High-consistency enzymatic fibrillation (HefCel) – a cost-efficient way to produce cellulose nanofibrils (CNF)

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ABSTRACT

High-consistency enzymatic fibrillation (HefCel) technology offers a cost-efficient way to produce fibrillated cellulose materials at high consistency (20-40%). The process is simple, consisting only of few steps and can utilize existing industrial equipment. The fibrillation degree and thus the material properties can be tuned by the process conditions. The produced fibrillated cellulose material is at high consistency and easy to handle. The higher dry matter content makes off-site production and transportation more feasible compared to traditional CNFs. In addition, HefCel material is not gel-like, which enhances the water removal. Additional benefit of the process is the recovery of high-value by-product, cellobiose. HefCel material has shown potential in many applications, such as in barrier films, as strengthening additive in board and in all-cellulose structures.

Keywords: cellulose nanofibrils, CNF, cellulase, energy, fibrillation

1 INTRODUCTION

Cellulose nanofibrils (CNF) are promising bio-based materials for numerous applications, either as replacement of oil-based materials in existing products, potentially with added functionality, or in generating completely new materials and products. The production of material consisting of thin cellulose fibrils with unique properties was invented already in the 1980's. However, back then the high energy consumption needed for manufacturing proved to be an obstacle for industrial production. Extensive research since then has resulted in more feasible production concepts and led to pilot, pre-commercial and even commercial plants all over the world.

Despite the rapid development, some challenges still remain with the traditional production of CNFs by mechanical treatments alone or in combination with enzymatic or chemical pre-treatments. Usually the production costs are still high, and the resulting material is at low consistency, typically between 1-3%. The high water content generates problems, such as difficulties in dewatering and drying, problems in post-treatment and restricted applicability for certain applications, such as composites. In addition, long-distance transportation is not feasible leading to limited availability of the material.

To overcome the problems related to high energy consumption of CNF manufacturing and low solids content of the resulting material, VTT has recently developed high-consistency enzymatic fibrillation (HefCel) technology [1].

2 HEFCEL TECHNOLOGY

Fungal enzyme system for hydrolysis of cellulose is well described in literature, especially that of the white-rot fungus *Trichoderma reesei* ([2], Figure 1). For modification of pulp fibers specific action of individual cellulases are exploited [2]. The HefCel technology is based on a tailored cellulase mixture enabling efficient unravel and fibrillation of pulp fibers wihout extensive hydrolysis.

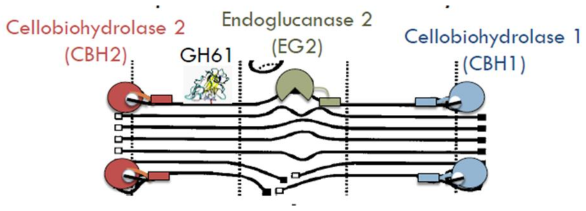

Figure 1. Enzyme system for hydrolysis of cellulose.

The HefCel method is applicape to diverse feed stocks; wood and non-wood pulps, recycled fibres, agro-based residues etc. General requirements for a raw material is low lignin content (<10%) and without residues or contaminants (e.g. plastics, glues, adhesives) inhibitive to the enzymes.

In the process, the slushed raw material is gently agitated at high consistency (20-40%) in a horizontal reactor in presence of cellulase enzyme mixture (Figure 2). This results in fibrillation of cellulose due to enzyme activity and fibre-fibre friction in low water content. After the treatment, the enzyme is inactivated by temperature increase, the material is washed with water and filtrated. The yield of the fibrillated cellulose material is ≥ 90%. After washing and dewatering the fibrillated cellulose material obtained is still at high consistency (20-30%) and paste-like material in appearance. During the process, the degree of fibrillation can be adjusted by the enzyme dosage and the treatment time. In addition, the fibrillated cellulose material can be further modified after treatment at high consistency.

Soluble sugars, mainly consisting of cellobiose, can be recovered from the washing filtrate. The yield of this

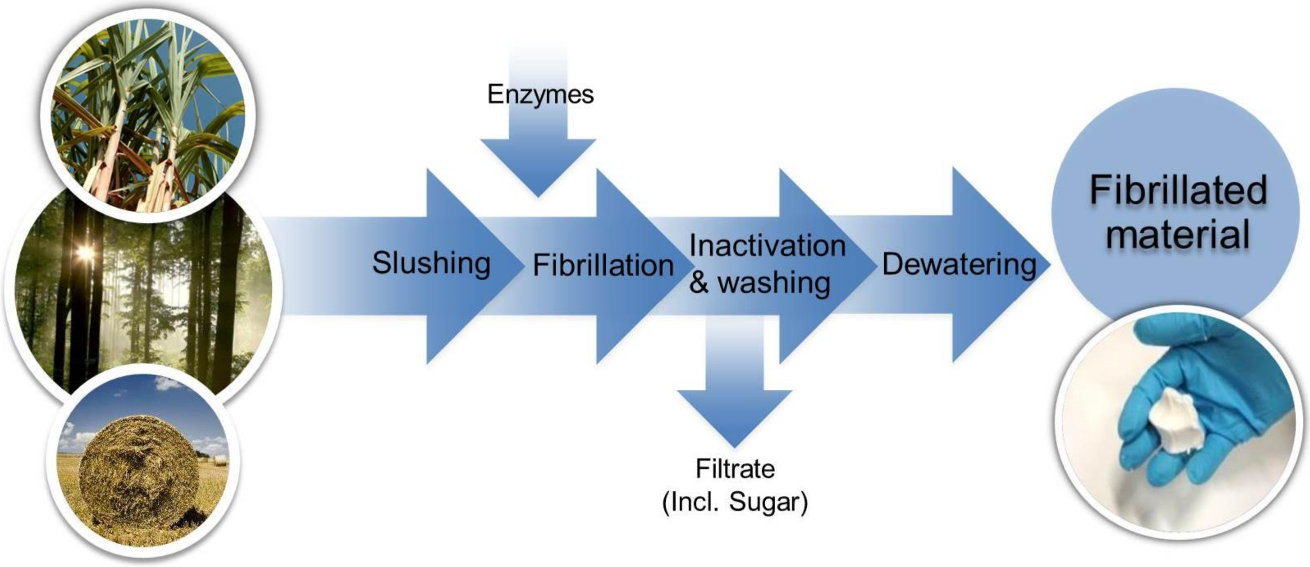

Figure 2. Outline of the HefCel process

valuable side product of the process is about 80% of the total amount of solubilized sugars.

The benefits of the HefCel technology compared to the traditional CNF production include simple and economic process of only a few process steps with existing industrial equipment. High material consistency enables off-site production and long-distance transportation. The material is easy to handle, dewater and dry.

2.1 Simple and economic process

Based on the conceptual process design estimates, the process has been shown to result in significant reductions in the energy needed for fibrillation and the chemical costs are also reasonable. The estimates for the variable costs of the production consists of raw material costs (for example pulp price), the chemical costs of 110 €/ dry ton of CNF and energy costs of 110 € / dry ton of CNF. The energy consumed for the fibrillation of the material has been estimated to be around 0.6MWh/ton, which is a much lower value as compared with the values for other state-of-the art technologies used to produce non-modified CNF [3,4].

In addition, there is a potential revenue from a valuable by-product of the process, cellobiose, which might have potential applications within chemical synthesis and as a functional additive in food and/or feed.

2.2 Potential applications

HefCel CNF can be considered as a platform chemical. The low water content of the material allows its modifications and processing for novel applications (Figure 3). It also facilitates the use of CNFs in applications where excess water is an unwanted element, such as composites or paint and coating formulations.

Examples of potential applications for the HefCel CNF include reinforcement of paper and packaging materials, and ductile films with good barrier properties. Novel cellulose structures, such as scaffolds for regenerative medicine, hard objects for replacement of plastics, electronic components (e.g. bio-based batteries) and biocomposites (e.g. reinforcement of PLA and PHB) can be produced e.g. by 3D printing or machining of dried CNF.

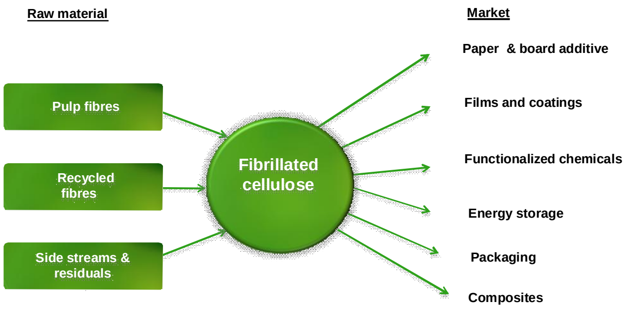

Figure 3. Envisioned applications for HefCel CNF.

HefCel CNF has been shown to have a strenghtening effect when added to the middle ply of board. Especially the bending stiffness was improved with the addition of 3% HefCel CNF, both compared to the reference with no CNF addition and to the case with similar addition of traditonal CNF. In addition, the structure was bulkier with the HefCel addition than the reference structure or the structure with standard CNF addition.

CNF films are known to have excellent oxygen barrier properties [5], better than many plastics. The oxygen barrier performance of HefCel CNF films is comparable to that of traditional CNF films (Figure 4).

The high intial dry matter content of the material and facile water removal also enable the production of light weight solid objects, manufactured by evaporation of moisture followed by pressing to form or milling to shape. Density can be adjusted by pressing. Functions such as threads can be added to shapes by normal machining methods. These kind of all-cellulose, biodegradable structures could potentially serve as replacement of plastics.

3 CONCLUSIONS

HefCel technology provides a cost-efficient method for producing fibrillated cellulose materials. With this technology, problems related to the low consistency of cellulose nanofibrils can be solved and thus, the use of CNFs in commercial applications in various industrial branches can be envisaged.

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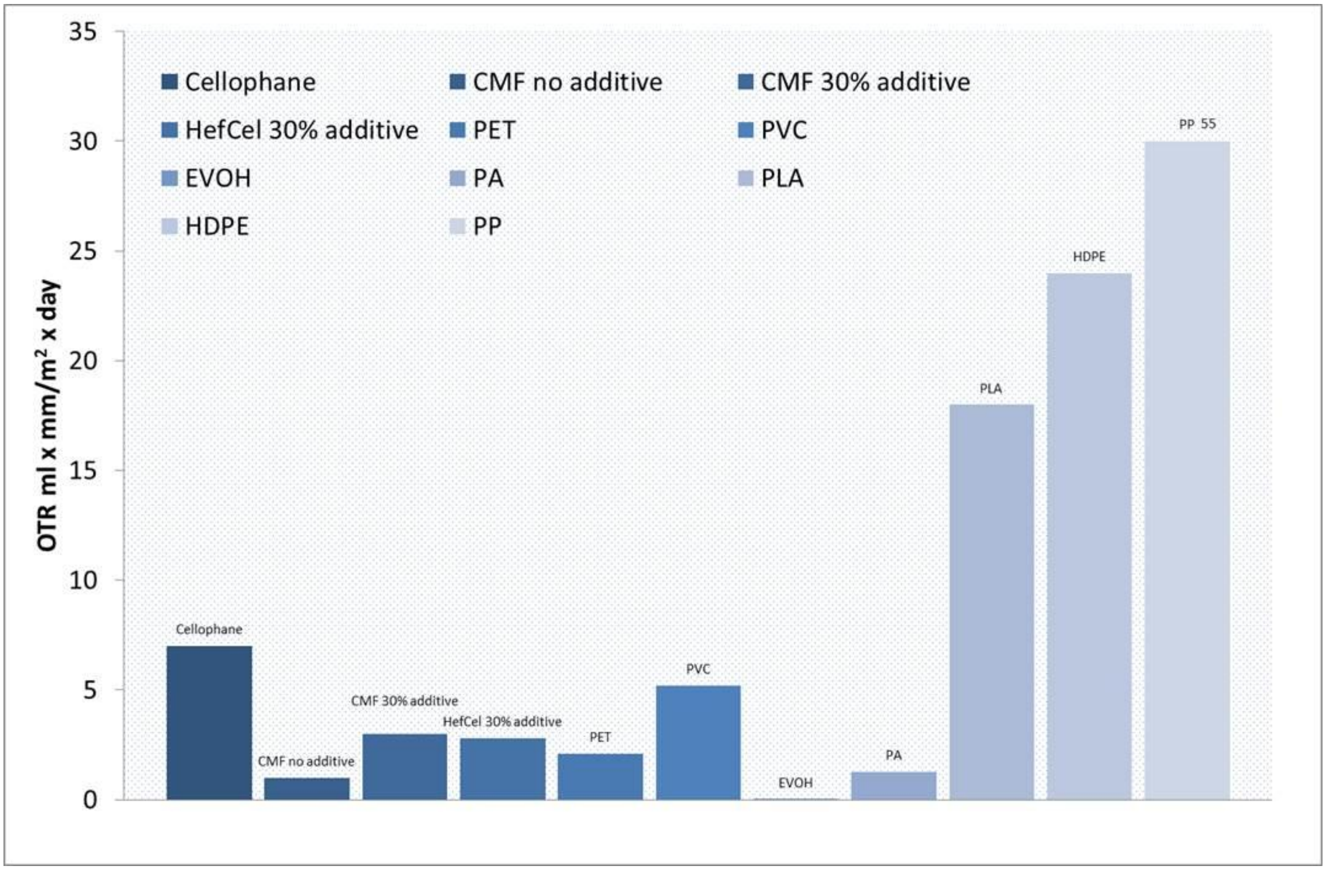

Figure 4. Comparison of oxygen transmission rate (OTR) of CNF materials to those of plastics and cellophane. Values for plastics adobted from [6].