Determining The specific energy Consumption for Grinding Rice straw with a Hammer mill

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ABSTRACT
The objective of this study was determining the relationships between moisture content (8 and 12 % w.b) and hammer mill in four screen sizes (2, 4, 7 and 8 mm) with energy required for grinding rice straw. An amount of rice straw was grinded in each test and the particle size of ground rice straw was determined. A watt metering system was used to measure the energy consumption of grinding of grinding for each test. The highest specific energy consumption was 32.46kWh.t⁻¹ for hammer mill screen size of 2mm at 12 % (w.b) moisture content. The hammer mill screen size was negatively connected with specific energy consumption. Therefore, the larger the hammer mill screen size, use less the specific energy consumption. The particle size was normally distributed for the rice straw ground by at 2 and 4 mm hammer mill screen sizes. The grinds from screen size of 8 mm had a large size distribution with a geometric mean particle diameter of 1.04 mm.

KEYWORD
Energy consumption, rice straw, hammer mill, grinding.

INTRODUCTION
Biomass has become an important renewable energy resource for producing electric power and other forms of energy with low greenhouse gas and low acid gas emissions. Direct-combustion and co-firing technologies have become commercially available. Co-firing biomass with coal in existing coal-fired power plants has emerged to be an attractive way for increased use of biomass as an energy source (Costello, 1998).

Agricultural biomass residues such as barley, canola, oat and wheat straw are potential feedstocks for the sustainable production of bio-fuels and to offset greenhouse gas emissions [1, 2]. Milling is an important pretreatment of biomass for energy conversion. It is also crucial to the densification process. For example, in the production of fuel pellets and briquettes, the feedstock has to be ground before being transformed into a denser product. Particle size reduction increases the total surface area, pore size of the material and the number of contact points for inter-particle bonding in the compaction process [3]. The grinding process is an important unit operation prior to densification.

Tabil (1996) obtained consumption of specific energy for alfalfa pellet mill at two hammer mill screen sizes of 2.4 and 3.2 mm using a watt-hour meter with a data logger attachment and sampling time of 15 s [4]. Specific energy consumption of grinding material depends on moisture content, bulk and particle densities, feed rate of the material, particle size distribution (initial/final particle size) and machine variables [5].

Energy consumption for grinding wheat straw, corn stover, and rice straw increases when screen opening size are changed from coarser to finer [6]. Several models such as Kick, Rittinger [7] and Bond [8] have been used to predict the required specific energy consumption for grinding agricultural materials. All three models proposed for dry grinding have given reasonably good results based on the type of grinding: the Kick model for coarse grinding; the Bond model for intermediate grinding and the Rittinger model for fine grinding [9].

MATERIALS AND METHODS
Rice straws in square bales were obtained from agricultural land at Daniel village of Mazandaran, Iran. The bales were of standard dimensions of 1.00 × 0.45 × 0.35 m with the moisture content of 8 % (w.b)

A. Chopping
The rice straw was chopped manually with cutter to the size of 40-50 mm (Fig.1). The chop size was determined using a chopped forage size analyzer specified in ASAE Standard S424.1 MAR 98 [10].

Fig.1. Chopped rice straw

B. Conditioning of rice straw

Conditioning of the rice straw to the required moisture content was done by spraying water uniformly into the chopped material. The wetted material was placed in a plastic bag and stored in a room at 22 °C for 72 h for moisture equilibration prior to grinding.

C. Moisture content

The moisture content of rice straw was determined according to ASAE standard S358.2 FEB03 for forage [11]. A sample of 25 g was oven dried for 24 h at 105±3 °C. The moisture content of the grind was determined by the procedure given in ASTM Standard D 3173-87 for coal and coke [12]. One gram of pulverized sample passing through a sieve with opening of 0.25mm (sieve no. 60) was taken and oven dried for 1 h at 104–110 °C. The moisture content of the grind was determined by weighing and expressed in percent wet basis [13].

D. Grinding test apparatus /Hammer mill

A hammer mill was used for grinding of rice straw (Fig.2). The hammer mill used in this study consisted of 25 swinging hammers, attached to a shaft powered by a 2.2 kW (3 hp) electric motor. The shaft rotated at a speed of 3000 r min⁻¹. A tapering hopper (with 500 mm small diameter 500 mm large diameter and 300mm height) was used for feeding system.

E. Particle size distribution

The particle size of rice straw was determined according to ASAE standard S319.3 FEB03 [14]. A sample grind of 100 g was placed in a stack of sieves arranged from the largest to the smallest opening for 10 min. The sieves number of 10, 16, 30 and 50 (nominal openings of 2, 1.18, 0.6 and 0.3 mm, respectively) were used for grinding from 2, 4, 7 and 8 hammer mill screen opening. After sieving, the mass retained on each sieve was weighed. Sieve analysis was repeated three times for each grind sample.

The hammer mill screen size of 4mm and 2mm were selected. The hammer mill was started and a known quantity of rice straw was fed into the hammer mill. The hammer mill was started. A known quantity of rice straw was manually fed into the hammer mill and the time required to grind the straw was recorded along with the power drawn by the hammer mill motor which was recorded every 6 s. The power required to run the empty hammer mill was measured before the material was introduced. This allowed determining the net power required to grind the material. The specific energy required for grinding was determined by integrating the area under the power demand curve for the total time required to grind a sample [15]. Each test was repeated three times.

The geometric mean diameter (d₉₀) of the sample and geometric standard deviation of particle diameter (S₉₀) were calculated according to the ASAE Standard S319.3 [14].

\[
d_{90} = \log^{-1} \left[ \sum_{i=1}^{n} W_i \log \frac{d_i}{d_{90}} \right] \frac{1}{\sum_{i=1}^{n} W_i}
\]

(1)

\[
S_{log} = \left[ \frac{\sum_{i=1}^{n} W_i (\log d_i - \log d_{90})^2}{\sum_{i=1}^{n} W_i} \right]^{1/2}
\]

(2)

\[
S_{log} = \left[ \frac{\sum_{i=1}^{n} W_i (\log d_i - \log d_{90})^2}{\sum_{i=1}^{n} W_i} \right]^{1/2}
\]

(3)
Where

- \( d_{gw} \): geometric mean diameter or median size of particles by mass (mm);
- \( S_{log} \): geometric standard deviation of log normal distribution by mass in 10 based logarithm (dimensionless);
- \( S_{gw} \): geometric standard deviation of particle diameter by mass, mm
- \( W_i \): mass on \( i \)th sieve, g
- \( n \): number of sieves plus one pan
- \( \bar{d}_i = (d_i \times d_{i+1})^{1/2} \)
- \( d_i \): nominal sieve aperture size of the \( i \)th sieve, mm
- \( d_{i+1} \): nominal sieve aperture size of the \( i+1 \)th sieve, mm.

**RESULTS AND DISCUSSION**

**A. Energy requirement for grinding**

Table 1 lists the average specific energy consumption for grinding rice straw using the hammer mill with four different screen sizes at two moisture content levels.

<table>
<thead>
<tr>
<th>Moisture content (% w.b)</th>
<th>Screen opening size of hammer mill (mm)</th>
<th>Average specific energy consumption (kW h t(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>2</td>
<td>19.73</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>11.58</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>8.24</td>
</tr>
<tr>
<td>12</td>
<td>2</td>
<td>32.46</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
<td>26.52</td>
</tr>
<tr>
<td>12</td>
<td>7</td>
<td>15.84</td>
</tr>
<tr>
<td>12</td>
<td>8</td>
<td>14.69</td>
</tr>
</tbody>
</table>

The specific energy consumption for grinding rice straw with 8% (w.b) moisture content by the hammer mill screen sizes of 2, 4, 7 and 8 mm were 19.73, 11.58, 8.24 and 8.12 kW h t\(^{-1}\), respectively. As the size of screen on the hammer mill increased from 2 to 8mm, the specific energy consumption for grinding of 8% (w.b) decreased from 19.73 to 8.12 KW h t\(^{-1}\). The specific energy consumption for grinding rice straw with 8% (w.b) decreased by 59% when the screen size was increased from 2 to 8 mm. Among the four hammer mill screen sizes, grinding from screen size 8 and 2 required the highest and lowest the specific energy consumption for grinding, respectively.

**B. Effect of hammer mill screen sizes on energy consumption for grinding**

Figure 3 represents the specific energy requirement for grinding rice straw as a function of screen size at moisture content of 8% (w.b). The smaller the screen size, the higher is the specific energy for grinding the rice straw samples. In other words, fine grinding requires high specific energy. Similar results have been reported for four biomasses namely corn stover, switchgrass, wheat and barley straw [13].

**C. The effect of moisture content on grinding**

Figure 5 represents the effect of moisture content on the specific energy requirement for grinding rice straw.

At 12% (w.b) moisture content, hammer mill screen size of 2 mm, consumed the highest amount of energy with a rate of 32.46 kW h t\(^{-1}\). The fig. 5 shows that the hammer mill screen size was negatively connected with specific energy consumption. Therefore, the larger the hammer mill screen size, use less the specific energy consumption.
results have been reported for grinding of alfalfa stem [16] and for four biomasses namely corn stover, switch grass and wheat and barley straw grind [13]. Sitkei reported a second-order polynomial relationship between the specific energy requirement and the mean particle size for alfalfa stems with a $R^2$ value of 0.99. Similarly, Holtzapple et al. (1989) reported the relationship for grinding energy with the length of wood cubes. They also concluded that grinding energy increased greatly as the particle size is reduced [17]. Moisture content is also an important factor for energy consumption during grinding. Moisture content had a positive connected with specific energy consumption. The higher the moisture content, use more the specific energy consumption. It can be stated that an increase in moisture content of rice straw would increase the shear strength of the material, although shear strength decreases with decomposition of rice straw [18]. Balk (1964) reported that for alfalfa grinding, moisture content had a positive correlation with specific energy consumption [15].

**Figure 6.** Particle size distribution of rice straw grinds (average of three tests) for different sizes

**CONCLUSION**

The highest specific energy consumption was 32.46KW.h $t^{-1}$ for hammer mill screen size of 2mm at 12% (w.b) moisture content. The hammer mill screen size was negatively connected with specific energy consumption. Therefore, the larger the hammer mill screen size, use less the specific energy consumption. The particle size was normally distributed for the rice straw grinded by at 2 and 4 mm hammer mill screen sizes. The grinds from screen size of 8 mm had a large size distribution with a geometric mean particle diameter of 1.04 mm.

**REFERENCES**


