Biomechanical pulping - the concept and status

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ABSTRACT

The biotechnological approach for pulp and paper manufacture is a new approach and gaining momentum world over. It offers solutions to the existing problems being faced by the industry and at the same time can open new vistas for overall process upgradation. Potential role of biotechnology in different areas of pulp and paper manufacture viz, forestry, pulping bleaching, pulp upgradation, waste management etc. are being increasingly explored.

The present paper reviews the experimental work carried out and ideas generated thereof in the area of biomechanical pulping. The mechanistics of biodelignification were also discussed. The present status of biomechanical pulping in terms of commercial application was also evaluated It has been concluded that extensive work is needed in this area to make the biomechanical process commercially attractive and viable.

Biotechnology, defined simply as the technological use of biological agents. The advent of genetic engineering which made possible the alteration of heritable make up of organism in an intended direction, has generated excitement in the industry as well. This is more true in case of forest based industries.

In the pulp and paper industry, which utilizes biomass as a major raw material, the potential advantages that could be realized due to biotechnology applications are immence[1]. The areas identified so far where advantage over present process is envisaged are : (1) Forestry, (2) Pulping, (3) Bleaching, (4) Pulp upgradation, (5) Biproduct utilization and (6) Management of wastes. However, at present in the pulp and paper industry the application of biotechnology is restricted to biproduct utilization and management of waste. Even these areas need technological upgradation and it is very difficult to visualise how and to what extent biotechnology is going to change overall industrial process of pulp and papermaking, because of the fact that biotechnology, when viewed through commercial utilization, is at an infant stags. However, a systematic biotechnological approch to the industrial process and problems would fasten the pace of development.

In the present paper an attempt is made to review the work carried out in the field of biopulping with a systematic approach. The approach used can be divided into three distinct phases :—

(1) Selecting/evolving the ligninolytic fungi which enhance pulp properties.

(2) Understanding the molecular reactions in ligninolytic and cellulolytic activities.

(3) improving the strains/conversion of science to technology.

The ideas generated during the experimental work conclusions drawn from these experimental results are presented in the following review.

Bio-Mechanical Pulping :

Both Mechanical and Chemical pulping of wood are energy intensive. To cut down the energy demands of these processes, a fungal pre-treatment of chips before refining/cooking was proposed. However, so far the studies were confined to bio-mechanical pulping only[2].

Among various groups of fungi, the white rot fungi is the one group which can degrade the major

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wood components viz., cellulose, lignin, hemicellulose to carbon dioxide, water and humic substances. Though in the initial stages other fungi like soft rot, brown rot were used in the pulping studies, with the time the studies were concentrated on white rot fungi only. (3)

When the chips were treated with white rot fungi at 2% weight loss, it was fund that the refining energy requirement could be reduced by 20-30%. While chips were impregnated with glucose to an extent of 17%, at zero weight loss the energy requirement could be reduced by 16-17%. However, in both cases the time required for treatment is in the order of days.

In another approach, wherein to avoid the glucose impregnation, wood chips were steamed to convert hemicelluloses to sugars, which can act as energy suppliers for fungal growth. (2)

Instead of treating whole chips, fungal treatment of coarse thermo mechanical pulp is proposed basing on the fact that secondary refining of TMP takes much energy. Further, to achieve specific delignification, cellulose-less mutants were proposed instead of wild type.

When Phlebia radiate or itscellulase-less mutant cell 26 were applied to pine chips or coarse TMP for about 14 days at 29 C, it was found that the fungal treatment could affect the following properties of pulps (4) :

a) Refining/beatability characteristics
b) Strength properties and sheet density
c) Light absorption and scattering coefficients

In the study the energy requirement of fungal treated chips/pulps were compared to control pulp/ against freeness and also against strength properties.

Both wild type and its mutant when applied to chips/coarse TMP showed a significant reduction in energy requirement at a particular freeness level.[4,8] However, the wild type of fungus has increased the amount of energy requirement at a particular tensile index over control, while the mutant slightly decreased it. For both fungal strains tensile index was lower at a certain density level and tear index was lower at a certain tensile index level. These observations clearly show that both wild type and its mutant have showed a deleterious affect on cellulose. However, with the addition of glucose strength properties could be maintained.

Regarding optical properties both wild and mutant contributed to brightness decrease of pulp. However, treatment with mutant resulted in more inferior brightness than wild type.

The study concluded that fibridized pulp had a larger affect than treatment of chips. S.S. Bar-Lev etal[5] in their study wherein coarse TMP of red alder was treated with Phanerochaete chrysosporium both with and without glucose has confirmed that glucose addition during fungal treatment could prevent the strength loss, at the same time could reduce the energy requirement to a tune of 20-30%.

The effect of glucose on fungal degradation of wood can be seen from Table—1. However, from the chemical analysis of the pulp following conclusions were made :—

1) Slight decrease in lignin content could significantly reduce the energy requirements.
2) The lignin content measured did not reflect the full extent of lignin degradation.
3) Other factors besides lignin degradation are involved in less energy consumption.

These observations clearly indicate the need for greater understanding of the fungal wood process mechanistics.

TABLE—1

Effect of glucose on degradation of alder TMP by Sporotyichum pulverulentum in two weeks[11]

Glucose (% dry pulp basis)	Lignin	Loss of component (% original amount) Carbohydrate	Total weight
0	31	23	24
7	34	24	25
35	29	0	6
70	25	0	0

As the wild types are contributing to strength losses, studies were concentrated to produce cellulase-less mutants. A comparison of wood losses due to wild type as well as mutant are given in Table—2.

In a sequence of studies on birch and pine woods with white rot fungi and their cell-mutants, K : E Erikssoon [6] etal have made following observations :

1) Energy requirement : Energy savings can be obtained to a tune of 17-30% by fungal pretreatment with both wild and mutants on wood chips.

2) Strength Properties : When no Glucose is present, strength properties are adversely affected. However with glucose addition, with mutants it is possible to produce pulp with higher strength properties.

3) Optical properties : The maximum brightness loss was observed at no glucose and high glucose concentrations. Minimum brightness loss was observed at low glucose concentrations.

It was also observed that brightness loss is due to both increase in light absorption coefficient and decrease in scattering coefficient.

When the fungal treated pulps were bleached with peroxide they showed a greater reduction in color than control pulps at equal chemical dose. Despite this improvement, however, optical properties of fungal treated pulps were not found satisfactory. However, when the fungal treatment process (BRMP) is compared with RMP the advantages are clearly established as can be seen from table-3.

TABLE—2

Effect of wild and mutant fungi on wood component loss[12]

Time (Weeks)	Loss of component (% of original amount) Glucan	Xylan	Lignin
Wild type			
4	7	13	13
6	9	22	21
8	8	33	34
10	12	22	22
Cell 44			
4	0	4	9
6	—2	15	12
8	1	35	23
10	0	32	31

TABLE—3

Properties of pulps and papers prepared from aspen wood.[10]

Chips treatment (Freeness, CSF) (ml)	Burst Index (KPam²/g)	Tear Index (mNm²/g)	Tensile Index (Nm/g)	Density (Kg/M³)	Brightness (%)	Opacity (%)	Scattering Coefficient (m²/kg)	Fibre Length Index (mm)	Pulping Energy (wh kg⁻¹)
RMP (120)	0.66	2.75	28.1	393	64.4	93.2	61.8	0.1005	2700
BRMP (110) Phebia	2.11	6.13	51.4	425	42.9	93.0	37.9	0.1060	1560
BRMP (100) Phanerochaete	2.04	4.64	52.5	402	40.5	94.8	39.9	0.1201	1480

RMP — Refiner Mechanical Pulp

BRMP — Refiner Mechanical Pulp from fungus—pretreated wood.

In an attempt to produce more effective mutants which can delignify without carbohydrate attack, K.E. Erikson has produced mutants using classical genetic method of crossing instead of UV irradiation. It was also found that mutants are always slower in delignification than wild type.

However, from these studies it is evident that more extensive studies are to be carried out to evolve a suitable fungus which can degrade lignin specifically and at a faster rate.

MECHANISM OF LIGNIN DEGRADATION BY FUNGI :

The mechanism of molecular reactions that are taking place between fungal produced enzymes and wood constituents like lignin and carbohydrates are described basing on the recent advances made in the area of fundamental studies.

The fungal delignification of wood is a physico-chemical phenomenon in the sense that fungal hyphae should penetrate enough into wood, where the enzyme produced will be in contact with lignin to react chemically.

In case of white rot fungi, the penetration of hyphae takes place in to two ways : (1) The fungus grows in the central cavity, the lumen of the cell and spreads in the neighbouring cells through pores and perforated zones; (2) The enzymes of the fungus facilitate penetration of the cell wall.

It is pertinent to recall here the fact that the same fungi affected the properties of coarse TM pulp more than wood. This indicates the importance of physical phenomena of fungal hyphae penetration.

There can be two possible approaches for bio-pulping as is for bio-bleaching :

(1) The removal of lignin, (2) The modification of lignin.

As with little lignin removal the energy requirement for chip refining is substantially reduced, it is not two optimistic to expect bio-pulping without much lignin losses.

Again the lignin removal/modification can be affected either by affecting the alkyl side chain or aromatic ring itself. The present status of biodelignification can be condensed into following points :-

1) The enzyme responsible for lignin depolymerization, lignin-peroxidase was identified in the P. chryso sporium system.
2) The mechanism of lignin-peroxidase has been described as that it simply oxidises aromatic nuclei in lignin by one electron to cation radicals, which undergo non-enzymatic degradative reactions of both radical and ionic nature. [10]
3) Other kinds of phenoloxidase are also described.
4) Production of xylanase may also be necessary since xylan is closely associated with lignin and xylose the monomer is readily metabolized.

The other facts those emerge out of the recent studies are :-

1) Glucose addition represses the cellulase activity.
2) Fungus can also degrade modified lignin, the finding of which lead to the concept of bio-bleaching.

However, despite the advancements made over last six years in understanding the mechanistics of biodelignification, an enzyme mixture that actually deploymerises or solubilises lignin has not been described.

APPLICATION AT INDUSTRIAL LEVEL :

Bringing the above discussed biological process to industrial level is a stupendous task. Selection and evolution of fungus and understanding the mechanistics involved in fungal treatment of wood represents the one face of the problem, where the other is finding ways to bring that understanding to industrial application benificially. Because the problems are many. For example :

1) Maintaining the humidity, aeration and temperature for the proper growth of micro-organism.
2) Prevention of other fungal contamination.
3) The slow rate of the process.

Despite gigantic nature of above said drawbacks, efforts are already underway to bring biopulping to reality.

K E. Eriksson (4) suggested large silos as treatment chambers, where wood chips and fungal inoculum would be introduced at the top and the treated chips removed at the bottom after a suitable residence time. For hardwood chips residence of one week or less appear to be adequate. Silos large enough to accommodata this residence time could be constructed to process 170,000 tonnes of pulp per year per silo. However, the gigantic size of silo required for this process makes it uneconomical. The other problems are maintenance of proper amounts of oxygen, moisture and nutrient.

CONCLUSION :

The biotechnological approach for pulp and paper manufacture appears to be highly promising. The biomechanical pulping offers energy savings and at the same time can provide a pollution free process. Despite the various problems mentioned above, it is expected that continuous afforts including pilot scale trials going on may bring decesive solutions and subsequently make biomechanical pulping process commercially viable.

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