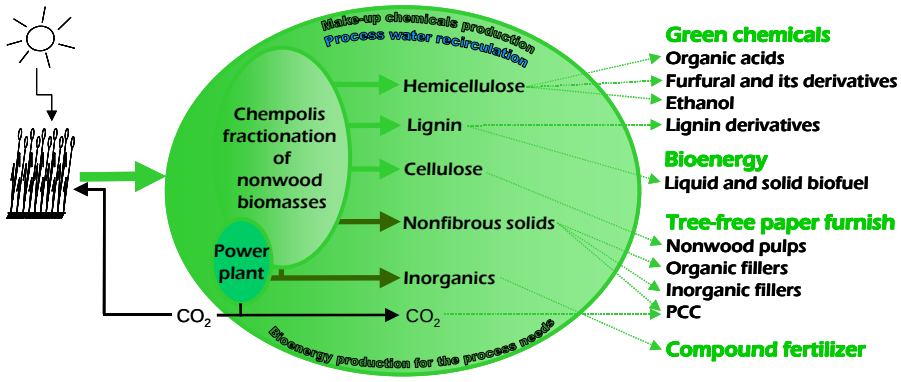
PEGRES:
Paper, bioenergy and green chemicals from nonwood residues by a novel biorefinery



1. Site of research and responsible persons

University of Oulu, Department of Process and Environmental Engineering, Chemical Process Engineering Laboratory, Prof. Juha Tanskanen, *responsible leader of the project*

University of Oulu, Department of Process and Environmental Engineering, Fibre and Particle Engineering Laboratory, Prof. Jouko Niinimäki

Lappeenranta University of Technology, Department of Chemical Technology, Prof. Kaj Henricson

2. Objectives of the project

The goal of the PEGRES project is to develop a conceptual process model of a sustainable nonwood biorefinery. This pursued biorefinery concept is characterized by (1) total utilization of biomass into selected high value added products, (2) integrated production of paper and papermaking chemicals from the biomass and (3) self-sufficient overall production in terms of energy and process chemicals.

The third character, i.e. self-sufficient production of energy and process chemicals, is obtained by implementing the formic acid nonwood fractionation method of Chempolis Company. The Chempolis platform offers reliable and profitable fractionation of nonwood biomasses to cellulose, hemicellulose and lignin. The two other characters, i.e. production of value added products and paper and papermaking chemicals, would be the research challenges of this project. The target product groups of the biorefinery have been set to be (1) green chemicals from hemicellulose, (2) bioenergy from sulfur free nonwood lignin (3) tree-free paper furnish components from nonwood pulps and nonfibrous solids and (4) compound fertilizers from the inorganics.

3. Research results 2009

3.1. University of Oulu, Chemical Process Engineering laboratory (CPElab)

During the year 2009 CPElab research in the PEGRES project was focused to acid catalyzed kinetic studies of (1) furfural formation from the xylose and (2) levulinic acid and formic acid from glucose. Both sulfuric acid and formic acid were used as catalyst. Following reasearchers contributed to the results: Kaisa Lamminpää (CPElab), Laura Kupiainen (CPElab), and Juha Ahola (CPElab). Kaisa Lamminpää and shortly Laura Kupiainen obtained financing from the PEGRES-budget. The main results of these studies are shortly described below.

Chemistry studies of hemicellulose conversion
Furfural is obtained from biomass pentosans in acidic conditions. In this study xylose was used as a model component for hemicellulose pentosans, and earlier completed sulfuric acid catalyzed experimentation was replicated by formic acid in similar hydronium ion concentrations. The study confirmed that formic acid is as effective catalyst as dilute sulphuric acid for furfural formation. The findings are similar than those, in literature, done with mineral acids. Maximum selectivity of 70% can be achieved with both acids. Because there is a potentiality that formic acid decomposes in the most interesting reaction conditions, formic acid decomposition studies were also carried out. The preliminary results indicated that the decomposition is quite insignificant.

The goal of this study is to create a reliable kinetic model for the biorefinery modeling purposes within PEGRES-project. The study pointed out the optimal reaction conditions; including acid level against xylose concentration, temperature and reaction time. However, the system is still far too ideal to predict conversions in industrial biorefining conditions, where all fractions of lignocellulosic biomass may contribute to the reaction media. Because furfural is quite reactive, experimentation with real mixtures need to be carried out. This research will be done in collaboration with Chempolis Company, who has demonstration facilities to fractionate nonwood lignocelluloses by own formic acid based technology.

Chemistry studies of glucose decomposition
In the PEGRES project the focus concerning organic acids is on the production of formic, acetic and levulinic acid from lignocellulosic biomass. While acetic acid source is acetyl groups of nonwood hemicellulose, levulinic acid and formic acid can be obtained from glucose hydrolyzed from the biomass celluloses. Thus, glucose decomposition was studied in formic acid media. The obtained experimental findings suggest that long reaction time and moderate temperature favoured the selectivity to levulinic acid (and formic acid), although the yield of solid by-products, humins, was significant at the same time. The experimental data was fitted successfully into a three kinetic models, in which different formation routes of humins were assumed.

Outcomes

Lamminpää K. and Tanskanen J. (2009) Study of furfural formation using formic acid. 8th World Congress of Chemical Engineering 23.-27.8.2009.

Kupiainen L., Ahola J. and Tanskanen J. (2009) Formic acid catalyzed glucose decomposition. 8th World Congress of Chemical Engineering 23.-27.8.2009.

3.2 University of Oulu, Fibre and Particle Engineering Laboratory (FPElab)

In Fibre and Particle Engineering laboratory research was continued with postgraduate studies and nonwood pulp analysis and fractionation. Summary of current nonwood literature was gathered up. The research of the agricultural residue utilization has long backgrounds and nowadays it is topical issue all around the world. However, it was noted that proper information about nonwood pulp fractionation in industrial type equipment is not available nowadays.

Analytical methods for the characterization of nonwood pulps were investigated in 2009. It was noticed that analytical methods used traditionally in pulp characterization can not necessarily be used in nonwood pulps analysis as such. Therefore analysis methods were validated for nonwood pulps. The results from these experiments will be published in 2010.

The industrially manufactured prototype of the analysis equipment developed in this project earlier is now in use in Fibre and Particle Engineering Laboratory. The prototype was manufactured in co-operation with a Finnish industrial partner. The importance of such an analysis method in nonwood pulp analysis is emphasized during the project. Nonwood pulps are going to be analysed with this method in the spring of 2010. New information about nonwood pulps is expected of these analyses.

Commercial Chinese wheat straw pulp was fractionated using Fibre and Particle Engineering Laboratory's pilot plant pressure screen and hydrocyclone. A wide analysis schedule for the acquired fractions of their pulp and paper technical properties was performed in co-operation with Laboratory of Paper Technology, LUT. The results from these fractionations are under processing and new information about wheat straw pulp fractionation and its effect on papermaking properties are going to be published in 2010.

Mikko Karjalainen continued his postgraduate studies in 2009. Studies consisted of analytical techniques for pulp and paper characterization, botany and statistical methods for data processing. Approximately 90% of Mikko's postgraduate studies are completed. Part of the annual working time has also used for teaching. Teaching includes lectures on a bachelor's and master's degree and guidance of a bachelor's thesis.

3.3 Lappeenranta University of Technology

Non-wood pulps are very heterogeneous material. Existing fiber dimension analyzers are designed for wood pulps and therefore they are not able to predict paper properties of non-wood pulps. Also basic knowledge of the effect of main cell types of non-wood pulps is still unclear. Therefore large wheat straw pulp fractionation study was performed together with University of Oulu (Fibre and Particle Engineering Laboratory) and LUT. Fractionation was done in University of Oulu and analyses were performed both in LUT and in UO. LUT concentrated on analyses of cell types as well as on pulp and paper properties. Paper sheets of various different cell type compositions were prepared. Large differences between pulp fractions were found out. Especially properties of fine fractions had significant differences, including dewatering, optical, and strength properties. For instance the differences in dewatering were not detectable from results of fiber analyzers. Therefore development of fiber analyzers for non-wood pulps is essential, especially concerning fine particles.

Cell types of pulp fractions were divided into four main types: fibres, vessels, parenchyma and epidermal cells. Clear effect of each cell types could be concluded. It was also found out that each cell type bonded well on other components. Information of effects of cell types can be exploited in papermaking. Better paper quality can be prepared when recognizing the effect of cell types and their mutual behavior. Risk of picking, linting and dusting can be controlled by several manners, e.g. by fractionation, paper formation (wet pressing) and chemical usage (starch).

Optimal utilization of fractions was also studied. Dewatering of straw pulps is typically critical property. Therefore fractionation can be utilized to improve drainage properties of wheat straw pulp. It was found out that utilization of the removed wheat straw pulp fraction improved significantly certain strength properties of wood pulp containing furnish without impairing notably other properties. At the moment two manuscripts of the research are in commenting phase of co-writers.

In addition to the laboratories of UO, co-operation has been mostly made with HUT, Chempolis Oy, UPM-Kymmene Oyj and Chinese parties that have provided part of the samples for the studies.

Outcomes:

Rousu, P, Sandqvist, J & Tanskanen, J. Sustainable production of chemical cellulose for paper and bioethanol. 2009 TAPPI International Bioenergy & Bioproducts Conference, October 14-16, 2009, Memphis, TN, USA. (Poster presentation).

Rousu, P. Paper, bioenergy and green chemicals from non-wood residues by a novel biorefinery. 2009 COST Strategic Workshop – The Future Needs of Paper Industry, Brussels, November 17 2009. (Participation to the Workshop and presentation of the research project).

Submitted articles:

Päivi Rousu, Heli Malinen, Tom Hultholm, Mikko Jokinen, Isko Kajanto, Jouni Paltakari and Hannu Manner. Wet pressing of wheat straw pulp – correlations between dewatering parameters. Submitted to NPPR (8.9.2009)

Päivi P. Rousu and Juha P. Tanskanen. Organosolv non-wood pulp in paper furnish – screening of non-linear effects of variables. Submitted to Paperi ja Puu (21.8.2009)