure as a supplement to chemical fertilizers. It improves soil fertility and helps in recycling of Biosolids in an economic and environmentally friendly manner. Due to large variations in pollutant load, USEPA standards for Exceptional Quality Sludge could be gainfully followed by FCO and other authorities for treated sewage sludge use in agricultural applications. The use of treated sewage sludge benefits all including the farmers, health & environment. FCO should include treated biosolids for use as manure by farmers for agronomical benefits and indirectly helping environment. Use of treated and limited sludge use outweighs the benefits over risks and financial costs involved.

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Development of sustainable hygiene products from sugarcane bagasse

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Abstract
Commercial sanitary napkins typically consist of three to four distinct layers, each engineered to perform a specific function. Most branded products incorporate a permeable top sheet composed of polypropylene to facilitate fluid transfer, an absorbent core consisting of superabsorbent polymers (SAPs) or cotton fibers for fluid retention, and an impermeable back sheet made of polyethylene to prevent leakage. However, these materials are predominantly synthetic, non-biodegradable, and pose significant environmental challenges due to their persistence in landfills.

This study addresses the environmental implications associated with conventional sanitary products and aims to develop an eco-friendly alternative utilizing agricultural waste. Specifically, sugarcane bagasse (SCB) a fibrous byproduct of the sugar industry—has been processed into a fine cellulosic pulp and evaluated for its suitability as an absorbent core material. A laboratory-scale prototype sanitary napkin was fabricated using a permeable top layer of absorbent cotton gauze, a three-layered core of sugarcane bagasse pulp, and a hydrophobic cotton fabric as the back sheet.

The research focuses on replacing petroleum-based synthetic components with biodegradable and sustainable materials without compromising performance. Preliminary findings indicate that the sugarcane bagasse-based sanitary napkin demonstrates favorable absorbency and fluid retention characteristics while being fully biodegradable, offering a viable solution for reducing environmental impact.

Key words:
Bio degradability, Eco friendly, Sustainability, Sugarcane bagasse, Sanitary napkin,

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1.0 Introduction

In recent years, there has been a growing demand among both consumers and environmental advocates for environmentally sustainable and biodegradable products for daily use [1]. This shift in consumer preference has significantly influenced the commercial market, particularly in the domain of hygiene-related products such as diapers for infants and adults, as well as feminine hygiene products including sanitary napkins [2]. However, the majority of commercially available absorbent hygiene products are composed of synthetic, non-biodegradable materials, raising concerns regarding their environmental sustainability.

Sanitary napkins currently available in the market typically comprise 30–40% non-biodegradable constituents, such as synthetic fibers, polyethylene, polypropylene sheets, and superabsorbent polymers (SAPs) [3,4]. Branded multinational products generally consist of a perforated polypropylene top sheet that remains in contact with the body to maintain dryness, a core composed of SAPs or cellulosic absorbents for fluid retention, and a hydrophobic polyethylene back sheet to prevent leakage [4]. Consequently, the disposal of these products poses a significant challenge to environmental agencies and municipal waste management authorities due to their persistence in landfills [5].

Moreover, the high cost of commercial feminine hygiene products often renders them inaccessible to rural populations. In India, pricing is a critical factor influencing consumer decisions, particularly in economically constrained regions. Studies indicate that a substantial portion of the rural population, especially from lower-middle-income groups, lacks access to hygienic menstrual products, often resorting to unhygienic practices during menstruation [6]. Therefore, to improve menstrual health and hygiene for millions of rural women in India and

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globally, there is an urgent need for low-cost, biodegradable sanitary pads derived from sustainable raw materials.

Similar biodegradability concerns exist for disposable baby and adult diapers, which also incorporate large proportions of synthetic, non-degradable materials [7]. The primary functional requirement of such products is their capacity to absorb and retain bodily fluids. To achieve high absorbency, manufacturers have conventionally employed synthetic polymers, which outperform natural fibers in moisture retention [7]. Despite significant technological advancements in the diaper manufacturing industry, critical challenges remain—particularly in enhancing biodegradability and environmental sustainability. With growing awareness of the environmental burden caused by disposable sanitary products in landfills, manufacturers are now increasingly exploring biodegradable alternatives [8–10].

In this context, the utilization of agricultural waste—such as sugarcane bagasse—for the development of superabsorbent hygiene products represents a promising and sustainable solution. Not only would this innovation improve access for economically disadvantaged populations, but it would also contribute to environmental conservation by reducing plastic waste. Sugarcane, a major cash crop, is extensively cultivated in several countries, with India's Uttar Pradesh, Maharashtra, and Karnataka accounting for nearly 80% of the nation's sugar production [11,12]. During the 2023–24 season, India produced approximately 4,531 lakh metric tons (LMT) of sugarcane, with Maharashtra alone contributing 1,076 LMT.

Sugarcane processing generates various forms of agricultural waste, including dry leaves, tops, press mud, molasses, and notably, sugarcane bagasse (SCB). For every 100 tons of sugarcane processed, roughly 30 tons of bagasse are produced as byproduct. Bagasse is a fibrous material rich in cellulose (approximately 40–50%), along with hemicellulose, lignin, and waxes [13,14]. Due to its high cellulose content, year-round availability, and status as a byproduct, SCB presents an ideal raw material for producing absorbent cores in hygiene products. Importantly, its processing does not require hazardous chemicals, making it an environmentally benign option. The conversion of bagasse into biodegradable sanitary products using green technologies thus represents a significant advancement in sustainable product development.

2.0 Material and methods

2.1 Materials

Sugarcane bagasse procured from a local sugarcane juice vendor in Mumbai. Sodium hydroxide (98%), Hydrogen peroxide (30%) and Sulphuric acid (95%) purchased from Merck India ltd.

2.2 Methods

2.2.1 Synthesis of pulp sheet from sugarcane bagasse

A predetermined quantity of sugarcane bagasse (SCB) was initially subjected to thorough washing with distilled water to eliminate surface waxes and residual sugars. The cleaned bagasse was then oven-dried to a constant weight. To remove lignin and facilitate delignification, the dried SCB underwent an acid pre-treatment using dilute sulfuric acid. Following the acid treatment, the material was rinsed thoroughly with water to remove residual acid and neutralize the pH.

Subsequently, an alkali treatment was applied to the delignified material to remove hemicellulose components and enhance cellulose purity. Sodium hydroxide (NaOH) solutions at varying concentrations (0.5% to 2.0% w/v) were employed in a series of trials conducted at 100°C to determine optimal treatment conditions. The resulting cellulose pulp was washed repeatedly with distilled water until a neutral pH was achieved.

The neutralized pulp was then molded into uniform thin sheet layers and air-dried. Each batch was evaluated based on key parameters including absorbency, softness, and flexibility of the formed pulp sheets. Additionally, the yield of cellulose pulp obtained from each treatment was quantified by measuring the final dry weight, enabling process optimization based on both material performance and processing efficiency.

2.2.2 Analysis of pulp sheet and SCB sanitary napkin

The absorbency of the cellulose pulp sheets and prototypes of sugarcane bagasse (SCB)-based sanitary napkins were assessed following the IS 5405 test method, which is standardized for the evaluation of absorbent materials. Absorbency tests were conducted on both commercial sanitary napkins and the developed prototypes using a blood substitute fluid, prepared in the laboratory. The blood substitute was formulated by dissolving 164 g of salt and 100 mg of red dye in 896 ml of distilled water to simulate the fluid absorption properties.

The vertical wicking behavior of the pulp sheet and napkin prototypes was analyzed in accordance with AATCC 197, a method for measuring the rate of liquid absorption through fabric. Fluid retention capacity, which quantifies the material's ability to retain absorbed fluids, was determined using an in-house test procedure designed to simulate typical use conditions.

Air permeability of the prototypes was evaluated following the IS 11056 standard, which defines the test for determining the resistance of fabrics to airflow. Finally, the environmental performance of the products was assessed based on the Oeko-Tex Standard, which provides guidelines for measuring ecological and safety parameters in textile products.

3. Results and Discussions

3.1 Synthesis of SCB pulp

A sample of 10.0 g of washed and dried sugarcane bagasse was subjected to pre-treatment with a 1.0% sulfuric acid solution, which was boiled for 2 hours. After the pre-treatment, the residue was thoroughly washed with distilled water to remove any residual acid. Following this, the residue was treated with sodium hydroxide (NaOH) solution under continuous stirring for 5–6 hours. Various trials were conducted using NaOH concentrations ranging from 0.25% to 2.0%, with the aim of achieving a soft pulp with optimized fluid retention properties.

A photographic representation of the various stages involved in the synthesis of the pulp sheets from the bagasse is shown in Figure 1A to 1D. The characteristics of the pulp obtained and the corresponding yield of the pulp residue at different NaOH concentrations are summarized in Table 1.

Fig 1A Sugarcane Bagasse

Fig 1B Acid pre treatment of SCB

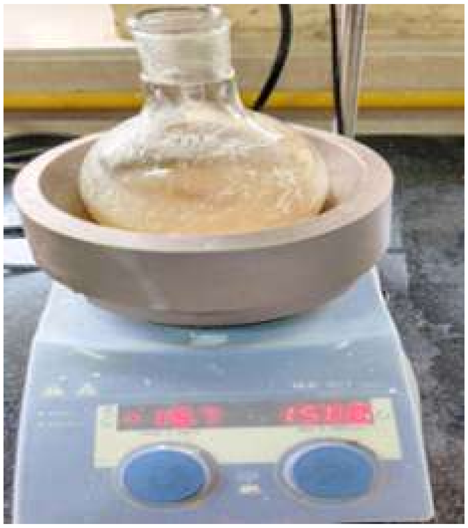

Fig 1C Alkali treatment of SCB

Fig 1D SCB pulp

Fig.1E SCB pulp sheets

Table-1 SCB pulp yield and properties

NaOH Concentration (%) for making pulp sheet	Product	Nature of product	Yield (%)
0.25	Fibre	Thick loose fibre.	90-95
0.5	Mixture of fibre and pulp	Soft sheet	45-47
1.0	Pulp	Soft sheet	40-42
1.5	Pulp	Slightly stiff sheet	35-37
2.0	Pulp	Very stiff sheet	33-35

From Table 1, it is evident that bagasse treated with a 0.25% NaOH solution remained in a fibrous form and could not be molded into a sheet. The yield of fibers in this case was 90–95%, indicating a mixture of hemicelluloses and cellulose fibers. In contrast, bagasse treated with 0.5% and 1.0% NaOH solutions resulted in a pulp form, which could be easily molded into thin sheets. The pulp yield for these treatments was 47% and 42%, respectively. Bagasse treated with 1.5% and 2.0% NaOH solutions also resulted in pulp sheets; however, these sheets were comparatively stiffer. This stiffness is likely due to the formation of a purer pulp, as higher concentrations of alkali likely converted all the fibers into pulp. Additionally, the yield of pulp obtained at 1.5% and 2.0% NaOH concentrations was lower than that from the 0.5% and 1.0% treatments. These findings suggest that the optimal concentration of NaOH required for producing soft pulp sheets with good molding properties is within the range of 0.5–1.0%.

3.2 Water absorbency of SCB pulp sheet

The water absorbency of the obtained pulp was qualitatively assessed using the AATCC 79 (drop test) method. In this procedure, a single drop of water was allowed to fall from the tip of a burette positioned 10 mm above the pulp specimen. The time taken for the water drop to lose its light reflection and transition into a dull, wet spot was recorded. The water absorbency values for each pulp sample, as determined by the drop test, are presented in Table 2.

.

Table-2 Absorbency of SB pulp sheet

NaOH concentration (%) for making pulp sheet	Character off pulp	Absorption time (sec)
0.25	No pulp formation. Loose fibres	? 3
0.5	Soft pulp sheet	< 1.0
1.0	Soft pulp sheet	< 1.0
1.5	Slightly stiff pulp sheet	< 1.0
2.0	Very stiff pulp sheet	< 1.0

From Table 2, it is evident that the pulp synthesized using NaOH concentrations ranging from 0.5% to 2.0% demonstrated excellent water absorbency, with absorption times of less than 1.0 second. In contrast, the pulp obtained from the 0.25% NaOH treatment exhibited poor absorbency, with the time to absorb water exceeding 3.0 seconds. This observation suggests that a 0.25% NaOH concentration is insufficient to produce an absorbent pulp.

3.3 Absorption property of SCB pulp sheet as vertical wicking time

The vertical wicking ability of the pulp sheets was measured in accordance with the AATCC 197 test method. This method evaluates the rate at which liquid travels along and through the specimen due to capillary action. The test was conducted by visually observing the rise of the liquid, manually timing, and recording the movement at specified intervals.

Specimens, measuring 165 mm in length and 25 mm in width, were marked at 5 mm intervals from one end of the specimen. The 5 mm line indicated the starting point at which the specimen was to be submerged into the fluid in the beaker. Additional markings at 20 mm, 50 mm, and 100 mm above the 5 mm line represented the heights to be monitored. The specimen was suspended in the beaker, and fluid was added until the liquid level reached the 5 mm line of the specimen, marking the commencement of the test. The stopwatch was started at this point, and the rise of the fluid through the specimen due to capillary action was observed. The time taken for the fluid to reach the 20 mm, 50 mm, and 100 mm marks was recorded. The wicking times for the pulp sheets synthesized using NaOH concentrations of 0.5%, 1.0%, 1.5%, and 2.0% are presented in Table 3.

From Table 3, it can be observed that the pulp synthesized using 0.5% NaOH exhibits a low wicking time, indicating a faster capillary action. This is likely due to the presence of more fibers in the pulp. As the NaOH concentration increases, more pulp is formed, and the fiber content decreases, resulting in a reduction in capillary action and an increase in wicking time. Figure 2 provides a photographic representation of the wicking experiment.

Table-3 Wicking time of bagasse pulp sheet

NaOH concentration (%)for making pulp sheet	Vertical height 20 mm	Vertical height 50 mm	Vertical height 100 mm
	Time (Seconds)	Time (Seconds)	Time (Seconds)
0.5	7	49	277
1.0	6	50	360
1.5	8	64	394
2.0	10	122	638

Table-4 Absorbency of bagasse pulp sheet

NaOH concentration (%) for making pulp sheet	Number of layer	Wt of pulp (g)	Vol. of water (ml)	Observation
0.5%	2	9.4	30	Fully absorbed
1.0%	2	8.4	30	Fully absorbed
1.5%	2	7.5	30	Fully absorbed

From Table 3, it can be observed that the pulp synthesized using 0.5% NaOH exhibits a low wicking time, indicating a faster capillary action. This is likely due to the presence of more fibers in the pulp. As the NaOH concentration increases, more pulp is formed, and the fiber content decreases, resulting in a reduction in capillary action and an increase in wicking time. Figure 2 provides a photographic representation of the wicking experiment.

Figure-2 Photograph of the wicking experiment

3.4 Horizontal absorbency of SCB pulp sheet

The absorption capacity of water in the pulp sheets was determined in accordance with the IS 5405 test method. Two layers of pulp sheets were placed on a transparent glass plate to allow observation of the underside of the sanitary napkin. A volume of 30 ml of colored water was gradually added drop by drop at a rate of 5 ml/min from a burette, positioned 1–2 mm above the sheet, and focused on the center of the specimen. Once the sheet had absorbed the entire 30 ml of colored water, a standard weight of 1.0 kg was placed on the area where the colored water was absorbed and left for 1 minute. After this, the entire length and width of the pulp sheet were examined for uniformity in absorption. The absorption properties are summarized in Table 4. Figure 3 illustrates photographs of the absorbency test procedure.
Table-4 Absorbency of bagasse pulp sheet

Fig.3A SCB sheet before absorption

Fig.3B Absorption process

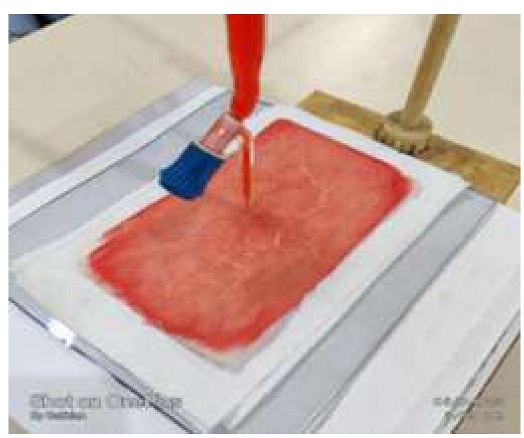

Fig. 3C fully absorbed sheets

Fig. 3D absorbed sheet under a load of 1kg.

From Table 4 it is observed that bagasse pulp sheet synthesized using 0.5, 1.0, 1.5 % NaOH is capable of holding 30 ml of coloured water with a pressure of 1 kg weight.

3.5 Water retention property of bagasse pulp sheet

The water retention capacity of the pulp sheets, defined as the maximum volume of water that can be absorbed per gram of material, was measured in terms of ml/g or g/g. To determine this property, two layers of pulp sheets were weighed and placed on a stand set at a 45° inclined angle. Colored water was then added from a 50 ml burette at a rate of 5 ml/min, positioned at the top of the sheet. Water was allowed to absorb from the top of the sheet, gradually progressing to the bottom until the sheet became saturated. The flow from the burette was halted when the first drop of water began to drip from the sheet. The burette reading was recorded, and the water retention capacity was calculated in terms of g/g. Additionally, the time taken for the sheet to absorb the water was also noted. The water retention capacity of bagasse sheets synthesized with 0.5%, 1.0%, and 1.5% NaOH concentrations is presented in Table 5. A photographic representation of the water retention test is shown in Figure 4.

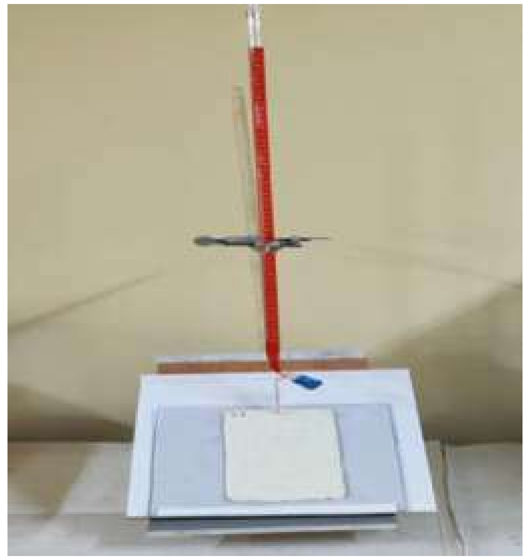

Fig.4 Photograph of water retention capacity test

From Table 5, it is evident that the bagasse pulp synthesized with 0.5%, 1.0%, and 1.5% NaOH concentrations exhibited average water holding capacities of 6.15 ml/g, 7.7 ml/g, and 4.4 ml/g, respectively. This clearly indicates that the pulp synthesized with 1.0% NaOH has higher water holding capacity compared to both the 0.5% and 1.5% NaOH treated samples. Additionally, the absorption time for the pulp synthesized with 1.0% NaOH was the shortest among all the samples.

Based on the trials conducted for synthesizing bagasse pulp using various NaOH concentrations, and considering the performance characteristics of the resulting pulp sheets, it was observed that the pulp synthesized with 1.0% NaOH exhibited superior water absorption and water holding capacity. Furthermore, this pulp was found to be softer and more flexible than the pulp produced with 0.5% and 1.5% NaOH.

Table-5 Water retention capacity of bagasse pulp sheet

NaOH concentration (%) for making pulp sheet	Weight of Bagasse pulp sheet (g)	Absorption time (min)	Volume of water (ml)	Water retention capacity (ml/g)	Average (ml/g)
0.5	3.9290	3.0	25.0	6.3	6.15
0.5	4.7832	5.0	28.9	6.0	
1.0	3.8985	2.5	30.0	7.7	7.7
1.0	3.7428	2.5	29.0	7.7	
1.5	3.4196	3.0	15.6	4.5	4.4
1.5	3.7095	3.2	16	4.3	

Consequently, in the laboratory-scale synthesis, approximately 100 sheets of bagasse pulp, each measuring 30 cm in length, 9 cm in width, and 2 mm in thickness, were produced using 1.0% NaOH. Since the goal of this study was to develop sustainable hygiene products from sugarcane bagasse, significant emphasis was placed on ensuring eco-friendliness and biodegradability, while not compromising on performance or comfort.

Eco-friendliness was assessed by testing various eco-parameters, including plasticizers, chlorophenols, formaldehyde, and bisphenols. Biodegradability was evaluated through soil burial tests. Performance evaluations were conducted with respect to absorption capacity and absorption rate. Additionally, comfort level was gauged through feedback obtained from user trials and user panels.

3.6 SCB sanitary napkin prototype design

Approximately 30 sugarcane bagasse (SCB) sanitary pads were prepared in the laboratory for performance evaluation. The SCB napkins were designed with a multi-layer structure, consisting of one hydrophobic cotton fabric as the outer layer, followed by three middle layers of SCB pulp sheets, and an inner layer of absorbent cotton gauze fabric. These five layers were stitched together along the outer borders after being shaped into the form of a sanitary napkin.

In contrast, most commercially available branded sanitary napkins consist of a polyethylene sheet as the outer layer, with cotton fibers or super absorbent polymer (SAP) forming the middle layer, and a perforated polypropylene sheet in the innermost layer. These three layers are typically thermally bonded.

Figures 5A and 5B depict cross-sectional photographs of a commercial sanitary napkin and an SCB-based sanitary napkin, respectively

A comparative study was conducted to evaluate the performance of SCB sanitary napkins in comparison to five branded commercial sanitary napkins: Whisper, Stayfree, Pro-ease, Sofy, and Paree. Most of the performance tests were carried out in accordance with the IS 5405 specifications for sanitary napkins. Since none of the existing specifications for sanitary napkins cover eco-parameters, these were tested using Gas Chromatography-Mass Spectrometry (GC-MS) (Shimadzu QP 2020 NX) in compliance with Oeko-Tex 100 standards. The air permeability of the napkins was evaluated using an APT/S auto air permeability tester, as per the IS 11056 method. The biodegradability of the napkins was assessed by conducting soil burial tests, following the ISO 11721-1 standard.

3.7 Performance evaluation of SCB sanitary napkin against commercial sanitary napkins.

The ability of SCB sanitary napkins to withstand pressure after fluid absorption was measured in accordance with the IS 5405-2019 test method. As per the procedure, the sanitary napkin was placed on a transparent glass plate to allow observation of the underside. A total of 30 ml of blood substitute fluid was added drop by drop from a burette, at a rate of 5 ml/min, to the center of the napkin from a height of 1-2 mm. After the napkin had absorbed the full volume of fluid, a standard weight of 1.0 kg was applied for 1.0 minute on the portion where the colored fluid had been absorbed. The bottom and sides of the napkin were then observed for any fluid leakage. The test sample passes if no liquid leaks through and fails if leakage occurs. The observations from the pressure tests of the sanitary napkins are presented in Table-6.

The fluid holding capacity of the sanitary napkins was evaluated using an in-house test method. To determine the

Fig 5 A Commercial sanitary napkin

Fig. 5 B Prototype of SCB sanitary napkin

fluid retention capacity, each napkin was weighed and mounted on a stand set at a 45° inclined angle. Blood substitute fluid was then added to the top of the absorbent layer at a rate of 5 ml/min from a 50 ml burette, with the tip of the burette adjusted to make contact with the surface of the napkin. The fluid was allowed to absorb from the top downwards until the napkin became saturated. The flow from the burette was stopped when the first drop of fluid began to drip from the napkin. The burette reading was recorded, and the fluid holding capacity was calculated in terms of g/g. The fluid holding capacity of both commercial branded napkins and SCB napkins is provided in Table-7.

Table-6 Pressure test of sanitary napkins

Brands	Volume of fluid (ml)	Pressure (Weight-Kg)	Observation
Whisper	30	1.0	No leakage
Stay free	30	1.0	No leakage
Pro ease	30	1.0	No leakage
Sofy	30	1.0	No leakage
Paree	30	1.0	No leakage
SCB napkin	30	1.0	No leakage

Table 6 demonstrates that all five commercial sanitary napkins, as well as the SCB napkin, comply with leakage protection standards. The commercial napkins utilize a polyethylene sheet as a barrier to prevent leakage, while the SCB napkin employs a hydrophobic cotton fabric in its outer layer to serve the same purpose.

Table-7 Fluid holding capacity of napkins

Brands	Weight of napkin (g)	Maximum fluid holding capacity (ml)	Fluid holding capacity (ml/g)
Whisper	6.38	55	8.6
Stay free	9.10	60	6.6
Pro ease	11.26	86	7.7
Sofy	9.23	43	4.7
Paree	9.10	50	5.5
SCB napkin	10.66	60	5.7

Table 7 indicates that Whisper exhibits the highest fluid holding capacity (8.6 ml/g) with the lowest weight of 6.33 g per specimen, attributable to the use of superabsorbent polymer as the absorbent material. Pro ease demonstrates a fluid holding capacity of 7.7 ml/g, accompanied by the highest specimen weight of 11.2 g. SCB napkins show a fluid holding capacity of 5.7 ml/g, which surpasses that of Paree and Sofy. The highest fluid holding capacity per specimen is observed in Pro ease (86 ml), followed by SCB napkins (60 ml). All other napkins exhibit lower fluid holding capacities than SCB napkins.

3.8 Liquid strike through time

Liquid strike-through time refers to the duration required for blood to penetrate the napkin at the dry stage. To perform this test, the napkin was placed on a plain glass plate to allow for clear observation of any changes occurring in the material. Two drops of artificial blood were applied to the sample using a syringe. The timer was started when the blood droplets made contact with the napkin and was stopped once the drops were no longer visible on the napkin's surface.

3.9 Wet back strike through time

Wet back strike-through time refers to the duration required for blood to penetrate the napkin when it is fully saturated. A colourless synthetic blood solution was prepared, and 10 ml of this solution was applied to the napkin using a syringe to thoroughly wet it. Two drops of coloured synthetic blood were then added to the napkin using a syringe, and the time taken for the blood drops to disappear from the top layer of the napkin was recorded. The liquid strike-through time and wet back strike-through time for several commercial napkins and SCB napkins are presented in Table 8.

Table-8 Liquid strike through and wet back strike through time of napkins

Brands	Liquid strike through time (Sec)	Wet back strike through time (Sec)
Whisper	2.7	18
Stay free	1.8	2.7
Pro ease	2.9	0.9
Sofy	3.0	2.0
Paree	2.6	3.0
SCB napkin	1.0	0.5

Table 8 shows that SCB napkins exhibit lower liquid strike-through time and wet back strike-through time compared to all other commercial napkins. This indicates that SCB napkins have a faster absorption rate than the other napkins, both under dry and wet conditions."

3.10 Analysis of Eco parameters

A comparative study of commercial sanitary napkins and SCB napkins was conducted with respect to their eco-friendliness. Various tests, including the analysis of Phthalates, Bisphenol A, Formaldehyde, and Butylated Hydroxy Toluene, among others, were performed on all the sanitary napkins. The eco-parameters of five commercial sanitary napkins and SCB napkins are presented in Table 9.

Table-9 Eco parameters of SCB napkin and commercial napkins

Parameters	Whisper	Stay free	Pro ease	Softy	Paree	SCB
pH	6.8	7.1	7.3	7.2	7.5	7.2
Phthalates (mg/kg)	ND	DNOP: 98.5	DBP: 377.4 DEHP:20.3	DNOP : 78.3	DNOP:108.2	ND
Bis phenol A (mg/kg)	1.4	0.54	ND	2.7	2.6	ND
Formaldehyde (mg/kg)	ND	ND	ND	ND	ND	ND
BHT (mg/kg)	848.9	1153.0	812.6	1030.7	766.8	ND
Bio-degradability (90 days)	Non bio-degradable	Non bio-degradable	Non bio-degradable	Non bio-degradable	Non bio-degradable	Fully bio-degradable

Abbreviations:
ND: Not Detected, DOP: Di-Octyl Phthalate, DBP: Di-Butyl Phthalate, DNOP: Di-N-Octyl Phthalate, DEHP: Di-Ethyl Hexyl Phthalate, BHT: Butylated Hydroxy Toluene.

Table 9 shows that the pH of the extract from all commercial napkins and SCB napkins falls within the range of 6.0 to 8.5, which complies with the IS 5405 specification. Formaldehyde was not detected in any of the napkins. Phthalates were detected in four of the commercial sanitary napkins, likely originating from the plastic components or adhesives used in the napkins. Similarly, trace amounts of Bisphenol A were detected in four commercial napkins, which could be a result of contamination from the packaging materials. All the commercial sanitary napkins tested contained BHT, which is likely sourced from the plastic or polymer components of the napkins. All five commercial napkins tested were non-biodegradable due to the presence of plastic and polymer materials. In contrast, SCB sanitary napkins were found to be fully biodegradable and compliant with all eco-friendly parameters, as they do not contain any plastic materials."

3.11 Size and dimensions of napkins

A dimension of the commercial sanitary napkins and SCB napkins were measured as per ASTM 1777 and is given in Table- 10.

According to the standard, the dimensions of sanitary napkins must not be less than 140 mm in length, 45 mm in width, 2.0 g in weight, and 1.0 mm in thickness. All the tested commercial napkins, as well as SCB napkins, comply with these specified dimensions.

3.12 Air permeability

The air permeability of five branded commercial sanitary napkins and SCB napkins was measured according to IS 11056, and the results are presented in Table 11. Air permeability refers to the breathability of the material; the higher the air permeability, the greater the comfort level.

Table-10 Dimensions of sanitary napkins

Parameters	Whisper	Stay free	Pro ease	Softy	Paree	SCB
Length (cm)	30	25	29	28	27	30
Width (cm)	7	7	7	7	7	10
Thickness (mm)	2.14	8.48	6.71	5.90	6.90	1.32
Weight (g)	6.46	8.56	11.28	9.25	8.90	10.60

Table-11 Air permeability of sanitary napkins

	Whisper	Stay free	Pro ease	Softy	Paree	SCB
Top portion	0.11	0.23	1.00	1.43	0.89	7.28
Middle portion	0.30	0.42	0.97	2.30	0.64	6.11
Bottom portion	0.33	0.93	0.28	2.90	0.36	6.34
Mean $ft^3/ft^2/min$	0.25	0.53	0.75	2.21	0.63	6.57

Table 11 highlights that all branded commercial sanitary napkins exhibit significantly lower air permeability compared to SCB napkins. The average air permeability of the commercial napkins ranges from 0.25 to 2.21 $ft^3/ft^2/min$, while the SCB napkins demonstrate a higher value of 6.57 $ft^3/ft^2/min$. The lower air permeability of commercial sanitary napkins can be attributed to the inner perforated polypropylene layer and the outer polyethylene layer, both of which serve as barriers to air flow. In contrast, SCB napkins feature an inner layer of absorbent cotton gauze and an outer layer of hydrophobic cotton fabric, both of which possess air porosity.

3.13 User panel assessment

User trials are essential for assessing the overall performance of a product. Two sets of commercial napkins (representing five different brands) and two sets of SCB napkins were provided to ten panel members for feedback. Each panel member was also given a set of questionnaires to provide their unbiased evaluations.

3.14 End user feedback summary

Feedback was collected from ten user panel members, and the summarized responses are as follows:

- 90% of the panel members reported that the overall performance of SCB sanitary napkins is comparable to that of the branded napkins available in the market.
- 80% of the panel members expressed the opinion that SCB napkins are fully leak-proof and on par with branded products in this regard.
- All panel members indicated that the comfort level of SCB napkins is superior to that of branded napkins, attributing this to the use of cotton fabric in both the inner and outer layers, as opposed to thermoplastic sheets used in branded versions.
- No panel members reported experiencing any skin rashes or irritations after using SCB napkins.
- All members highlighted that SCB napkins possess excellent absorbent properties and are durable for use.
- 20% of the panel members suggested that SCB napkins could benefit from improvements in shape and appearance to better compete in the commercial market."

Conclusions

In the present study, laboratory-scale sugarcane bagasse-based sanitary napkins were developed. SCB sanitary napkins present a promising solution, offering advantages in terms of cost-effectiveness, hygiene, and sustainability. A 1.0% NaOH solution is sufficient to convert bagasse into a soft, absorbent pulp, which can effectively replace the superabsorbent polymers used in branded commercial napkins. The SCB pulp sheet has proven to be a viable alternative for the manufacturing of biodegradable sanitary napkins. The developed SCB napkins demonstrated their efficacy through a series of laboratory tests. Absorbency tests confirmed that SCB napkins exhibit excellent fluid absorption capacity, outperforming several commercial sanitary napkins. Additionally, the SCB napkin was found to be free of toxic substances and fully biodegradable, as no synthetic materials were used during production. Since bagasse is an agricultural waste product, the conversion of this material into a value-added product using green technology represents the novelty of this project. The SCB napkin can be economically produced by rural women, particularly in regions with a sugarcane industry. Overall, this project paves the way for entrepreneurs to develop affordable, eco-friendly, and sustainable sanitary napkins, providing a new avenue for economic empowerment and environmental sustainability.

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Conflict of Interest

Authors hereby declare that there is no conflict of interest for publishing this paper. The findings published in this paper are fully authentic and based on the R&D work conducted in BTRA.

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