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Microbial Retting of Jute Bast Fibre Using Aerobic Sequencing Batch Reactor

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Abstract: This article focusses on the microbial retting of jute bast fibres under aerobic condition using sequencing batch reactor. Retting operation was carried out for varying time period namely 10, 15, 20, 25, 30 and 35 days respectively. The optimum retting period was judged based on the characteristics of the retted fibre with respect to fibre fineness, tenacity, modulus, strain at break and linear density. The morphological characteristic were visualized based on the scanning electron microscope image. As the retting period increased the fineness of the fibre improved; however based on the tenacity (0.468 N/tex) and modulus (50.23 N/tex) a 25-day retting period was found to be optimum in this present study. The predominant microbial species present in the jute retting liquor were found to be species of *Bacillus, Clostridium, Aspergillus* and *Mucor*. As the current method of retting operation was carried out under aerobic condition, the emission of green house gas doesn't arise. Moreover the wash water arising due to rinsing of retted fibre was recycled, thereby achieving a zero discharge concept.

Key words: Microbial retting, jute, bast fibre, tenacity, geotextile fibre, sequencing batch reactor.

Introduction

India is the leading jute producer in the world, which accounts for approximately 66% of total jute produced. Jute is one of India's important foreign exchange yielding crops and are grown approximately in about 80,00,000 ha. In India and Bangladesh brown jute (*Corchorus capsularis* L.) is grown both in water-logged and upland areas. White jute (*Corchorus olitorius* L.) can withstand water-logging if the plants are more than 1.2 m high. These plants by themselves are not involved in the elimination of methane, which are produced under waterlogged anaerobic conditions (Jarman, 1985). Jute occupies the most important place among the bast fibre. The dried jute plant when subjected to retting process yields two important products namely jute fibre and jute stick. While the jute fibre finds its way in numerous application including apparels, the jute sticks are mainly used as fuel by the farmer during the rainy season (Banerjee, 2001). Flax, jute, hemp and ramie, to name but a few of the best fibres, have traditionally taken a secondary role in terms of consumption and functional requirements. They are relatively coarse and durable, and flax has traditionally been used for linen making. Jute, ramie and to a lesser extent other fibres have received attention within the geotextile sector of the fibre markets which seeks to combine the need for temporary to short-term usage with biodegradability, taking into account the regional availability of the fibres (Horrocks and Anand, 2000).

Fibre retting process aims on removing non-cellulosic material attached to fibres to release individual cellulosic fibres. During retting, phloem-derived fibre bundles are loosened from other stem tissue, composed of hemicellulose, lignin and pectin. Several enzymes are known to be able to degrade the abovesaid binding

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polymers namely: hemicellulases (xylanases), ligninases (mostly of polyphenol oxidase type), and pectinases (polygalacturonidase, pectin-lyase, pectinesterase). Traditionally, two retting methods namely dew retting and water retting have been used; both were carried out by pectic enzymes secreted by indigenous microflora. The pectin depolymerization reactions are generally the most important components in the process known as fibre retting which can also be accomplished by the following types of retting processes viz. mild alkali retting, enzymatic retting, ribbon retting and steam retting. The degree of retting can be judged from the fibre quality criteria. One easy subjective test for fibre quality estimates the ease in which the fibre can be separated from the stem, by breaking and crushing the stem between the fingers (Ray and Mandal, 1967; Avella et al., 1992; Bailey and Pessa, 1990; Basal et al., 1987; Hart, 1990; Tanner et al., 1993; Elena et al., 2003). Seawater retting of bast fibres had also been tested (Zhang et al., 2008).

Microbial retting has been carried out on various type of bast fibres namely *Crotalaria juncea* (sunhemp) (Maheshwari et al., 1994), kenaf fibre (He and Zhao, 1990; Feng et al., 1997; Yu and Yu, 2007) and jute (Banerjee and Bhargava, 1980; Ghosh et al., 1983; Bhattacharyya et al., 1987; Sun, 1991). As microbial retting of jute fibre are based on the controlled fermentation process in which the cortical and phloem tissues of the bark of the plants containing free strands are decomposed to separate fibre from non-fibrous woody stem (Asaduzzaman and Abdullah, 1998; Bose, 1969). During the fermentative process the microorganisms consume the cementing materials viz., the pectins, hemicelluloses and proteins with release of galacturonic acid and sugar in retting water (Basak et al., 1998). Methane emission from jute-retting tanks was measured for a period of four years during the months August to October 1988-1991 at West Bengal, India. The rate of methane emission varies between 8 and 779 mg per square metre per hour (average 148 mg m^{-2} h^{-1}) (Banik et al., 1993). The methane emission from jute retting tank was about 10-100 times greater than that of the methane production rate in Indian rice fields (Parashar et al., 1991).

The traditional method of jute retting operation is carried out by submersing the jute stem portion in stagnant water or slow flowing water of tanks or wayside ditches for about 2-4 weeks when soil microorganisms degrade the cementing material, pectin and hemicelluloses, freeing the phloem fibre, which are then washed in water. The organic matters which were released during the decomposition include sugars, aminoacids and proteins, which support the growth of various microorganisms including the anaerobic methanogens present in the soil. Consequently pH of retting water drops and redox potential reaches a highly negative value, indicating that the aquatic bodies are turning anaerobic which in turn leads to environmental pollution problems. Apart from water pollution the atmospheric pollution also arises due to evolution of green house gases. Large volumes of methane are emitted during the retting season of August through October under Indian conditions (Banik et al., 1993).

Hence the current study aims to overcome disadvantages posed by the traditional retting process by adopting aerobic retting process using a sequencing batch reactor. To the best of our knowledge, no study has been presented based on this concept. Therefore, this paper attempts to remove non-cellulosic materials from jute bast fibre during the retting operation using consortium of microflora isolated from the highly degraded jute present at its natural site. The retted jute bast fibre shall be analyzed for its physical strength namely fibre fineness, tenacity, Young's modulus, strain at break and linear density. The morphological analysis shall be carried out based on the scanning electron microscopic images. As the current method of retting operation was carried out under aerobic condition, the emission of green house gas doesn't arise. Moreover the wash water arising due to rinsing of retting fibre shall be recycled thereby achieving a zero discharge concept.

Materials and Methods

Biomass Acclimatization in Aerobic Sequential Batch Reactor

The seed microflora was collected from the highly decomposed jute biomass which occurred in a naturally retted site (dump yard of the trash jute plant). The biomass was cultured in five numbers of 2-litre shake flask using nutrient medium under aerobic condition at 27°C and 250 rpm for a period of two days. The nutrient medium consisted of the following constituents in mg/l namely $C_6H_{12}O_6$ (900), KH_2PO_4 (55), K_2HPO_4 (45), NH_4Cl (460), $MgSO_4$ (40), $CaCl_2$ (30), $FeCl_3$ (16), $FeSO_4$ (5) and $NaHCO_3$ (2500). The culture broth was spiked with micronutrient at following concentration namely H_3BO_3 (0.15), $ZnCl_2$ (0.05), $CuCl_2$ (0.02), $MnSO_4$ (0.05), $(NH_4)_6Mo_7O_{24}$ (0.06), $CoCl_2{\cdot}6H_2O$ (0.15), and $NiCl_2$ (0.04) mg/L. Thereafter the biomass was transferred into the aerobic sequencing batch (ASBR) reactor in order to be acclimatized in retting operation along with raw jute bast fibre. The aeration was achieved using diffused aeration system with a maximum air flow rate of 5 m^3 hr^{-1}.

Characteristics of Jute Bast Fibre

The jute plants having an average plant age of 116±2 days were harvested and were preserved at 10°C in airtight plastic bags. The samples were preserved for a maximum period of five days before subjecting to retting operation. Thereafter samples were taken to analyze the initial composition of α-cellulose, wax, pectin, hemicelluloses, lignin, ash and gum content (APHA, 1985). The chemical characteristics of jute bast fibre are as shown in Table 1 on dry basis. Simultaneously samples were cut in length of 30 cm and subjected to retting operating in the ASBR.

Table 1: Chemical characteristics of jute bast fibre

Parameter	*Composition (%)*
α-Cellulose	56.25
Wax	0.73
Pectin	10.23
Hemicelluloses	15.72
Lignin	12.94
Ash	2.15
Gum	1.21

Testing Methods—Retted Jute Fibres

The retted jute fibres were subjected to washing and air drying under shade. Random sample of jute fibres were drawn in order to determine the fibre fineness, tensile strength, Young's modulus, strain at break and linear density (ASTM, 2008).

Morphological Analysis of Retted Jute Fibres

Samples of the retted jute bast fibres were mounted on the stubs and sputter coated with gold followed by analysis of fracture surfaces of the fibre using Joel JSM 5910 scanning electron microscope.

Microbial Retting Process of Jute Plant

The microbial retting operation of jute plant was carried out in the aerobic sequential batch reactor. Before commencing of the retting operation the jute bast fibre was chopped into a length of 30 cm. During the retting operation samples were drawn from the retted material over a varying period of time viz. 10, 15, 20, 25, 30 and 35 days respectively, in order to ascertain the fibre quality of retted jute. The biomass concentration in the ASBR was maintained around 5160±120 mg/l throughout the retting operation. Retted materials were washed with fresh water, and the same was recycled back to retting tank. Hence adopting ASBR with the concept of recycling wash water from retted fibres resulted in achieving the zero discharge of process wastewater into the environment.

Analytical Technique—Biomass Estimation

The biomass concentration was determined based on mixed liquor volatile suspended solids concentration (MLVSS) in the reactor. MLVSS was determined by evaporating the well mixed sample in a weighed crucible and dried to constant weight in an oven at 105°C. The increase in weight over that of the empty crucible represents the total solids. The volatile solid (biomass) was determined by igniting the residue that was left out after the determination of total solids at 550°C. The weight loss after the ignition represents the MLVSS content (APHA, 1985).

Results and Discussion

The reason for choosing harvesting period of jute plant at a plant age of 116±2 days was that as the plant gets older the retting period of bast fibre increases. Researchers had proved that increase in plant age for jute (bast) fibre resulted in an increase in retting period thereby its fibre quality was decreased. Thus indicating cost benefit ratio for optimum harvest time (110-120 days) for the extraction of bast fibre by retting operation (Banik et al., 2003). The correct time for jute plant harvesting were judged when the plants are in the small-pod stage (120 days) (Jarman and Robbins, 1986). Hence the harvesting period chosen for the jute plant in this study was in conformity with other researchers.

Biomass Acclimatization in Sequential Batch Reactor

Figure 1 shows the biomass concentration build-up during the acclimatization period when retting jute plant. The acclimatization period was carried for a period of 12 weeks, which was characterized into two phases namely first phase consisting of addition of carbon and nutrient source, while second phase began with the addition of nutrient source alone. During the first phase the ASBR was supplemented with carbon (1 % glucose) and nutrients like nitrogen and phosphate at a ratio of 100:5:1 for a hydraulic retention time of one day. Subsequently the addition of micro-nutrients was also carried out during the process in the following concentration: H_3BO_3 (0.15), $ZnCl_2$ (0.05), $CuCl_2$ (0.02), $MnSO_4$ (0.05), $(NH_4)_6Mo_7O_{24}$ (0.06), $CoCl_2 \cdot 6H_2O$ (0.15), and $NiCl_2$ (0.04) mg/l once a week. The first phase was completed at the end of five weeks of operation. Thereafter in the second phase the supplementation of carbon source was stopped, while the addition of macro and micro nutrients was carried out once in every four days and the biomass was forced to feed on the jute fibre. As shown in Figure 1 with the increase in acclimatization period the biomass concentration also increased. For example in the case 1, 3 and 5 weeks of operation during the first phase of acclimatization period the biomass concentration was found to be 2145, 3479 and 4705 mg/l respectively. While during the second phase of acclimatization period namely on the 6, 9 and 12 weeks of operation the biomass concentration was found to be 4946, 5424 and 5796 mg/l respectively. Till the five weeks of acclimatization period the biomass build-up was relatively more when compared to 6 to 12 weeks of acclimatization period.

As shown in Figure 2, with the increase in acclimatization period the biomass concentration also increased. For example during the first phase of acclimatization, for a period of five weeks of operation the biomass concentration showed a rapid increase from a value of 2145 to 4705 mg/l. The reason behind for this observation was due to the supplementation of carbon source during the initial period which resulted in more biomass concentration. During the second phase of acclimatization period namely 6 to 12 weeks of operation the biomass concentration showed a rise from a value of 4946 to 5796 mg/l respectively. In the second phase of acclimatization period biomass build-up was solely dependent on the jute as substrate. Moreover during the second phase the biomass showed a steady rise thus confirming the ability of microbes in degrading the fibre as the values of MLVSS were found to be increasing with the increase in acclimatization period. Banik et al. (2003) stated that the mixed bacterial culture was effective in reducing time of retting. Jute retting proved to occur faster at 34°C than at 27°C (Ray and Mandal, 1967). Whereas while adopting ribbon retting the length of the retting period could be reduced considerably (Mitra, 1999). Microbial retting of jute by mixed bacterial microflora resulted in fine fibres, but it did not improve the strength of fibres (Alam, 1998).

Mechanical Properties of Microbial Retted Jute Fibre

Figure 2 shows the fibre finesses of the retted jute bast fibre for varying retting period. For example by varying the retting period of jute bast fibre for 15, 25 and 35 days the fibre fineness was found to be 2.4, 1.3 and 0.9 tex respectively. As the fineness increased with the increase in retting period, it can be concluded that the microflora are well adapted in the retting operation under aerobic condition. Fine fibre is preferred, but at the same time those fibre should retain the tenacity and modulus in order to be made as a yarn. But prolonged retting period above 25 days resulted in negative effect as the fibre became brittle. The chemical modification of jute fibre by treating in sodium hydroxide at a concentration of 30 g/l resulted in a fineness value of 1.85 tex (Wang et al., 2008). In practice, manufacturers of multifilament yarns produce a number of standard linear densities that, for industrial filtration purposes, may range in fineness from 120 decitex to 2200 decitex, with individual filaments varying from 6 to 10 decitex. From this it can be shown that the diameter of such filaments will be of the order of 0.03 mm (Horrocks and Anand, 2000). The optimum

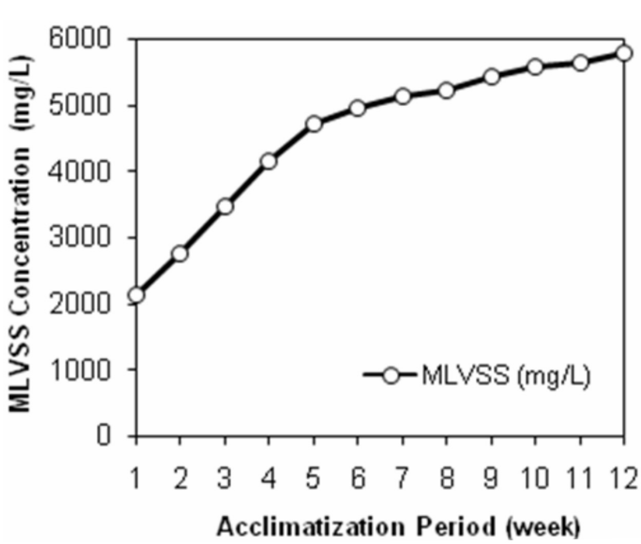

Figure 1: Biomass concentration versus acclimatization period.

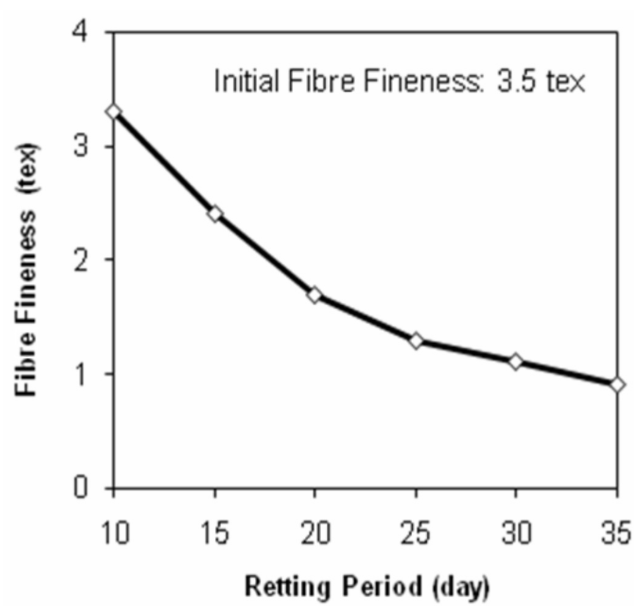

Figure 2: Fibre fineness versus retting period.

fineness in this present investigation was found to be 1.3 tex, when the jute were retted for a period of 25 days.

The tenacity of the retted jute bast fibre versus varying time period namely 15, 25 and 35 days are shown in Figure 3. For the abovesaid retting period the tenacity was found to be 0.367, 0.468 and 0.385 N/tex respectively. After a retting period of 25 days the tenacity showed a downward trend. Figure 4 shows the modulus of the retted jute bast fibre for varying time period. For example in the case of retting period of 15, 25 and 35 days the modulus was found to be 39.48, 50.23 and 45.18 N/tex respectively. Similar to tenacity the initial modulus also showed a downward trend above a retting period of 25 days. As the retting period increased the tenacity and modulus of fibre increased, but prolonged retting period resulted in negative effect above 25 days. The differences in tenacity seem to be related to morphological aspects other than crystallinity variations, but also on the method of retting operation. The tenacity of the jute fibre reached upto a maximum of 0.468 N/tex in this present investigation, whereas the corresponding modulus was 50.23 N/tex. The tenacity of jute fibre derived from this experiment was incomparable with jute (0.31 N/tex) or hemp (0.47 N/tex). Also the modulus of jute bast fibre was higher when compared to other fibres such as flax (18.0 N/tex), jute (17.2 N/tex) or ramie (14.6 N/tex) (Eromosele et al., 1999). On the other hand, the differences in value which were observed between different researchers are associated with the process operation involved in retting or mechanical processes. These results could be associated with chemical changes of non-cellulosic components as pectins of the cell wall during the biological process.

Tensile modulus depends on the stiffness and the orientation of the microfibrils in the cell wall (Mark, 1967; Davies and Bruce, 1997). In the blast fibres the microfibrils are oriented at small angle to the fibre axis. For example, in hemp this angle has been reported to be in the region of 2-3° to the axis of the fibre (Preston, 1974) and with a Young's modulus estimated to be in the region of 134 GPa (Sakurada et al., 1962). Distinct drop in tensile strength of the fibres followed with the increase in retting period. The validation for the drop in tensile strength could be due to removal of pectins and other cellular cementing materials during the retting process, that was present in the inter-fibre, thereby weakening the fibre. These observations are in corroboration with the results obtained from the flax fibres (Stuart et al., 2006). Hemp, jute and kenaf are bast fibres exhibiting brittle fracture and have only a small extension at break. They have a high initial modulus, but show very little recoverable elasticity. Tensile analysis and modulus has revealed that the mechanical behaviour of jute fibre were comparable with other lignocellulosic fibre bundles such as flax, ramie or hemp. A tenacity of 70 g/Tex was found to be a reasonable middle value for a wide range of jute fibres (Rowell and Stout, 1998). The pertinent factor for a geotextile, especially for reinforcement, is that it must possess a high tensile strength. It is known that the best way of obtaining this criterion is in the form of fibres which have a high ratio of molecular orientation. This is achieved naturally by vegetable fibres. Hence nature provides ideal fibres to be used in geotextiles.

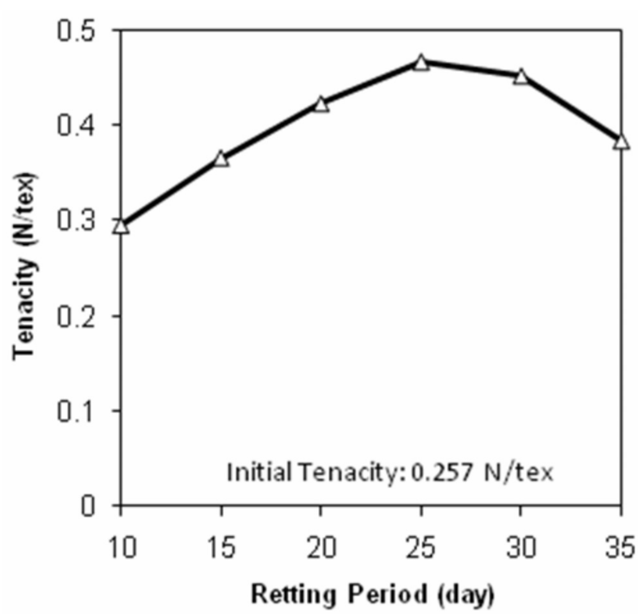

Figure 3: Tenacity versus retting period.

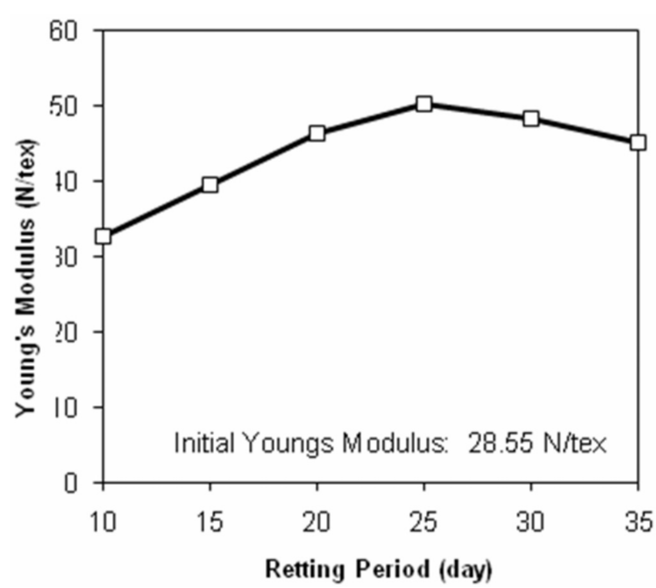

Figure 4: Young's modulus versus retting period.

In strength terms, vegetable fibres compare very well with chemical fibres, in that the tenacity for cotton is in the region of 0.35 N/tex and for flax, abaca and sisal it is between 0.4 and 0.6N/tex when dry, increasing when wet to the strength of high tenacity chemical fibres. The tenacity of ordinary chemical fibres (polyester) is around 0.4 N/tex (Horrocks and Anand, 2000). The structural changes induced by the microbial action alter the mechanical properties of the fibres as indicated in tenacity and modulus value. This effect is primarily accounted for by loosening of the pectin lamellae. The microbial retting process smoothed the fibre surface, degraded the pectin and separated the fibre cells which results in the increase in the surface area. As seen in the Figures 3 and 4, a longer retting period was not favoured due to reduction in tenacity and modulus of the retted fibres.

Figure 5 shows the strain at break percent for the jute bast fibre for varying retting period. For example in the case of retting period of 15, 25 and 35 days resulted in a strain beak percent of 24, 42 and 33% respectively. The drop in strain at break percent shows that the fibres were over retting above a retting period of 25 days. As the retting period increased the fibre fineness increased, but prolonged retting period resulted in negative effect. In untreated jute fibres, hemicelluloses and lignin remain dispersed in the interfibrillar region separating the cellulose chain from one another. The cellulose chains are, therefore, always in a state of constraint. Removal of hemicelluloses and lignin after microbial retting, removed internal constraint and the fibrils became more capable of rearranging themselves in a compact manner, leading to a closer packing of the cellulose chain, which causes improvement in fibre strength and its mechanical properties.

Figure 6 shows the linear density of the jute bast fibre during the varying retting period. For example in the case of retting period of 15, 25 and 35 days, linear density of the fibre was found to be 236, 115 and 70 tex respectively. Even though linear density decreased with the increase in retting period, a retting period above 25 days were not preferred as the tenacity and modulus dropped. The fibres were brittle which could have arisen due to over retting of jute fibre.

The linear density of the jute bast fibre during the varying retting period is as shown in Figure 6. For example with the increase in retting period from 15 to 25 and 35 days, linear density value was found to be 236, 115 and 70 tex respectively. Rowell and Stout (1998) stated that as the linear density increased by 0.1 tex, the tenacity reduced by about 1.5 g/tex. This inverse dependence of tenacity on linear density was common to most fibres and also to fine metal wires. The characteristics of the retted fibre are as shown in Table 2 for an optimized retting period of 25 days. The bast and leaf fibres consist of elongated sclerenchyma cells that are assembled in bundles forming a part of the phloem. The fibres in plant cells are surrounded by thin walled tissue which consisted of sieve elements, companion cells, parenchyma of rays, bark and mesophyll. In order to extract the fibre the thin cell walls of the later structures has to be broken for releasing the fibre bundles of varying dimensions (fibres). This is achieved by subjecting

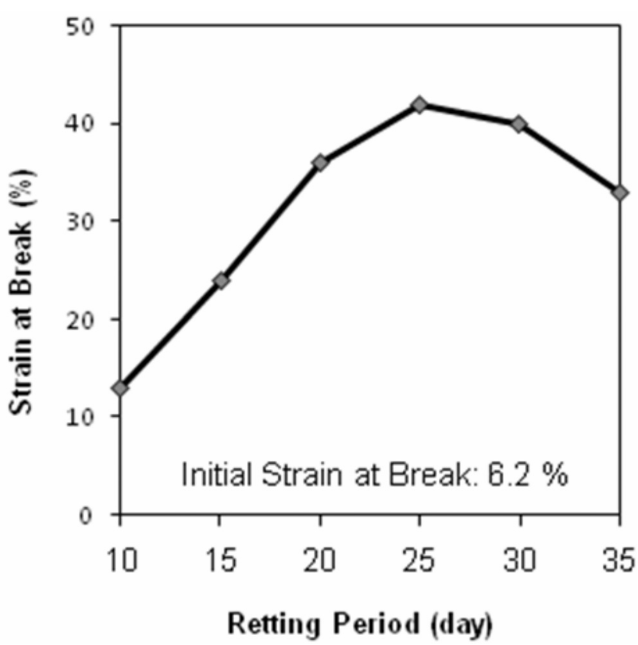

Figure 5: Strain at break versus retting period.

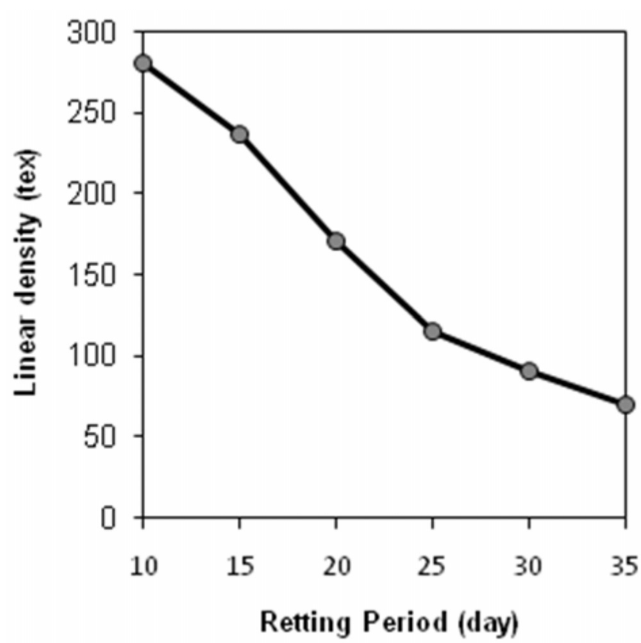

Figure 6: Linear density versus retting period.

the stalk of fibre plants into a complex microbial decomposition processes referred as retting (indirectly enzymatic reaction also occurs).

Table 2: Characteristics of retted jute fibre for a period of 25 days

Parameter	*Value*
Fibre fineness	1.3 tex
Tenacity	0.468 N/tex
Modulus	50.23 N/tex
Strain at break	42 %
Linear density	115 tex

Effective retting allows the isolation of fibre bundles of reduced thickness. Residual cell wall fragments remain on the surface of the fibre bundles leaving behind a pattern of imprints of the neighbouring cells. To improve jute fibre quality additional refining procedures are required, i.e. cleaning the surface and splitting fibre bundles into finer units, ideally into individual fibre cells. The predominant microbial species present in the jute retting liquor of ASBR were found to be species of *Bacillus, Clostridium, Aspergillus* and *Mucor*. Earlier researches had stated that the retting organisms releases cell wall degrading enzyme comprises polygalacturonases, pectin esterases, pectin lyases and pectate lyases. The pectinases help in degumming of the vegetable fibres (Jayani et al., 2005; Hoondal et al., 2002). Cellulases helps in degrading the cellulose of the primary and secondary cell wall layers particularly, at the nodes and causes the dislocation of fibres (Akin et al., 2004; Khalili et al., 2002).

Scanning electron microscopy image shows the quality of the retted jute blast fibre. The lateral and cross section images of the retted fibres are as shown in Figures 7 and 8. The scanning electron microscope images also revealed the absence of neighbouring cells imprints due to the microbial retting operation, which was in analogus to the enzymatic treatment with pectinase on the hemp blast fibre (Ouajai and Shanks, 2005; Saleem et al., 2008).

Conclusions

The foregoing study proved the capability of eco-friendly retting method based on the microbial retting of jute bast fibres under aerobic conditions using sequencing batch reactor. When compared to traditionally microbial retting operation, the present avoided the emission of green house gases. Moreover the rinse wash water arising during retting operation was recycled back into the retting unit, thereby the water pollution doesn't arise. The optimum retting period was found to be 25 days, which was judged based on the characteristics of the retted fibre with respect to fibre fineness, tenacity, modulus, strain at break and linear density. The morphological characteristic were visualized based on the scanning electron picture. The predominant microbial species present in the jute retting liquor of ASBR were found to be species of *Bacillus, Clostridium, Aspergillus* and *Mucor*.

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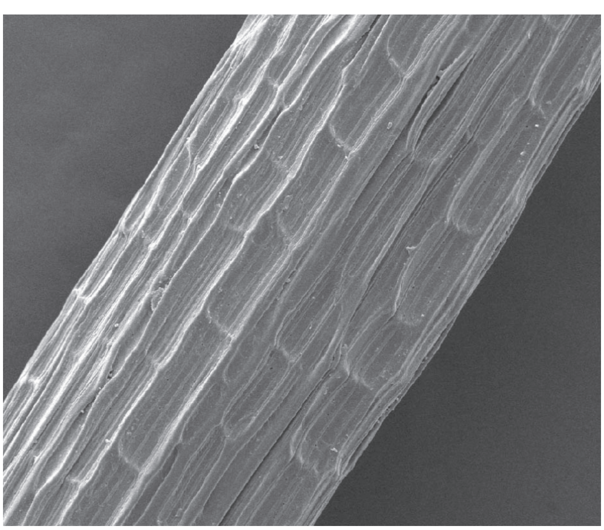

Figure 7: SEM image of retted jute fibre in lateral section.

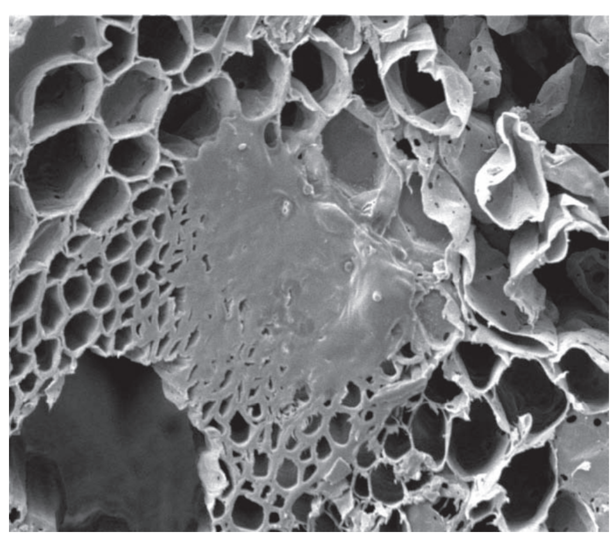

Figure 8: SEM image of retted jute fibre in cross section.

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Calendar of Events

2012 1st Journal Conference on Environmental Science and Development (JCESD 2012 1st)
7 to 8 April 2012
Bangkok, Thailand
Website: http://www.ijesd.org/jcesd/1st/
Contact name: Journal Secretary
Organized by: JCESD

Smart Water Systems
16 to 17 April 2012
London, United Kingdom
Website: http://www.smi-online.co.uk/events/overview.asp?is=17&ref=3698
Contact name: David Leakey
Organized by: SMi Group

2012 NGWA Ground Water Summit: Innovate and Integrate (#5095)
6 to 10 May 2012
Garden Grove, California, United States
Website: http://groundwatersummit.org/
Contact name: NGWA
Organized by: National Ground Water Association

Sixteenth International Water Technology Conference (IWTC16)
7 to 10 May 2012
Istanbul, Turkey
Website: http://www.iwtc.info
Contact name: Magdy Abou Rayan
Organized by: International Water Technology Association

7th Annual International Symposium on Environment
14 to 17 May 2012
Athens, Greece
Website: http://www.atiner.gr/environment.htm
Contact name: Gregory T. Papanikos
Organized by: Athens Institute for Education and Research

BALWOIS 2012 Fifth International Scientific Conference on Water, Climate and Environment
28 May 2012 to 2 June 2012
Ohrid, Macedonia
Website: http://www.balwois.com/2012
Contact name: Marc Morell
Organized by: Balkan Institute for Water and Environment - IB2E

Mountain Resource Management in a Changing Environment
29 to 31 May 2012
Kathmandu, Nepal
Website: http://www.himunet.com/downloads/international-symposium-may-2012.pdf
Contact name: Roshan M Bajracharya
Organized by: Kathmandu University and Institute of Forestry

ECWATECH-2012 - International Water Forum
5 to 8 June 2012
Moscow, Russian Federation
Website: http://www.ecwatech.com
Contact name: Elena Zakharova
Organized by: SIBICO International Ltd.

International Conference of Water and Wastewater Treatment-ICWWT
21 to 23 June 2012
Kuala Lumpur, Malaysia
Website: http://www.warponline.org/iccwwt.php
Contact name: Inam Bhatti
Sponsored by: World Academy of Research and Publication

International Conference on Environmental Science and Technology 2012
25 to 29 June 2012
Houston, Texas, United States
Website: http://www.AASci.org/conference/env/2012/index.html
Contact name: George Sorial
Sponsored by: American Academy of Sciences

2012 International Conference on Geological and Environmental Sciences (ICGES 2012)
29 to 30 June 2012
Jeju Island, Korea (South)
Website: http://www.icges.org/cfp.htm
Contact name: Conference Secretary
Sponsored by: CBEES