ISSN: 0379-5462
IPPTA: Quarterly Journal of Indian Pulp and Paper Technical Association
Vol. 35, E1, 2023, p. 133-137

PRESERVATION OF QUALITY AND RESOURCE RECOVERY THROUGH IMPROVED LACTIC ACID FERMENTATION DURING BAGASSE STORAGE





Chinnaraj S*
Dy. General Manager (R&D and QC)

Rajeshkanna P. *
Assistant Manager (R&D)

Santhakumar J.*
Assistant General Manager (Pulp)

Varadarajan S. J.*
Chief General Manager (P and PC)

R. Seenivasan*
Chief General Manager (P , R&D and SO)

**Tamilnadu Newsprint and Paper Ltd, Kagithapuram, Karur dt. Tamilnadu – 639236, India*

Abstract:

Bagasse is one of the main alternate raw material resource for wood used for paper making. To meet the bagasse requirements during off-season, it is necessary to store the bagasse in the paper mill site. Being lingo-cellulosic material with 2-3% residual sugar, other organic content and moisture, bagasse is subjected to severe decay during storage that makes large quantity of bagasse less suitable for papermaking. Wet Bulk Storage (WBS) method is used to store large quantity of the bagasse under wet and compact condition. The disadvantage of WBS is degradation of bagasse in the surface and subsurface layers of the pile, because, percolation of water inside the pile promotes the air penetration in surface and subsurface of bagasse pile through capillary action. Presence of O_2 rich air in the pile induces the growth of cellulolytic mesophlic and thermophlic microorganisms and leads to decay of bagasse present in the surface and subsurface layers resulting in the reduction of bagasse brightness, pulp yield, strength and optical properties, increase in pith generation & chemical consumption and less productivity. Impact of water sprinkling with good pile compaction to enhance hetero lactic acid fermentation and other organic acid fermentation to preserve bagasse quality during storage is discussed in this paper. Good compaction and water sprinkling favored hetero lactic acid fermentation along with other acid fermentation resulting in production of high amount of organic acids that reduced bagasse pile pH and O_2 level and prevented the growth of cellulolytic microorganisms. This has avoided bagasse decay and resulted in better bagasse fibre to pith ratio & brightness, pulp yield, strength and optical properties of the pulp. In addition, conversion of sugars into organic acids preserved the major chemical energy content of the sugars by conversion of sugars to sugar acids. Whereas in the aerobic process, this energy is lost by oxidation to form CO_2 and water. Further, these sugar acids are converted into biogas by the bio-methanation process and used as renewable green energy in the mill instead of releasing it to the atmosphere from bagasse pile during storage. Conservation of bagasse by avoiding decay, generating green energy from the waste and replacing the fossil fuel makes manufacturing process greener and environmentally friendly.

Keywords: Bagasse storage, Lactic acid fermentation, Pulp yield and strength properties, Green energy.

Introduction:

Bagasse is one of the main source of fibrous raw materials for paper making[1,2] and also used as fuel[3,4] Harvesting and processing of sugarcane in sugar mills is a seasonal activity, on the other hand papermaking is perennial activity. Therefore, to bridge the shortage of bagasse during off-season, it is necessary to store the bagasse in the paper mill site[5]. Also, fresh bagasse is not desirable for pulp production due to the presence of residual sugars which consumes higher amount of pulping chemicals.

The storage period varies from three months to maximum of nine months depending on the availability and sugar season. Being lignocellulosic organic matter with considerable residual sugar content and moisture, bagasse is subjected to microbial degradation upon storage. Severe decay of fibre due to microbes during storage makes large quantity of bagasse less suitable for papermaking[6-9]. Therefore, proper raw material storage method is highly essential for bagasse to conserver quality[5], reduce the waste, environmental impact which are part of green manufacturing process. Various storage methods are followed in different geographical locations to store the bagasse depending on local conditions, such as availability of space and end use. The dominant storage methods are 1: Baled storage, 2: Ritter Biological Process and 3: Wet Bulk Storage Method[5].

Wet Bulk Storage Method: In this method bagasse is stored in high volume, wet and compact condition along with water. This creates the pure anaerobic condition in the middle and bottom layers of bagasse pile. The anaerobic condition promotes the growth of acidogenic and lactic acid microorganisms. As a result, high amount of organic acids produced inside the bagasse pile and reduce bagasse pile pH and prevents the growth of cellulolytic microorganisms which attack bagasse fibre during storage. However, the surface and subsurface layers of the bagasse pile remain in aerobic condition, because in the surface percolation of water inside the pile promote the air penetration in surface and subsurface of the bagasse pile and creates aerobic condition. This induces the growth of cellulolytic mesophlic and thermophlic microorganisms and decomposes bagasse at the surface and subsurface layers and reduce the quality[6,7,10,11]. The presence of residual sugars (sucrose, fructose, glucose), proteins, fatty acids minerals etc., makes bagasse as a good source of substrate for the growth and reproduction of all kinds of microorganisms. The disadvantage of the undesired microbial action is storage loss, generation of pith content (fibre fragments), reduction of bagasse brightness, pulp yield & quality, increase in chemical consumption and less productivity. Finally and more importantly, the loss of dissolved organics due to oxidation which in turn are washed out as COD and used for biogas generation before pulping[12]. Therefore, there is a need to study the impact of the environment and other parameters which influence on the microbial activity in bagasse pile. Our efforts to improve the anaerobic condition or reducing the aerobicity to promote acidolytic and lactic acid fermentation during the storage of bagasse by regular water sprinkling are discussed in this paper.

REVIEW OF LITERATURE

Efficient and optimum utilization of waste and raw-materials are becoming more and more important for sustainable production and consumption in entire life cycle of economic activities from the extraction of natural resources, production, use, and finally disposal of resources. Efficient use of resources including the waste to reduce the resource consumption will have positive impact on environment as well as on economy[13]. Adaptation of circular and resource-efficient models would reduce environment impact by efficient use of both virgin and waste resources[14,15]. Pulp and paper manufacturing is more sustainable when compared to other manufacturing industry and many of the in house wastes are utilized as raw materials or energy sources[16]. It is reported that bagasse, sugarcane waste from the sugar mill is effectively used in the pulp and paper industry by adding more value than utilizing it as fuel in the sugar mill boilers[17]. As indicated earlier, it is necessary to store the bagasse to meet requirements of the pulp production throughout the year in the paper mill. The various methods of storage and its merits and demerits are earlier discussed in detail by various authors[5]. Among the various methods used for large scale storage of bagasse, Wet Bulk Storage is considered to be more suitable for paper and pulp industries when compared to other storage methods[2,6-10]. Though the WBS is used in many paper mills, preservation of the quality in the surface and sub-surface is still an issue and quality difference exists at various levels of the pile. Top layer bagasse yields a pulp of low brightness and poor strength properties due to the aerobic condition and suffers severe discoloration and degradation[18].

The reason for bagasse deterioration especially in the surface and subsurface layer is profuse growth of aerobic bacteria, actinomycetes and fungi[10]. Presence of residual sugar content in bagasse, soluble organics, heterogeneity of the tissues, vast exposed surface area and atmospheric openness of the pile are making bagasse a fertile substrate for these microbes[6,7,10]. Extent of degradation is subjected to various environmental conditions such as temperature, pH and aerobicity. Thermophylic fungi, bacteria and actinomycetes are more adapted to higher temperatures and start to proliferate as the temperature approaches 45^{0}C and mesophylic organisms that dominated the pile previously, become inactive. Cellulolytic action is intensified by this stage and does more damage to fibre. Thermophylic microbes continue to develop until a maximum temperature is reached (65^{0}C). This inactivates the different extracellular enzymes that limit the nutrient availability. This type of microbial succession happens in the core and bottom layers of the pile where heat loss is minimum[l6]. However in the surface and surface layers due to diffusion of heat to atmosphere and infusion of air makes pile more vulnerable to microbial attack. The pH of surface and subsurface of a pile is 5.5 to 6.5 which creates an ideal environment for the microbes and in the core area of the pile pH is 3.5 to 4.0 which is not favorable for microbes[6,7]. Lactobacilli and other acidogenic microbes which can produce organic acids reduce the pH and prevent microbial growth and bagasse degradation. The literature clearly indicates that Temperature, pH and aerobicity are the main factors that contribute towards degradation of the bagasse in the WBS method specifically in the surface and subsurface layers. These conditions are needed to be monitored and maintained at level that is unfavorable for the growth of microbes which degrade the bagasse and at the same time promote the microbes which produce the organic acids such as lactobacillus and other microbes viz. *Streptococcus Escherichia, Acetobacter, Propionibacterium* and *Clostridium*. Regular sprinkling of water using sprinklers systems, in order to keep the pile as moist as possible and reduce aerobicity and good compaction by running Chain Dozers on the pile during pile formation to improve the compaction of pile and to reduce air penetration will certainly preserve the bagasse quality.

MATERIALS AND METHODS

The standard pulping conditions adopted for the pulping are listed in the Table 1. Other major parameters analyzed as per the following standard methods such as fibre pith ratio (Tappi UM 3), Kappa Number (ISO 302:2015), Brightness (ISO 2470-1: 2016), CSF (ISO 5267 2), Tensile Index (ISO 1924-3:2005), Tear Index (ISO 1974:2012), Burst Index (ISO 2758:2014), Color (ISO 7887:2011) Total Solids, Total Dissolved Solids, Total Suspended Solids (IS 3025) and Chemical Oxygen Demand - Soluble (ISO 15705: 2002).

Table 1: Standard pulping conditions

S. No	Parameters	Unit	Conditions
1	Chemical addition	%	12
2	Sulphidity	%	20
3	Bath ratio		01:04.0
4	Cooking temperature	°C	170
5	Cooking time	minutes	20
6	H - Factor		450

RESULTS AND DISCUSSION

The presence of residual sugars (sucrose, fructose, glucose), proteins, fatty acids minerals etc., makes bagasse as a good source of substrate for the growth and reproduction of all kinds of microorganisms. In the conventional WBS method, bagasse deteriorates at a rapid rate in the subsurface area due to microbes. The intensity of microbial degradation is dependent on various environmental parameters, such as, temperature, pH moisture and aerobicity. Conditions, such as moisture from 30-60%, temperature 30-55^{0}C, pH from 5.5 to 8 and high aerobicity or O_2 availability in bagasse pile[6,7]. Water sprinkling on the bagasse created a positive impact on bagasse quality by reducing the air penetration thereby anaerobic condition in the sub-surface of the pile i.e. about 15 cm to 30 cm below the surface of pile and upto 150 to 200 cm.

This has led to preservation of bagasse brightness and fibre pith ratio. The results clearly indicate that the brightness and fibre pith ratio of the bagasse is preserved well (brightness: initial 38.6, final 33.5 %ISO & fibre pith ratio: initial 2.15:1, final 2.03:1) and quality of the bagasse is superior when compared to pile stored without water sprinkling where both brightness and fibre pith ratio are reduced significantly from initial 38.6 to 18 %ISO & fibre pith ratio from 2.15:1 to 0.5:1 (Table: 2). The reduction of bagasse quality in the subsurface area is reported in the earlier studies[5,18]. Water sprinkling supports the bagasse preservation by limiting the growth of aerobic microbes such as fungi, and actinomycetes and encourages the acidogenic bacteria that converts the organic compounds into organic acids and make the environment more acidic by reducing the pH to the level of less than 4,0 which is not suitable for growth of any microbes. Reduction of microbial growth and attack on bagasse led to preservation of bagasse quality even in the subsurface layer.

Table 2: Impact of water sprinkling on bagasse quality during storage

S. No	Period	Without water sprinkling		With water sprinkling	
		Brightness %ISO	Fibre: Pith ratio	Brightness %ISO	Fibre: Pith ratio
1	Initial	38.6	2.15:1	38.6	2.15:1
2	Two months old	37.5		37.9	
3	Three months old	28.3		36.3	
4	Four months old	22.5		35.5	
5	Six months old	18	0.5:1	33.5	2.03:1

The study was carried out for six months and after six months of storage and water sprinkling, samples were collected from subsurface layer of water sprinkled, non-sprinkled area and from the bottom of the pile and used for pulping study in the laboratory to find out the impact of water sprinkling on the bagasse pulp quality. The results are presented in the Table 3. From the above studies, it is clear that water sprinkled over the bagasse pile preserved the bagasse quality relatively well when compared to non-sprinkled area. Water sprinkling resulted in nearly 15.5 points higher bagasse brightness and 1.53 points higher fibre pith ratio.

Also, the sub-surface samples collected after six months from both the water sprinkled, non-sprinkled and from bottom of the pile were used for pulping study. The results of the pulping study are presented in the Table 3. The results indicate that Kappa number (54.0) and rejects (2.8%) are higher for the pulp collected from water non-sprinkled when compared to water sprinkled (Kappa number 11.9, rejects (0.58%) area. The pulp yield, strength

Table 3: Impact of water sprinkling on bagasse pulp quality

S. No	Particulars	Without water sprinkling		With water sprinkling
		Sub-surface	Bottom	Sub-surface
1	Fibre:Pith ratio	0.5:1	2.31:1	2.03:1
2	Bagasse Brightness, %ISO	18	37.5	33.5
3	Total yield, %	41.1	55.7	54.7
4	Rejects, %	2.80	0.47	0.58
5	Kappa number	54.0	10..6	11.9
6	Brightness, %ISO	18.1	39.4	36.1
7	CSF, mL	500	450	440
8	Tensile index Nm/g	24.5	67.6	61.8
9	Tear index mNm^2/g	3.98	5.64	5.23
10	Burst index $kPam^2/g$	1.15	4.09	3.68

Table:4 Characteristics of wastewater from bagasse WBS yard

S. No	Parameters	Bagasse wash water	Central channel water
1	pH	4.6	3.9
2	VFA meq/L	48	112
3	Color Pt.-Co.	350	540
4	Total solids mg/L	5283	10400
5	TDS mg/L	4283	9560
6	TSS mg/L	1000	840
7	COD soluble mg/L	3651	15400

Table: 5 Fuel saving and GHG reduction from biogas plant for the year 2021-22

Biogas generation, m^3/year	95,67,079
Furnace oil saving, kL/year	5,740
Bagasse wash wastewater treated m^3/year	48,15,750
COD reduced, MT/year	18,261
GHG Emission reduction, MT CO_2eq	18,636

and optical properties (pulp yield 54.7%, brightness 36.1, tensile index 61.8, tear index 5.23, burst index 3.68) were also better in the water sprinkled area when compared to water non sprinkled (pulp yield 41.1%, brightness 18.1%, tensile index 24.5, tear index 3.98, burst index 1.15) area (Table 3). However, the quality of the bagasse, pulp yield, strength and optical properties were found to be relatively good in the bottom layer of both water sprinkled and non-sprinkled areas (Table 3). This clearly indicates that pile compaction and anaerobic conditions of the pile are important criteria for the bagasse preservation in the WBS as evidenced by the earlier studies[5]. In addition, production of organic acids by anaerobic microbes through heterogenic lactic acid fermentation and other microbial reaction are responsible for the production of organic acids which reduce the pH and make the environment unsuitable for the growth of cellulolytic microbes that are responsible for bagasse degradation. (Figure 1). It is clearly evidenced by the high volatile fatty acids (VFA) content and low pH of the bagasse wash water (Table 4).

Efficient and optimum utilization of waste and raw-materials are becoming more and more significant for sustainable production and consumption in entire life cycle of economic activities[13-15]. These practices are important foundation for green manufacturing process. Proper management of bagasse WBS not only yields good quality bagasse but it also adds value to the residual sugars present in the bagasse which are not extracted from the sugar mill. It is know that the bagasse received from the sugar mill contains about 2.5 to 3.0 % sugars. In aerobic process, residual sugars and other organics are oxidized into water and carbon dioxide by taking the oxygen from the air. The energy stored in the sugars are simply oxidized by aerobic microbes and released to atmosphere as waste. However in well managed WBS system, these organics undergo hetero lactic acid fermentation or other anaerobic fermentation and converted to sugar acids and nearly 90% of energy is transferred from sugar to sugar acids. The sugar acids are removed by washing in the fibre preparation plant before pulping and sent along with bagasse wash wastewater to the bio-methanation plant. Also, the waste water generated in the bagasse WBS yard is collected in the central channel (Plate 1) and recycled back to increase the bagasse consistency and compaction during the bagasse pile formation. The excess central channel water containing high VFA content and COD is also sent to bio-methanation plant.

These two wastewaters viz. bagasse wash wastewater from fibre preparation plant from chemical bagasse pulp mill and central channel wastewater from bagasse WBS yard (Table 4) are mixed together and used as feed to bio-methanation plant where the chemical energy from the bagasse residual sugars (transferred to sugar acids) are converted into biogas in the closed biogas reactors again by the anaerobic microbes The biogas is used as in-house renewable green fuel in the Lime Kiln to replace the furnace oil and to reduce greenhouse gas emissions. The economic and environmental benefits of the biogas utilization are listed in the Table 5 and reported by earlier studies[12,16].

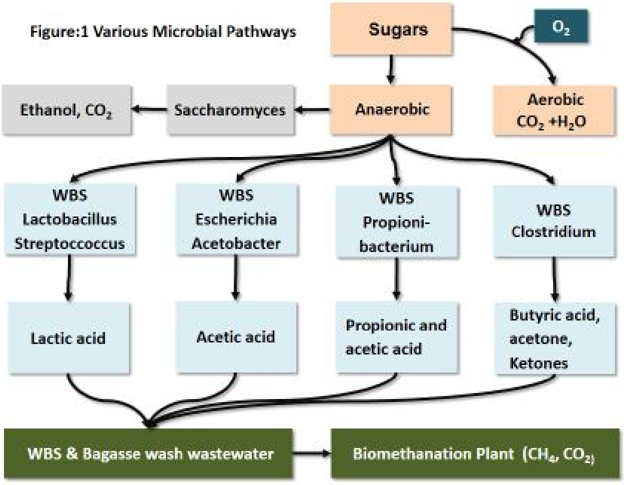

Plate 1. Central channel water recycling in WBS system

CONCLUSIONS

Impact of water sprinkling with good pile compaction to enhance lactic acid fermentation and other acid fermentation preserves the quality of subsurface bagasse during WBS storage by 15.5 % ISO brightness and 1.53 points higher fibre pith ratio when compared to non-sprinkling pile. Similarly, pulp yield, strength and optical properties of the pulp are also found to be high for the subsurface bagasse of water sprinkled pile when compared to non-sprinkling pile.

Another major benefit of well managed bagasse WBS system is that the majority of chemical energy stored in the residual sugars present in the bagasse is converted in to sugar acids by anaerobic fermentation. Then these sugar acids are converted to green energy viz. biogas in the bio-methanation process and used as in-house renewable fuel in Lime Kiln to replace fossil fuel and to reduce carbon foot print, climate change are the main objectives of the Green Manufacturing process.

Acknowledgements

The authors are thankful to TNPL management for support and permission to present this paper in IPPTA seminar.

REFERENCES

1. Atchison J.E., Bagasse. In: Pulp and Paper Manufacture: Secondary fibers and non-wood pulping. Vol. 3, Ed.by F. Hamilton and B. Leopold. Tappi, Atlanta. 22-66 (1987).
2. Atchison J.E., The bagatex-20 process for rapid drying and preservation of bagasse in large bales by accelerated and controlled fermentation. Non-Wood Plant Fibre Pulping Progress Report 18, Tappi Press, Atlanta: 11-25 (1988).
3. Morgan R., et al., Wet Bulk storage of bagasse. Proc. Int. Soc, Sugarcane Technology, 15: 1793-1819 (1974).
4. Purchase B.S. et al., Challenges and potential solutions for storage of large quantities of bagasse for power generation. Proc. South African Sugar Technology Association 86: 495 - 513 (2013).
5. Singh, N. Influence of fungal diversity and production of cellulolytic enzymes on decay of stored bagasse. M.Sc. Dissertation, Department of Microbiology and Plant Pathology, University of Pretoria (2007).
6. Ramaswamy V. et al., Role of fungi in the biodegradation of wet pile stored bagasse under tropical conditions. Tappi Pulping Conference: 803-806 (1989).
7. Rangamannar G., et al., Improved wet bulk storage of bagasse for newsprint pulp production, Part one. Tappi Pulping Conference, 391-395 (1993).
8. Salaber J. & Maza F. (1971). Ritter biological treatment process for bagasse bulk storage. Non-Wood Plant Fibre Pulping Progress Report 2. Tappi Press, Atlanta 89-136 (1971).
9. Wang J.S.I. & Tao H.Y. (1978). Bagasse handling and storage system at Pingtun pulp factory, Taiwan Sugar Corporation. Non-Wood Plant Fibre Pulping Progress Report 9, Tappi Press, Atlanta: 73-81 (1978).
10. Cusi D.S. (1979). Storage and conservation of bagasse. Non-Wood Plant Fibre Pulping Progress Report 10, Tappi Press, Atlanta (1979).
11. Misra D.K. (1971). Comparative study of bagasse and wheat straw for pulp and papermaking. Non-Wood Plant Fibre Pulping Progress Report 2, Tappi Press: 51-87 (1971).
12. Chinnaraj S. and G. Venkoba Rao. Implementation of an UASB anaerobic digester at bagasse based pulp and paper industry. Journal of Biomass and Bio-energy, 30: 273 – 277 (2006).
13. The Circularity Gap Report, (2020). www.Circule-economy.com
14. Oberle, B. et al. Global Resources Outlook: Natural Resources for the Future We Want (2019). A Report of the International Resource Panel. United Nations Environment Programme. Nairobi, Kenya
15. A Paris Agreement for recycling the Earth's resources, (2022). World Business Council for Sustainable Development. www.wbcsd.org.
16. Chinnaraj S. Circular economy for resource conservation, GHG emission reduction and carbon sequestration. IPPTA, 34(3): 68-75 (2022).
17. Chinnaraj S. et al. Green manufacturing practices: TNPL case study on value addition to waste. IPPTA, 27(3): 37-45 (2015).
18. Reedy K.P. Wet bulk storage- quality variations in bagasse within the pile. IPPTA 3(3): 32-40 (1991).