Description of an efficient and ecological technology for the combined production of furfural and glucose-containing solution for further processing

The Latvian State Institute of Wood Chemistry has developed a pretreatment technology for the efficient processing of birch wood for the biorefining system. The pretreatment technology is based on a mutually adapted mechanical, chemical and biological treatment that enables the selective and direct production of furfural from birch wood and produces an appropriate by-product (lignocellulose) from which a glucose-containing solution for bioethanol production can be obtained by the enzymatic hydrolysis. The developed technology also is adaptable to other pentosans and cellulose-rich biomass such as aspen wood, grey alder and wheat straw.

Furfural is a bio-based product (a liquid with a strong almond smell) produced only from biological resources containing pentosans. Due to its unique properties, furfural has been recognized as one of the 30 most important bio-based platform chemicals, which are commonly used as raw materials for the production of other high-value-added products in the field of industrial organic synthesis. The main market for furfural is the production of furfuryl alcohol and other 5-element oxygen-containing heterocycles - furan, methylfuran, furfurylamine and furoic acid, etc. Furfural is obtained from industrial-sized wood chips, which have been pre-mixed with mineral acid or its salt before entering the hydrolysis reactor. The hydrolysis process is organized as a batch process. The number of reactors is adjusted so that the furfural production process is continuous. During hydrolysis, the pentosans in the hemicellulose part of the biomass are hydrolysed to pentose molecules, which are immediately cyclodehydrated into furfural. Furfural from the reactor is removed by the continuous steam-flow and fed to rectification stage. In it, furfural is purified from water and other biomass destruction by-products (acetic acid, 5-hydroxymethylfurfural, levulinic acid, formic acid, etc.) and concentrated to the desired concentration (>98%). The yield of furfural is influenced by the used catalyst, its amount and how it is mixed with biomass, the processing temperature, the physical-chemical properties of the raw material, and a number of technological processing parameters. The technology can achieve 65% conversion of pentosans into furfural when obtained in a biorefinery system, and 75% conversion is possible when furfural is the main target product.

Depending on the chosen application of the technology, after furfural extraction, approximately 60-70% of the initial biomass, which mainly contains depolymerized cellulose and lignin (lignocellulose), remains in the hydrolysis reactor. Using steam, lignocellulose is unloaded at high pressure in unique cyclones. As a result, the structure of the lignocellulose is destroyed and is suitable for immediate processing into the glucose-containing solution through enzymatic hydrolysis. The part of the lignocellulose is transported to the boiler house, where it is burned to produce the necessary water vapour to ensure the operation of technological processes.

The enzymatic hydrolysis stage is implemented as follows: 1) the obtained lignocellulose is transported to the enzymatic hydrolysis reactor, where it is mixed with a buffer solution, 2) the mixture is heated to the desired temperature and the pH of the medium is adjusted with base or acid to achieve an environment for optimal enzyme activity, 3) the enzymatic hydrolysis process begins when the cellulase enzyme complex is added. The process takes 3 days, during which the cellulose is broken down into glucose monomers. The achievable conversion efficiency is at least 65% of the theoretically possible amount. After the enzymatic hydrolysis step, the glucose-containing solution is separated from the solid biomass (mainly from lignin). The liquid fraction is transported to a fermentation reactor where it can be converted to ethanol or another target product where glucose is used as a feedstock. The remaining biomass (mainly lignin) can be granulated and sold as fuel or fertilizer.

The economic indicators of the technology provide that furfural production before the enzymatic hydrolysis stage is fully profitable and economically justifiable. Furfural production technology has been developed at the Latvian State Institute of Wood Chemistry and is protected by Latvian patent 14240 “Method and device for furfural and acetic acid extraction”.

Technology related benefits

General advantages of technology:

- ✓ No competition with the food industry;
- ✓ Technology makes it possible to diversify production and adapt it to market needs;
- ✓ The technology opens up the opportunity to produce acetic acid used in the food industry in a competitive volume;
- ✓ The potential of the technology can be realized with equipment already available on the market, thus not creating unnecessary expenses related to the design/production of technological equipment.

Advantages over existing furfural plants:

- ✓ The technological solution allows achieving at least a 20% higher yield than with today's traditional furfural production technologies if it is produced together with a glucose solution
- ✓ The technological solution allows achieving at least 30% higher yield than with today's traditional furfural production technologies if it is produced alone
- ✓ Producing furfural in the context of biorefinery, at least 90% of the initial amount of cellulose is preserved, as well as acetyl groups, which are inhibitors of the enzymatic process, are removed. In addition, the degree of polymerization of cellulose is also reduced as well the specific surface area of biomass is increased to improve the efficiency of cellulose conversion into glucose.

Advantages over existing cellulosic ethanol plants:

- ✓ Efficient and selective production of furfural before the enzymatic hydrolysis significantly reduces the content of pentosans in biomass, which allows the use of simpler enzyme cocktails, namely those intended only for cellulose conversion.

The target audience for technology

The technology can be implemented separately as a furfural production plant or as a set of pretreatment processes that can be integrated into a cellulosic ethanol production system where furfural is produced as a by-product. Considering the amount of required raw materials, the main users of the technology for furfural production are forest management, woodworking and/or agricultural companies that want to use their by-products from other production streams more efficiently and are not afraid of the production of chemicals. Using the technology as a set of biomass pretreatment processes for the production of cellulosic ethanol, the target groups of the technology include bioethanol producers. Integrating such solution into an ethanol plant will simplify the management of biological processes and accelerate the payback time of the initial investment due to the increase in the market price of furfural.