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Mechanical Pretreatment of Lignocellulosic Biomass Using a Screw Press as an Essential Step in the Biofuel Production

Qingqi Yan, Michael Modigell

RWTH Aachen University, Aachener Verfahrenstechnik, Mechanical Process Engineering, Turmstrasse 46, 52056 Aachen, Germany
qingqi.yan@avt.rwth-aachen.de

Since mechanical pretreatment makes lignocellulosic biomass accessible to any further solution and (bio-)chemical modification processes, it is a step which is essential for the entire downstream processing. The objective of the work presented is to develop a mechanically based pretreatment process for biomass using a screw press. The screw press used for this purpose is an oil press which is known to provide continuous high shear and pressure forces. The results obtained in this study show the feasibility and potential for degradation of the lignocellulosic structure as well as dewatering of biomass in the screw press. Adsorption and extraction studies indicate that the products from the screw press have a larger specific surface area and more disruption of cell structure than those treated only with a cutting mill. Furthermore, it is found that the process with a screw press requires considerably less energy in comparison to the conventional thermal-mechanical process.

1. Introduction

Various lignocellulosic materials, such as wood, agricultural residues, forest waste and energy crops are promising feedstocks for biofuel production. Pretreatment of the raw materials is an important step as it has a large impact on the further processes. Kumar et al. (2009) gives a comprehensive summary on possible methods for pretreatment of lignocellulosic biomass. In general, comminution - size reduction - is a fundamental preliminary step by any of the available methods. The objective of mechanical pretreatment is to alter the inherent lignocellulosic structure, increase the accessible surface area, and decrease the crystallinity of cellulose (Taherzadeh and Karimi, 2008).
However the mechanical pretreatment is considered to be one of the most expensive steps with a high energy demand in the biomass conversion process. Thus, by reducing the energy requirement, the optimal mechanical pretreatment process for biomass would improve the whole process economics. The energy requirement of mechanical comminution usually depends on the machine type, the initial and final particle size, and the physical properties of the biomass (Kratky and Jirout, 2011).
In this study, the experiments were performed using a screw press. The original application of this screw press is the oil extraction from oilseeds. Due to its continuous shear and pressure forces, the walls of the oil containing cells are broken and oil is released. By proper geometrical design of the screw-channel and adjusted rotational speed of the screw, the mechanical stress should also be applicable for disruption of lignocellulosic cell walls. This study aims to show that a screw press can be used in the mechanical pretreatment process, which is sketched in Figure 1, for achieving an optimal decomposition of the lignocellulosic structure with low energy demand.

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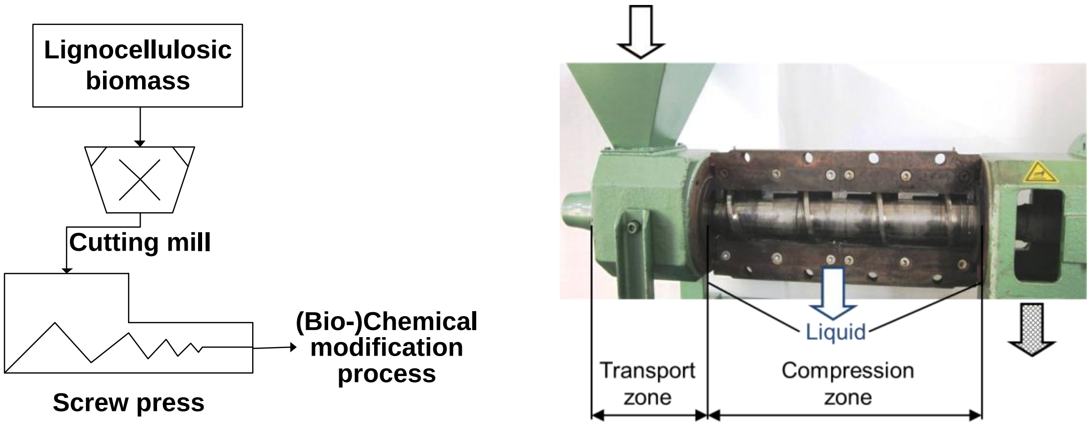

Figure 1: Simplified flow diagram for mechanical pretreatment of lignocellulosic biomass (left) and Photograph of a screw press (right)

2. Materials and Methods

2.1 Feed material

Three different types of materials: wood (spruce and beech), reed and perennial ryegrass were chosen as feed materials. The woodchips were purchased from sawmills (near Aachen, Germany) with an average size of 0.5 × 2 × 3 cm. The materials were fresh with high moisture content (80 - 100%, dry basis). Reeds were harvested from a location near Dümmer See (Osnabrück, Germany) of about 2 meters in length. Perennial ryegrasses were obtained (in Aachen, Germany) with an average length of 5 cm.

The wooden materials and reed were pre-comminuted using a cutting mill (Fritsch, "Pulverisette 19"), equipped with a 6 mm and 10 mm sieve, respectively. Because of the structural property, the lengths of the coarse-milled reed were inhomogeneous from 0.5 to 5 cm.

2.2 Pretreatment with screw press

Pretreatment was carried out by using a screw press (Reinartz, AP08) with a screw diameter of 80 mm and screw length of 450 mm in the compression zone (Figure 1). It is driven by a 4 kW motor.

As the screw turns, the flights in the transport zone push the feed materials forward to the compression zone, whereat the flight height decreases, forcing the materials to a smaller area and causing compression of the biomass. The combination of compression and screw rotation produces frictional forces between the biomass, the inner surface of the strainer barrel and the screw surface. The key idea is to apply these forces in order to simultaneously disrupt and dewater the biomass.

The screw speed was fixed to 17 rpm. The barrel wall temperatures were measured using thermal elements (NiCr-Ni), which are positioned at the strainer.

2.3 Analytical methods

Simple and quick analytical methods were investigated to quantify the advantages of the pretreatment with a screw press. The analyses only focused on the characterization of wooden materials.

2.3.1 Moisture content

The moisture content of the wood was determined by drying a sample to constant weight in an oven at 105°C (TAPPI T12 os-75).

In order to compare the samples without the influence of moisture content, all the materials were dried to the same condition for the further adsorption study and extraction experiments.

2.3.2 SEM observations

The morphology of the treated materials was observed by scanning electron microscope (HITACHI S300N). The samples were dried and coated with a thin layer of gold.

2.3.3 Adsorption study

The adsorption capacity of the treated materials was measured by dye adsorption method. The dye used in this study was Congo red (Sigma-Aldrich). Some studies (Namasivayam and Kavitha, 2002; Fu and Viraraghavan, 2002) have reported about the removal of Congo red from water solution by adsorption. The pH of Na-phosphate buffer solution was adjusted to 6.5. The adsorption of Congo red was carried out by mixing 0.2 g of biomass in 20 mL of 175 mg/L dye solution in a rotary shaker at 200 rpm. After 24 h the dye solution was separated from the biomass by centrifugation at 10,000 rpm for 10 min. The final dye concentration in the solution was measured using a UV-VIS spectrophotometer (Varian Cary 1E). The absorbance of the dyes was read at 498 nm. The dye adsorption capacity of the samples was calculated by material balance.

2.3.4 Extraction with dioxane

Possible methods of disintegration and suitable solvents for extraction of lignin from wooden materials were tested. According to Fukushima and Hatfield (2004), dioxane as a neutral solvent was chosen for the extraction experiment for measuring the extracted lignin content in the samples. Wood (0.25 g) and dioxane (10 mL) were stirred at 80 °C for 2 h. After centrifugation, the absorbance of supernatant solution was measured with a UV–VIS spectrophotometer.

3. Results and discussion

3.1 Feasibility study

The study shows the general feasibility of the targeted process for comminution of lignocellulosic biomass in a screw press (Figure 2). It is shown by means of sieve analysis that the final sizes of reed and ryegrass are smaller than 2 mm after screw press process. Particle sizes of 1-2 mm are optimal to reduce heat- and mass-transfer limitations during the hydrolysis reactions (Schell and Hardwood, 1994). With optical microscope inspection (Figure 2A), more fine fibres and fluffy powder are visible in the wooden products. Agglomerated wooden particles are observed which can be easily deagglomerated into very small particles.

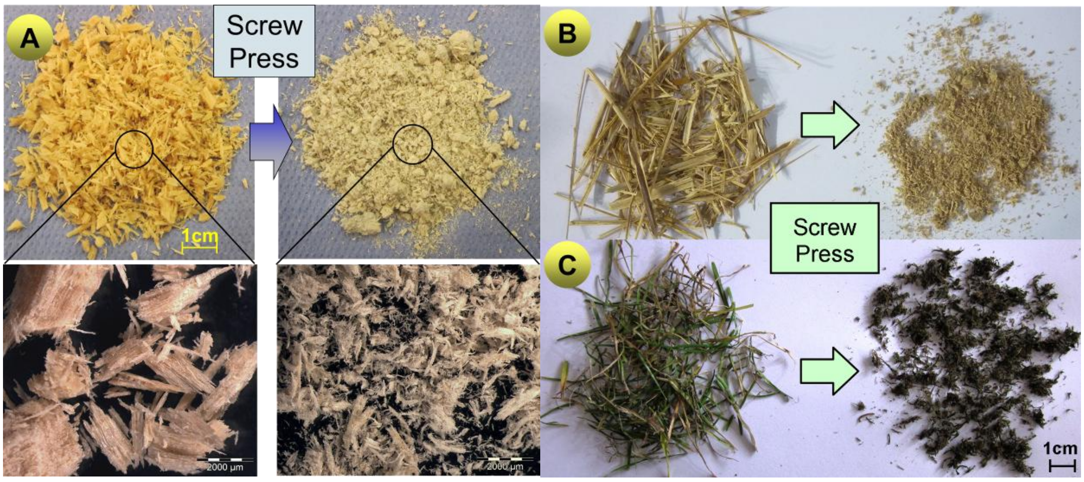

Figure 2: Mechanical pretreatment of beech wood (A), reed (B) and ryegrass (C) using a screw press

Due to dissipation of mechanical energy, a temperature rise along the barrel wall of the screw press was measured. In the cases of wood and reed processing, the maximum barrel temperature exceeded 95 °C and emission of steam occurred.

3.2 Analysis of wooden biomass

3.2.1 Moisture content

Fresh wood contains a large amount of water that is almost equal to the original weight of the wood. With the continuous compression in a screw press, the water in the biomass can be removed effectively. The moisture content of biomass decreases from about 100 % to 20-30 % (dry basis). This dewatering effect can eliminate an additional drying step.

3.2.2 SEM observations

Physical changes in the wood structure for treated materials were analyzed by scanning electron microscopy (SEM). As can be seen in Figure 3, the fibre bundles in the products from screw press are compressed, twisted and partly separated from the initial connected structure.

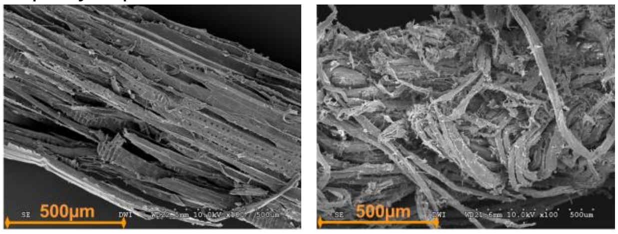

Figure 3: SEM micrographs of wood particle (spruce) before (left) and after (right) pretreatment with a screw press

3.2.3 Adsorption study

Dye adsorption studies with Congo red by measuring the final dye concentration in the solution demonstrate a better adsorption capacity of the pressed products. As indicated in Figure 4, the smaller the particle size, the higher the adsorption capacity, which is due to the increased specific surface area of the biomass. The adsorption capacity of treated spruce wood (cutting mill 6mm + screw press) for Congo red is 6.49 mg/g. According to this information, a calculation with a polynomial interpolation has been performed, which shows that this adsorption effect is as good as the materials treated with a cutting mill with a sieve of 2.2 mm.

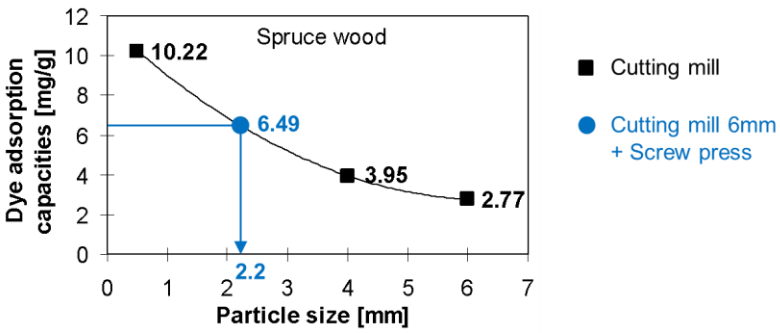

Figure 4: Dependence of particle size on the dye adsorption of Congo red

3.2.4 Extraction with dioxane

At the absorbance of about 278 nm of the supernatant solution, a peak can be noted (Figure 5, left). The difference between the absorbance-curves of dioxane and the supernatant of dioxane with beech wood (at 278 nm) has been calculated and is presented in Figure 5 (right). As can be seen, the materials treated with a screw press have a higher value of absorbance compared with those treated with a cutting mill which has a 6 or 4 mm sieve insert. This information shows that dioxane is able to extract more lignin from the pressed products and indicates that the wood structure is more disrupted during the process with screw press.

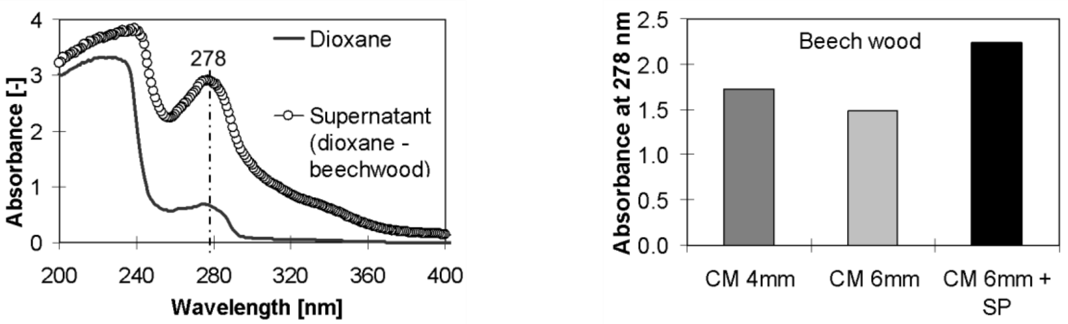

Figure 5: UV- spectra of dioxane and supernatant of dioxane + beech wood (left); Effect of pretreatment on lignin extraction with dioxane (right) (CM: Cutting mill, SP: Screw press)

3.3 Comparison of energy consumption

The energy consumed in the pretreatment process with screw press is calculated for spruce wood and evaluated in comparison to the conventional thermal-mechanical process (Figure 6).

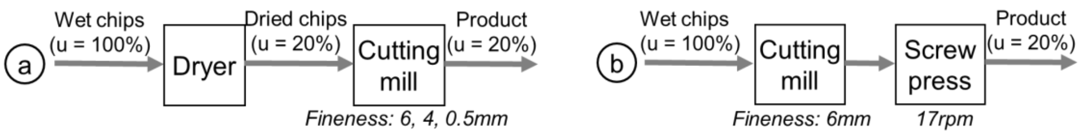

Figure 6: (a) Conventional thermal-mechanical process; (b) Process with a screw press (u: Moisture content, dry basis)

In the conventional method (Figure 6a), the wet chips are first dewatered in a dryer to a moisture content of 20% (dry basis). The dried chips are then comminuted in a cutting mill to final particle sizes of 6, 4 and 0.5 mm. The energy required for drying wet woodchips is 0.9 kWh/kg_{Water} (Gruber and Becker, 2003). The energy consumption in the cutting mill was determined experimentally.
In the process with a screw press (Figure 6b), the wet chips are first comminuted in the cutting mill to a particle size of 6 mm with an energy demand of 0.038 $kWh/kg_{WetChips}$ and then treated in the screw press. The screw press combines comminution and dewatering of the biomass. The energy required is 0.084 $kWh/kg_{WetChips}$.

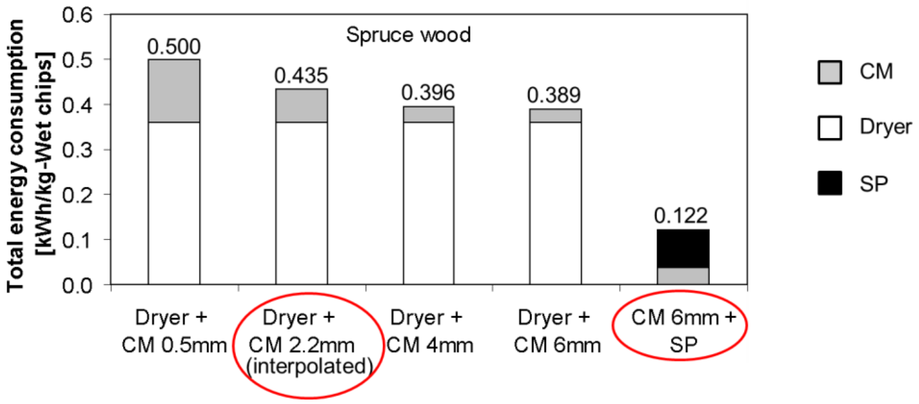

Figure 7: Comparison of the specific energy consumption
(CM: Cutting mill, SP: Screw press, Products with the same specific surface area)

Figure 7 shows a comparison of the specific energy consumption for the conventional thermal-mechanical method and the screw press process. As can be seen, drying of the woodchips is a process step with relatively high energy consumption. The screw press process requires 0.122 $kWh/kg_{WetChips}$ to produce particles with the same specific surface area as conventionally created 2.2 mm particles (shown in Chapter 3.2.3) and reduce the moisture content to 20 %. To achieve the same size reduction and dewatering by the conventional process requires 0.435 $kWh/kg_{WetChips}$. Thus, the process with a screw press requires about 72 % less energy than the conventional process.

4. Conclusions

The results obtained in this study indicate the feasibility and potential of the application of a screw press for comminution of lignocellulosic biomass and degradation of the cellular structure. In addition, simple analytical methods have been found to quantify the benefits of pretreatment with a screw press. Significant decreases of moisture content and structural changes of the wood fiber are observed. The adsorption study with Congo red and extraction experiments with dioxane show that the wooden materials treated with a screw press have a larger specific surface area and more disrupted cell structures than those treated only with a cutting mill. Because of simultaneous drying and comminution, the pretreatment process with a screw press requires considerably less energy than the conventional thermal-mechanical process. Besides this, the screw press has additional advantages such as short processing time and its adaptability to process modification. Therefore it holds promise for further investigation and development.

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