Microbial utilization of Cellulosic materials as a commercial venture

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Wood has held for many centuries a significant place in the human requirement. It has served man as a structural material for building, furnishing, tools, weapons, transport and until recently was his only readily available fuel. Other parts of the tree such as fruit, flowers, bark, seeds and needles have been used as food, clothing, medicine and for decoration.

The possibility of using hydrolyzed wood as a source of fermentable carbohydrate has been recognised for many years. This fermentable carbohydrate or "wood sugar" as such hydrolyzates are usually called may be utilized by a microbial process. In 1943 the Forest Products Laboratory undertook the hydrolyzes of various woods on a pilot scale for the production of ethyl alcohol and fodder yeast. The interest at that time stemmed from war-time conditions.

With the increased interest in microbial fermentation of the last fifteen years and with renewed interest in national resources our interest once again turns towards "wood sugar."

Wood sugar is obtained from the hydrolysis of cellulose and hemicellulose found in plant material. Forest products are part of this pool which also embraces agriculture residues and peatlands. Utilization of these resources will mean that new frontiers in hydrolysis and fermentation must be crossed.

Forests are a unique resource. They are inexhaustible compared with oil and coal etc. They may be sited, with planning, where required. In addition forests have great ecological significance. It is estimated that one fourth of the earth's land mass is covered with forest thus making this resource one of the most widespread.

Conversion of cellulosic material to "wood sugar" involves the breakdown of high polymer carbohydrates present and the hydrolysis of the bonds between them and other compounds.

There are now several processes for obtaining wood sugar. The following methods are reviewed by Prescott and Dunn (1959).

1. The Bergius—Rheinau process: This is based on the fact that 40% HCl will hydrolyze cellulose at room temperature. In this process the wood is shredded and then dried in revolving

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drums to a water content of 0.5%. The dried wood is transferred to a battery of dicusers where HCl acts on it and produces water soluble sugars.

2. The Scholler-Tornesch Process: this method employs dilute acid, elevated temperatures and steam under pressure.
3. The Giondani-Leone Process: uses sulphuric acid.
4. The Madison Process: in this process wood is percolated with dilute sulphuric acid (150°—180°C).
5. Another process which liberates wood sugar is the sulphite process used in mills in Europe and North America. In this process wood is digested in an aqueous solution of bisulphites with an excess of sulphur dioxide, this solubilizes the lignin, leaving the wood cellulose intact whereas the less resistant hemicelluloses are hydrolyzed to sugars. Virtually all sulphite pulp mills are faced with spent sulphite liquor disposal problems.

These processes yield not only wood sugar but also chemicals of importance. Although the author is interested in the biological utilization of cellulosic material one cannot ignore the chemical significance. The following is a short account of some of the chemicals obtained using the above processes.

The main chemical product of wood is cellulose—this has many and diverse uses which are too numerous to discuss here.

Hydrogenation of hexoses and pentoses, found in wood sugars, in the presence of a nickel catalyst under pressure and at elevated temperatures yield the corresponding polyhydric alcohols, hexitols and pentitols which are important in industry. Sorbitol, a polyhydric alcohol obtained on reducing glucose is important in resin manufacture, paint manufacture and in the confectionery industry. Dulcitol, a polyhydric alcohol related to galactose has industrial significance.

Dehydration of pentoses in an acid medium yields the heterocyclic aldehyde furfural which is of significance in the manufacture of plastics, synthetic fibres, resins etc.

Hydrogenation of furfural yields furfuryl alcohol used as a raw material for resin synthesis and tetra hydrofuryl alcohol used as a solvent for cellulose esters.

Oxidation of furfural yields maleic anhydride and maleic acid which is important in resin manufacture. Furfural based compounds are significant as chemotherapeutic agents in medicine.

Lignins also yield chemicals of some industrial significance. These products include activated carbon, nitrolignin, chlorolignin, oxalic acid and protocatechuric acid. Vanillin, a product obtained from lignin is of importance in the confectionery industry.

Fermentation based on wood is known for many decades now. Originally wood sugar was used for the manufacture of ethanol and protein. The ethanol based industry could not compete with similar industries based on petroleum thus after the war this process became less popular and at the moment is carried out only in Russia.

The protein based industry found its impetus in the shortage of animal protein during World War II when countries such as Germany and Sweden replaced much of their protein requirements with protein obtained from yeast. This industry played a less significant role after the war and gradually was linked to the sulphite process.

With the awakening of interest in protein obtained from microorganisms at the moment the wood industry is sadly trailing the petroleum industry. B.P., Esso and Shell have invested many millions of pounds in factories built for the production of yeast protein on hydrocarbons. Their process is costly and toxicologically has not ben proven. Table I compares the cost of protein from different sources.

TABLE I

Comparable prices of protein-rich foods (US$)

Food	Protein content %	Price/lb. protein
Beef	15.2	4.6
Pork	11.6	4.3
Non-fat dry milk solids	36.0	0.6
Soy-flour	52.0	0.13
Yeast grown on sulphite liquor	50 (approx.)	0.27
Yeast grown on hydrocarbon	50 (approx.)	0.35

The main weakness in the production of war-time protein was that enough research was not carried out to make the product more palatable. Recent research has shown that with various treatments the protein may be made to take on certain desirable flavours and textures.

Yeasts in addition to yielding protein are also rich sources of biochemicals. There are at least one hundred enzymes listed that are produced by yeasts. Many of these enzymes are at present of purely academic interest, for instance in connection with research or intracellular metabolic pathways. Enzymes of commercial importance obtained from yeasts include alcohol dehydrogenase, glucose-6-phosphate dehydrogenase, gluthathionine reductase, hexokinase and uricase.

Another group of important cell components includes the coenzymes which in contrast to the complex protein structure of the enzymes themselves are usually relatively small molecules which act as carriers of simple molecular groups or elements such as hydrogen, hydroxyl, acetyl and phosphate. These compounds are important in biochemical research.

Amino acids, nucleotides and nucleic acids in addition to vitamins may also be obtained from yeast grown on wool hydrolyzates and in fact are produced commercially from yeast grown on the waste sulphite liquor of the pulp industry.

Among the more recent fermentations carried out on wood sugar, by yeasts, are the production of citric, gluconic and pyruvic acids.

Examples of other chemicals obtained from yeast include the production of ephedrine, which is of medical significance, by the conversion of benzaldehyde.

Fermentation is the conversion of sugar by microrganisms to form various products. Thus by varying the types of microorganisms it is possible to obtain such commercial products as fumaric, kojic, lactic and propionic acids. It is also possible to obtain solvents such as acetone, butanol etc., but in this field it is more enconomic to obtain these products from the petroleum industry.

Some of these processes (solvent production, ethanol and protein production) were used during the war years but were not viable economic process in the post-war years. The reasons for economic failure was probably due to low yields, high processing costs and low quality low priced products. In general, reliance was placed on a single product to carry the economic burden and little or no attention was directed towards fractionation of the major wood components, with subsequent processing of the separated fractions for high yields of high quality products. Another reason for the failure of some of the biological processes was due to the failure of the fermentation process for example, the production of ethanol, acetone or butanol. It was only incidental that the substrate used was "wood sugar."

Thus in any future development of projects for the utilization of cellulose it must be seen that forests are a pool of raw material. The wood consuming industries will take only what they need from this reservoir. For efficient utilization of this reservoir it will be necessary for each industry to return its waste for some other use. It is envisaged that conversion of cellulose waste to wood sugar is one of these subsidiary industries.

Much research has been carried out in an effort to develop this industry. Much of this research has been product orientated—the emphasis being laid on the conversion of a substance to some end-product—without enough basic research into the structure of the cellulose and lignin molecule. Suggested areas of research in this field include the effects of cathode rays and also the effect of amines on the crystalline structure of cellulose, Enzymic degradation of cellulose may prove a fruitful field.

The economics of wood sugar utilization is very difficult to assess. Kobayashi (1971) calculates that reducing sugar at a concentration raging from 3—4% can be obtained at a cost of approximately .67p per pound of reducing sugar excluding the cost of wood waste, by the use of the Scholler process.

Table I outlines the cost of protein produced on sulphite liquor and compares it with other proteins.

Thus it appears that the future of wood hydrolysis lies in the modification of existing wood hydrolysis processes such as pulping. However, there is still a potential for wood hydrolysis processes to be developed further. One way of achieving this is to integrate it with other industrial processes e.g. the sulphuric acid methods could be linked to the fertiliser industry.

In summary it may be said that the wood hydrolysis process is a difficult process to develop, the reasons are as follows:

1. It is associated with war-time conditions. Many who object to the process claim that if it was viable why was there not greater strides after the second World War. This argument fails to recognize the developments in fermentation technology since the forties.

2. The structure and decomposition of cellulose is not sufficiently known.

3. There is necessity for more pilot scale studies especially on a large scale.

4. The possibility of new biochemicals for microorganisms grown on wood sugar must be examined further.

5. There must be a greater integration of the wood processing industries and subsidiary industries.

REFERENCES

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