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Power requirement for particle size reduction of wheat straw as a function of straw threshing unit parameters

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Abstract

Wheat straw at moisture content of 8.5 % w.b. was threshed using a straw thresher machine. Power requirement for size reduction of the straw was measured at different conditions. The thresher parameters were: drum speed at three levels: 400, 540, and 800 rpm, two screen sizes (2.5 and 4 cm), and two states for number of blades on each flange (4 and 8 blades). Based on the results obtained, the power requirement increased with increasing drum speed and with decreasing screen size and number of blades on each flange. The power requirement increased from 1.506 to 5.144 kW and 1.134 to 4.093 kW, for screen sizes of 2.5 and 4 cm, respectively, with an increase in the drum speed from 400 to 800 rpm. The maximum power requirement (5.377 kW) occurred at 2.5 cm screen size and drum speed of 800 rpm with 4 blades on each flange, while the minimum power requirement (0.985 kW) occurred at 4 cm screen size and drum speed of 400 rpm with 8 blades on each flange.

Keywords: Size reduction; straw thresher; power requirement; drum speed; screen size

Introduction

Cereal straws are a major part of crop residues and considered as an important feed resource in many developing countries such as Iran, even though their quality and nutritional values are low. Among the cereal straws, wheat straw is the most abundant field crop residue in Iran because of its high cultivated area (6.95 million hectares) and annual production (14 million tones) of wheat (FAO, 2007). The straw usually serves as feed for animals and sometimes is incorporated into the plowed layer or used as mulch. For animal nutrition and other applications, size of the harvested straw must be reduced as much as possible. For proper design and optimization of straw size reduction equipment, it is necessary to know mechanical properties of the straw. Power or energy requirement for size reduction of straw is one of these properties. It depends on initial particle size, moisture content, material properties, feed rate of the material and machine variables (Mani et al. 2004).

Balk (1964) studied the specific energy requirement of a hammer mill for grinding of coastal Bermuda grass. He related the specific energy requirement with moisture content and also with the feed rate of the material. Von Bargen et al. (1981) reported that the corn residues used more energy among three crop residues tested viz. wheat straw, corn residues and grain sorghum residues at a hammer mill peripheral speed of 15.8 m s^{-1}. They also found that the grain sorghum residues required the least specific energy. Datta (1981) reported that coarse size reduction (0.2–0.6 mm) of hardwood chips required 20–40 kW h t^{-1}, whereas size reduction to 0.15–0.3 mm required 100–200 kW h t^{-1} of grinding energy. However, He did not report the

Table 1. Mean comparison of power requirement for threshing wheat straw in different drum speeds, screen sizes and number of blades on flange

Drum speed (rpm)	Power requirement (kW)*
400	1.320 [a]
540	2.349 [b]
800	4.619 [c]
Screen size (cm)	
2.5	3.074 [a]
4	2.451 [b]
Number of blades on flange	
4	2.952 [a]
8	2.573 [b]

* Means with minimum common letter are not significantly different (P>0.05).

moisture content of the feedstock, type of mill and particle size distributions. Samson et al. (2001) reported a specific energy of 44.9 kW h t^{-1}, when a hammer mill with screen size of 5.6 mm was used to grind switchgrass. Schell and Harwood (1994) studied the energy requirement for milling of lignocelluloses biomass and concluded that hammer milling used less energy than disk milling. A study on grinding of switchgrass at 10–12% wet basis (w.b.) moisture content in a hammer mill was reported by Jannasch et al. (2002). They reported a specific energy of 55.9 kWh t^{-1} for both 5.6 and 2.8 mm screen sizes. Power requirements of hemp cutting and conditioning were determined by Chen et al. (2004). Their results showed that the measured value for the power requirement of hemp cutting significantly increased from 99 to 256 W when the feed rate increased from 24 to 40 plants s^{-1}. Further increase in feed rate to 60 plants s^{-1} resulted in a power of 280 W, which was not statistically significant. The results showed that the cutting force and energy were significantly greater at a higher moisture content and specific mass of hemp stem. The average values of the maximum force and the total cutting energy required for cutting a hemp stem were 243 N and 2.1 J, respectively. Mani et al. (2004) studied grinding performance and physical properties of wheat and barley straws, corn stover and switchgrass. They showed that among the four materials, switchgrass had the highest specific energy consumption (27.6 kW h t^{-1}), and corn stover had the least specific energy consumption (11.0 kW h t^{-1}) at 3.2 mm screen size.

About effect of threshing unit variables on the power requirement for size reduction of wheat straw, no research effort was seen in the literature. Therefore, the objective of this study was to determine the effects of drum speed, screen size, and number of flange blades on the power requirement.

Materials and methods

Wheat straws in square bales were obtained from the University of Tehran agronomy farm. The bales were of standard dimension of 1.00 × 0.45 × 0.35 m with the moisture content of 8.5 % w.b. For each treatment, about 10 kg of the straws were used.

A schematic diagram of the straw thresher used for size reduction of wheat straw in this work is shown in Fig. 1. It is observed that the thresher consisted mainly of frame, power transmission system, threshing unit, and conveying system. The conveying system was removed during doing the experiments and the threshed straws were collected under the thresher. The threshing unit was powered by the tractor P.T.O. shaft via the power transmission system. The threshing unit had a drum with 11 flanges mounted on its shaft (Fig. 2). In this study, the effect of threshing drum speed in three levels of 400, 540 and 800 rpm on the power requirement for size reduction of wheat straw was investigated. Blades bolted on the flanges, reduce particle size of straw by shear and impact action. Furthermore, effect of the number of blades on each flange (4 and 8 blades) on the power requirement was evaluated. A rethreshing screen was placed beneath the threshing drum. According to Nazari Galedar (2008), appropriate range of straw size for animal feed is 2-5 cm. Therefore, two rethreshing screens with opening size of 2.5 and 4 cm were used. For determining particle size distribution of threshed wheat straws, two sieves with opening sizes of 2.5 and 4 cm were used.

As shown in Fig. 3, the threshing drum speed was measured using a tachometer having a magnetic sensor and a gear. The threshing drum torque was also measured using a torque transducer with strain gauges. During performing each experiment, signals of the torque and speed sensors were continuously recorded using a data acquisition system. The set of the tachometer and torque transducer was installed between the tractor P.T.O. shaft and the power transmission system of the straw thresher. The power requirement was calculated using the measured torque and speed data. Before each experiment, the thresher was operated without any load for 20s in order to measure no-load power. The measured no-load power was then subtracted from the total power to obtain the net power required to actually thresh the straw. This study was planned as a completely randomized block design. The experiments were conducted with three replications in each treatment. Experimental data were analysed using analysis of variance (ANOVA) and the means were compared at 1% and 5% levels of significance using the Duncan's multiple range tests in SPSS software (version 13, SPSS, Inc., Chicago, IL, USA).

Table 2. Mean comparison of power requirement for threshing wheat straw considering interaction effect among drum speed, screen size and number of blades

Drum speed (rpm)	Power requirement (kW)*			
	Screen size (cm)			
	2.5		4	
Number of blades on flange	4	8	4	8
400	1.692 [efg]	1.321 [fg]	1.282 [fg]	0.985 [g]
540	2.732 [d]	2.411 [de]	2.231 [de]	2.022 [def]
800	5.377 [a]	4.912 [ab]	4.397 [bc]	3.789 [c]

* Means with minimum common letter are not significantly different (*P*>0.05).

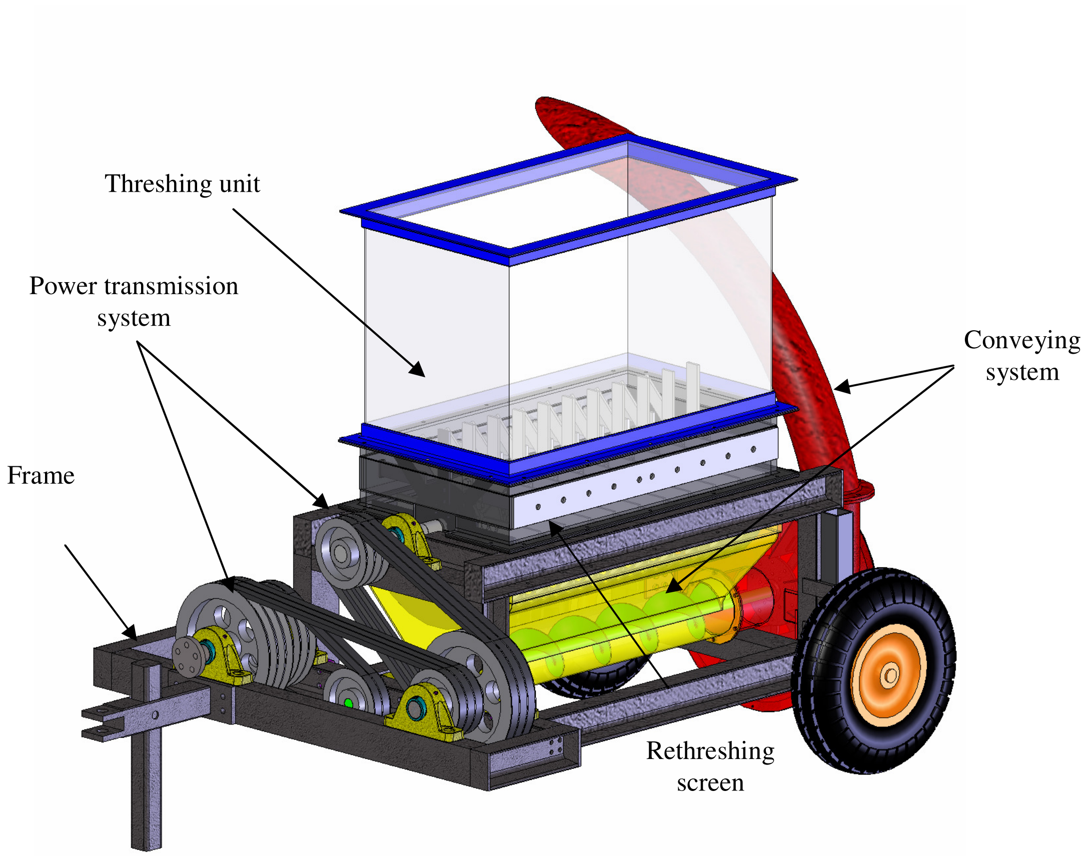

Fig 1. Schematic of straw thresher used for size reduction of wheat straw.

Results and discussion

Variance analysis of the data indicated that the drum speed and screen size created a significant effect at 1 % probability level on the power requirement. In addition, the number of blades had significant effect at 5 % probability level on the power requirement. The average power requirement for size reduction of wheat straw was obtained as 2.763 kW varying from 0.985 to 5.377 kW. Based on the statistical analysis, interaction effects of drum speed × screen size, drum speed × number of blades, screen size × number of blades, and drum speed × screen size × number of blades on the power requirement were not significant (*P*>0.05). In the following paragraphs, the effects of each factor on the power requirement are comprehensively discussed.

Drum Speed

The drum speed had a significant effect (*P*<0.01) on the power requirement as shown in Table 1. The power requirement increased linearly with an increase in the drum speed. As shown in Fig. 4, the power

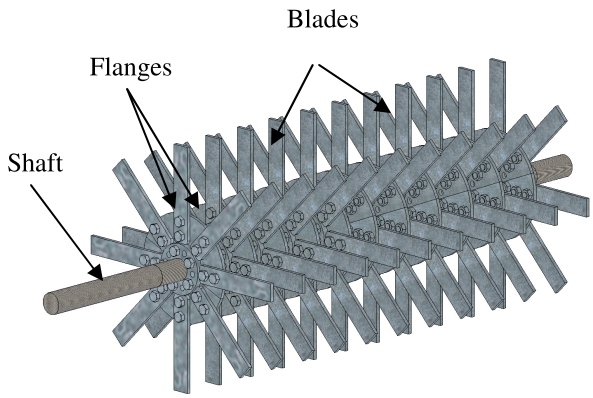

Fig 2. Schematic of threshing drum of the straw thresher.

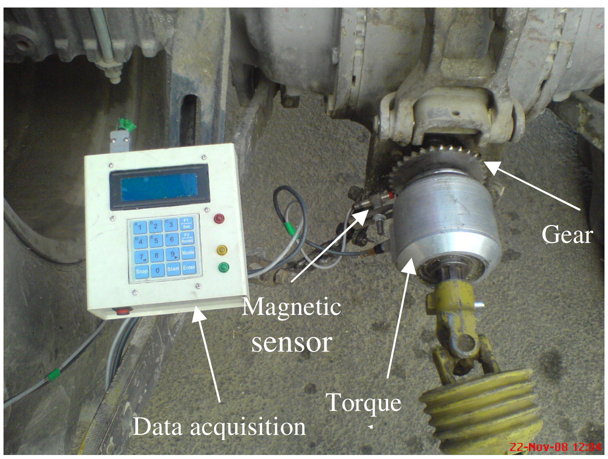

Fig 3. Apparatus used for measuring the power requirement.

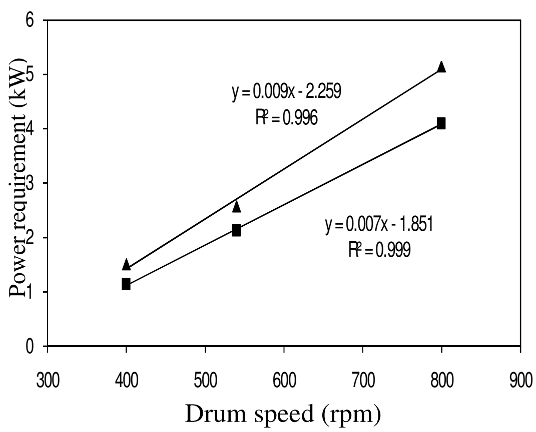

Fig 4. Effect of drum speed and screen size on the power requirement; (▲) screen size of 2.5 cm; (■) screen size of 4 cm.

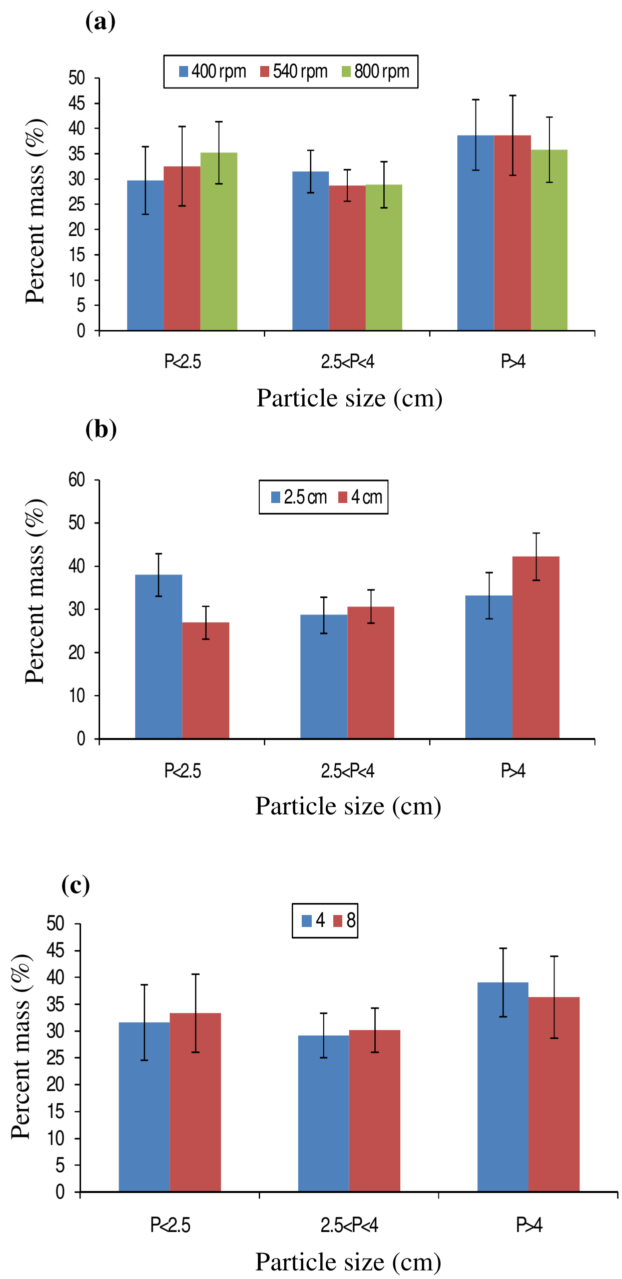

Fig 5. Particle size distribution of threshed wheat straw at (a) different drum speeds, (b) various screen sizes, and (c) different number of blades on flange.

requirement increased from 1.506 to 5.144 kW and 1.134 to 4.093 kW, for screen sizes of 2.5 and 4 cm, respectively, with an increase in the drum speed from 400 to 800 rpm. The power requirement of threshing unit increased with increasing the drum speed because of the increased feed rate which accounted for the extra energy required for threshing the material. In other words, the increase in feed rate required greater compression of the material as it passed between the threshing drum and rethreshing screen causing an increase in power requirement. Similar increasing trend for power requirement was reported by Sudajan et al. (2002) for sunflower threshing in the drum speed range of 550-1150 rpm. Persson (1987) reviewed several studies on the cutting speed and then concluded that cutting power is only slightly affected by cutting speed, although an increase in cutting speed will often increase the power losses caused by material acceleration. Vejasit and Salokhe (2004) conducted a study for determining effects of machine-crop parameters of an axial flow thresher for threshing soybean. They showed that the power required for threshing soybean at 540 to 720 kg (plant)/h feed rates at 14.34% (w.b.) grain moisture content was between 0.89 to 1.85 kW, when the drum speed was increased from 500 to 700 rpm. Particle size distribution of threshed wheat straws at different drum speeds is presented in Fig. 5a.

Screen Size

The mean values of the power requirement at two screen sizes of 2.5 and 4 cm are presented in Table 1. It is observed that the power requirement decreases significantly (P<0.01) with an increase in the screen size. In other words, fine threshing requires high power. This is in agreement with the results for alfalfa stem grinding reported by Sitkei (1986). He 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 increases greatly as the particle size is reduced. Mani et al. (2004) showed that specific energy consumption for grinding wheat straw and corn stover decreased with an increase in screen size. The specific energy consumption for grinding wheat straw with the hammer mill having screen sizes of 0.8, 1.6 and 3.2 mm were 51.6, 37.0 and 11.4 kW h t^{-1}, respectively, at 8.30 % (w.b.) moisture content. Energy consumptions in order to reduce corn stover sizes to particle sizes of 3.2, 1.6 and 0.8 were 7.0, 14.8 and 22.0 kW h t^{-1}, respectively. Particle size distribution of threshed wheat straws at different screen sizes is presented in Fig. 5b.

Number of blades on flange

The power requirement was significantly affected by number of blades at 5 % probability level. The values

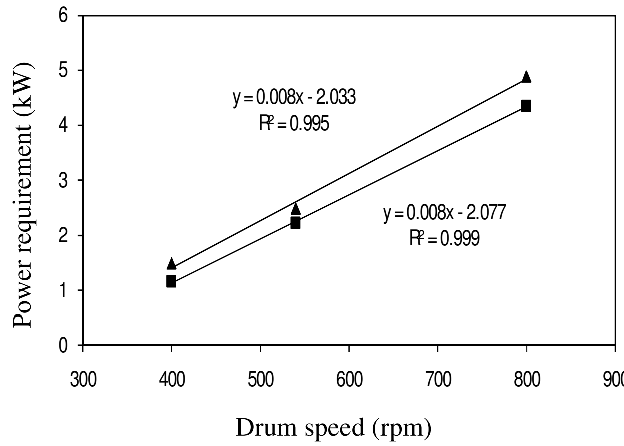

Fig 6. Effect of drum speed and number of blades on the power requirement; (▲) 4 blades on each flange; (■) 8 blades on each flange.

increased with decreasing the number of blades (Table 1). As shown in Fig. 6 the power requirements increase from 1.487 to 4.887 kW and 1.153 to 4.350 kW, for 4 and 8 blades on each flange, respectively, with an increase in the drum speed from 400 to 800 rpm. Fig. 5c represents particle size distribution of threshed wheat straw according to number of blades. It is observed that 8 blades on each flange creates finer particle size than 4 blades. Based on the results obtained, for decreasing power requirement for size reduction of wheat straw and for creating finer particle sizes, 8 blades on each flange is recommended. The interaction effect of drum speed × screen size × number of blades on the power requirement is presented in Table 2. It is observed that the maximum power requirement (5.377 kW) associated with 2.5 cm screen size and drum speed of 800 rpm with 4 blades on each flange, while the minimum power requirement (0.985 kW) correlated to 4 cm screen size and drum speed of 400 rpm with 8 blades on each flange.

Conclusions

The following conclusions were drawn from the investigation of the effects of drum speed, screen size and number of blades on each flange, on the power requirement for size reduction of wheat straw:

1. The power requirement increased with an increase in drum speed and a decrease in screen size and number of blades on each flange.
2. The average power requirement for size reduction of wheat straw was obtained as 2.763 kW varying from 0.985 to 5.377 kW.
3. Based on the result obtained, for decreasing power requirement for size reduction of wheat straw and for

creating finer particle sizes, 8 blades on each flange is recommended instead of 4 blades.

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