Invited Paper

EAEF 4(3) : 62-65, 2011

Fine-crushing of Wood-cellulosic Material Modified for its Hydrolysis for Bioethanol Production*

Koichi Shoji[*1], Daizo Yamaguchi[*2], Hisashi Horio [*3]

Abstract

A prototype of a fine-crusher (grinder) of wood-cellulosic materials has been constructed with flail-knives and a rotary sieve rotating independently of each other. Pieces of bamboo in batches were fed into the fine-crusher, the crushed material was then treated with pressurized hot water (sub-critical water) to modify its structure and then hydrolyzed into glucose. With an increase in the diameter of the pores of the rotary sieve, the specific energy requirement for fine-crushing decreased remarkably from 500 to 250 kJ/kg, while the estimated glucose yield at 200°C decreased negligibly from 38% to 35%. The best rotational speed of the rotor and the diameter of the sieve pores were 1500 rpm and 4 mm, respectively.

[Keywords] grinding, energy requirement, enzymatic hydrolysis, glucose yield, bamboo

I Introduction

Bioethanol production from lignocellulosic materials such as crop residue or wood is a promising technology that obviates conflict with food resources. Unlike simple fermentation of starch- or sugar- based biomass, however, additional and specialized processes are required for trating the lignocellulosic materials, as comprehensively reviewed by Sun and Cheng (2002) and Duff and Murray (1996). After chipping the material into a few centimeters, pretreatment is needed for facilitating the following chemical and biological treatment: hydrolysis (saccharification) of cellulose and fermentation of glucose. Currently, major pretreatment methods such as explosion or alkali/acid hydrolysis require large-scale and heavily equipped facilities at the expense of well-established efficiency. In our view, mechanical fine-crushing (grinding, comminution) for size reduction plus hot (pressurized, sub-critical) water treatment for exposing cellulose from the lignin and hemi-cellulose structure are practically suited to small-scale and on-site treatment that could potentially enhance the production of bioethanol.

Therefore, questions as to whether finer crushed materials produce higher hydrolytic yield and whether the energy required for the fine-crushing justifies the whole process of bioethanol production remain to be resolved, especially that this mechanical process cannot recover energy as other processes associated with heat treatment do. For example, ball-milling or hammer-milling of dry hardwood from 25 mm to 1.6 mm requires a specific energy of 470 kJ/kg (Cadoche and Lopez, 1989). This is actually equivalent to 19% of the calorific value of ethanol produced by theoretically ideal conversion from lignocellulosic material containing 40% cellulose.

We have developed a portable fine-crusher operable continuously on-site (Yamaguchi *et al*., 2006), and the removal or modification of lignin has been evaluated and correlated with the complexity of the crushed material (Yamaguchi *et al*., 2008). Here, energy requirement for the fine-crushing is evaluated with the use of a batch-based prototype of the fine-crusher. The extent of fine-crushing is related to the glucose yield after enzymatic hydrolysis of the crushed material. Finally, the best operating setup of the fine-crusher is suggested from the viewpoint of energy requirement vs. glucose yield.

II Materials and Methods

1. Fine-crusher

The prototype of the fine-crusher consists of a flail-knife rotor and a rotary sieve, both rotating on a common shaft driven by variable-speed induction motors 2 kW and 0.2 kW, respectively (Fig. 1). Six flail-knives (untwisted) attached to the rotor and four fixed blades in the rotary sieve function as the crushing mechanism. The width of the prototype is 150 mm that represents about 23% that of the fine-crusher

* Presented at ISMAB2010, Fukuoka, Japan, April 2010
*1 JSAM Member, Corresponding author, Graduate School of Agriculture, Kobe University, 1-1 Rokkodai-cho, Nada-ku, Kobe, 657-8501, Japan; shojik@kobe-u.ac.jp
*2 JSAM Member, Tsuyama National College of Technology, Numa 624-1, Tsuyama, Okayama, 708-8509, Japan
*3 JSAM Member, Graduate School of Agriculture, Kobe University, 1-1 Rokkodai-cho, Nada-ku, Kobe, 657-8501, Japan

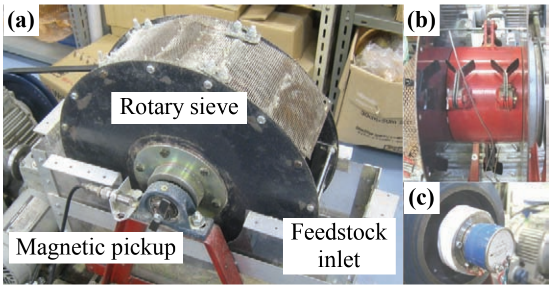

Fig. 1 Fine-crusher with the upper casing removed: (a) overview with the feedstock inlet open, (b) flail-knives on the rotor with the rotary sieve removed, (c) slip ring for torque measurement.

(Yamaguchi *et al*., 2006; Yamaguchi *et al*., 2008), the material is fed in batches, the crusher is covered with a plastic casing, and the crushed material is collected in a drawer set at the base of the casing. The rotational speed of the rotor (hereinafter "rotor speed") is varied to 1000, 1500, and 2000 rpm, whereas that of the rotary sieve set at 50 rpm throughout the experiment. The rotary sieve is a punching sieve with circular pores (opening ratio of 22.3%), and the diameter of the pores (hereinafter "sieve-pore diameter") is varied to 2, 3, and 4 mm. Real-time measurement was carried out on the rotor speed with a magnetic pickup, and on the torque of the shaft with strain gauges, to calculate the energy requirement.

The size of the fresh bamboo (*Phyllostachys bambusoides*) used as feedstock was controlled to reduce experimental variability; the pieces (weighing approximately 0.1 kg per batch) fed into the fine-crusher measured approximately 30 × 30 mm and 30 × 60 mm. The duration of the fine-crushing was varied to 60, 40, and 30 s for the rotor speed of 1000, 1500, and 2000 rpm, respectively, for equal impact of the flail-knives with the material. Namely, the total revolutions of the rotor was fixed at 1000 (= 60 × 1000 / 60 = 40 × 1500 / 60 = 30 × 2000 / 60) for the same total impact between the flail-knives and the material. Above a total of 1000 revolutions, almost no throughput was observed at any setup in the preliminary trials.

2. Glucose yield

The crushed material was classified according to standard 4.0, 2.4, and 1.7 mm wire mesh, added at 2 mg/mL to 0.25

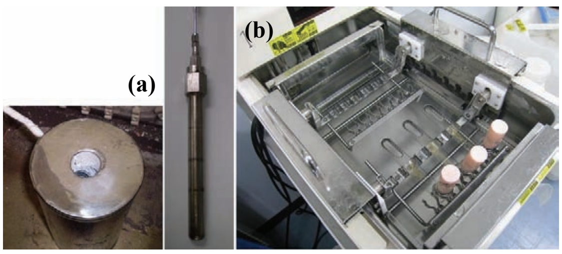

Fig. 2 Apparatus for evaluation: (a) heater and autoclave for hot water treatment, (b) thermostatic bath shaker for enzymatic hydrolysis.

mg/mL- buffered cellulase (spp. *Trichoderma viride*) solution at pH 5.0, and shaken for 24 hours at 40°C (Fig. 2b). After devitalizing the enzyme, the glucose content was measured with a spectrometer using a coloring reagent kit.

Glucose yield was calculated as follows:

$$y = \frac{cva}{m} \times 100 \tag{1}$$

where y is the glucose yield (%), c the glucose content in the buffer solution, v the volume of the solution, a the ratio of the molecular weight of cellulose to the weight of glucose after hydrolysis (*i.e.* 162/180), and m the weight of the substrate (*i.e.* cellulose). The portion of cellulose in the crushed material was unknown, but was tentatively assumed to be 0.4 to convert glucose content into the yield. The weighted average of the glucose yield for each run was then calculated, as weighted by the portion from the wire mesh classification.

3. Hot water treatment

The effect of hot water (sub-critical water) treatment was studied with the use of representative samples of crushed material. This treatment is similar to acid or alkali treatment of the material, so that the structure of lignin and hemi-cellulose can be loosened or modified to expose cellulose for the hydrolysis into glucose in the next step. The purpose of this experiment was to acquire basic data for estimating the glucose yield for each setup of the fine-crusher, according to the size distribution of the crushed material.

Because of the diverse size of the crushed material, and to avoid variability, direct application of the hot water treatment was not attempted. The material was classified according to standard 3.35, 2.00, 1.00, and 0.50 mm wire mesh. A 1-gram sample of the classified material was heated in water enclosed

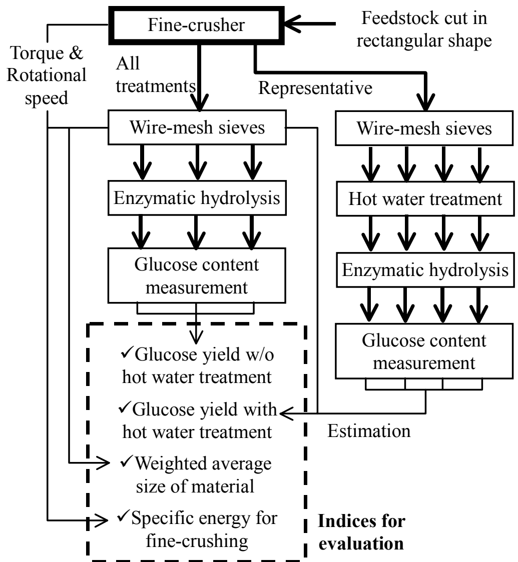

Fig. 3 Schematic flow of material (bold arrows) and measured values (thin arrows)