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A Cylindrical Chopper with Crusher for Water Hyacinth Volume and Biomass Reduction

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ABSTRACT

A water hyacinth chopper with crusher was developed at the College of Technology and Engineering, Udaipur, India to reduce volume and weight of freshly harvested water hyacinth to facilitate transportation. Two variables, feed rate and knife speeds, were studied to determine relationships between changes in specific volume, knife speeds, percent weight loss and feed rates. Weight reduction studies showed that increasing feed rate and knife speed resulted in a decrease in weight loss. Maximum weight loss of 34% was achieved with the minimum feed rate of 1 t h^{-1} and a knife speed of 3.1 m s^{-1}. Regression models were developed to predict the specific volume and weight loss at different feed rates and knife speeds. The prototype machine reduced the specific volume and weight of fresh water hyacinth up to 64% and 32% respectively at a feed rate of 1 t h^{-1} and knife speed of 4.7 m s^{-1}. The average power and specific energy required to run the machine was 0.10 kW and 1.4 kW-h/t dry matter, respectively. The output capacity of the chopper with crusher was found to be 1.4 t h^{-1}.

Key words: Aquatic weed, volume and weight reduction, regression models, transportation, *Eichhornia crassipes*.

INTRODUCTION

Water hyacinth (*Eichhornia crassipes* (Mart.) Solms) is the most predominant, persistent and troublesome aquatic weed in the world and has posed ecological and economical problems in several countries. It was first introduced as an ornamental plant in India in 1896 from Brazil. Many studies have been conducted to evaluate utilization of water hyacinth for such uses as animal feed, as a fuel, handicrafts, furniture, biogas, compost, pollution abatement and paper pulp with limited success (Lindsey and Hirt 1999, Julien et al. 2001). In these applications, one of the major problems is the high cost of transportation of freshly harvested water hyacinth from water bodies to the factories. A major contributory factor to the failure of water hyacinth harvesting machinery is the large volume and moisture content which greatly reduces harvesting efficiency by increasing requirements for handling and transport.

Capacities of mechanical management systems for aquatic plants are usually limited by the volume of the plant material that must be handled, transported and stored. Water hyacinth plants are usually harvested and transferred in their natural state to the hauling unit which, in turn, delivers the plants to a disposal site which may be at a considerable distance from the harvesting site. As fresh water hyacinth has around 92% moisture content with the bulk density of approximately 96 kg m^{-3}, it necessitates handling a plant volume of 130 m^3 and disposing of 9.2 tonnes of water for every tonne of dry matter removed from the site. Chopping and compressing or compacting has been proposed as a means of reducing volume and weight or increasing density to increase the efficiency of water hyacinth removal operations (Cifuentes and Bagnall 1976, Bagnall 1980, 1982, Mathur and Singh 2000). The literature indicates that three types of choppers; flywheel, flail and cylindrical are used for agricultural forage chopping and published data suggests that power loss due to water resistance and mechanical losses were high in flail cutters and the accuracy of cutting was not acceptable (Kanafojski and Karwowski 1976, Mathur 2000). Therefore a cylindrical type chopper with crusher was developed and evaluated for chopping and crushing of water hyacinth for volume and weight reduction.

MATERIALS AND METHODS

Bosoi et al. (1990) suggested that the optimal diameter of a smooth roller for moving forage should be between 200 mm and 220 mm. The average length of the plant material (water hyacinth) to be fed to the chopper varies between 350 mm to 400 mm. Assuming the plant material falls horizontally on the cylinder, the length of the cutter cylinder was selected as 425 mm with a diameter of 250 mm. The blades were mounted parallel to the cylinder axis to give better performance (Persson 1985). Preliminary tests were conducted to decide the minimum cut size of freshly harvested water hyacinth for volume and weight reduction. These samples were compressed on a Hounsfield universal testing machine to increase its density. Minced samples were also tried, but the handling of minced samples was difficult and it converted into slurry. Based on this preliminary study, less than 10 mm size was selected and 66 blades were mounted on the cylinder. Blades were made of 25 mm by 5 mm mild steel flat (MS) with the cutting edge sharpened at a bevel angle of 24° (Chancellor 1958). The length of the blade was kept equal to the length of the cylinder. Bearing in mind, the ease of resharpening the blades and their replacement, they were bolted to the cylinder periphery at a distance of 12 mm apart.

Laboratory tests were conducted and the results showed that chopping started at a peripheral velocity of 3.1 m s^{-1} but the

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machine choked when the numbers of plant stalks fed simultaneously increased beyond two or three. Hence, for design and testing purposes, the cylinder speed was selected as 4.7 m s^{-1}.

To achieve weight loss of chopped water hyacinth plants, a plane wooden roller of 250 mm diameter was selected and covered with 5 mm thick rubber lining for protecting the blade edge when it strikes the cylinder (Mathur 2000).

The width of the hopper was 450 mm to cover the full length of the cylinder. The coefficient of friction between the surface wall of the hopper and fresh water hyacinth was taken as 0.77 (Mekvanich and Bagnall 1978). The angle of repose was calculated with the coefficient of friction and its value was 37°. The height of the hopper was taken as 200 mm to get the desired volume (0.04 m^3) and was fabricated of 2 mm thick MS sheet.

A three phase, electric motor developing 0.75 kW at 960 revolutions min^{-1} was used to drive the various components of the machine. A speed reduction unit (eddy current coupling) was connected to the motor and operated from the control panel. V-belts were used to transmit the power to the cutter cylinder, pressing cylinder and conveyor belt of the machine. A schematic drawing of the machine is provided in Figure 1.

Performance of this machine was evaluated on the basis of volume and weight reduction of freshly harvested water hyacinth. The average weight and height of fresh water hyacinth plants was 0.4 kg and 400 mm, respectively. Material was packed loosely and its initial specific volume and weights were determined. Water hyacinth was fed into the chopper with crusher at three predetermined feed rates of 1, 1.2, 1.4 t h^{-1} at knife speeds of 3.1 m s^{-1}, 4.7 m s^{-1}, 6.3 m s^{-1} and 7.9 m s^{-1}. The material coming out of the machine was collected in a container placed just below the conveyor belt and its volume and weight was again recorded. The power required to run the chopper with crusher was recorded from a three phase digital power meter. In the present study, varying the weight of the feed varied the feed rate (Persson 1987) and knife speed was varied with the help of a variable speed drive. The desired knife speed was achieved by adjusting the speed reduction unit. Analysis of Variance (ANOVA) was performed to determine the significance of each variable. Regression analysis was conducted to develop relationships among dependent and independent variables.

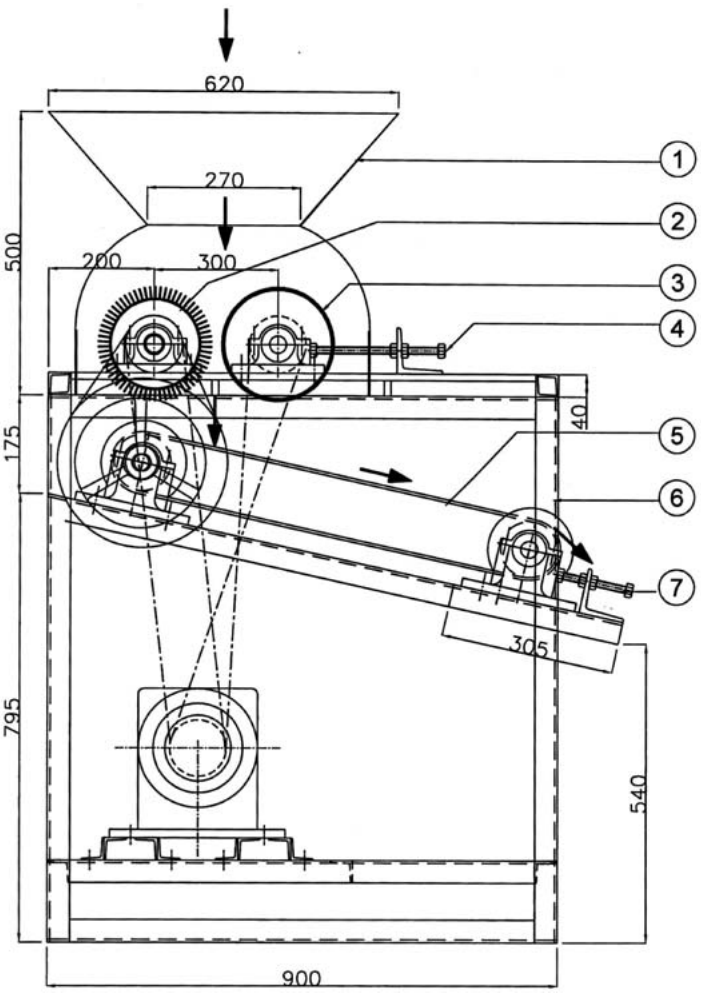

Figure 1. Water hyacinth chopper cum crusher: (1) hopper; (2) cutting roller blades; (3) pressing roller; (4) roller gap adjustment screw; (5) conveyor belt; (6) frame; (7) conveyor belt tension screw; all dimensions in mm.

RESULTS AND DISCUSSION

Feed rate. The average initial specific volume and weight of the freshly harvested water hyacinth fed in to the machine was 8.3 m^3 t^{-1} and 15 kg, respectively. The average reduction in specific volume of the chopped samples and reduction in weight of fresh water hyacinth are plotted in Figures 2A and 2B respectively. The trends of the curve (Figure 2A) show that higher percentage of reduction in specific volume of chopped and crushed fresh water hyacinth can be achieved at higher feed rates. This may be due to the fact that at higher feed rates, the material thickness between the rollers increased which resulted in more crushing and there by reducing the specific volume. Data reveal that the maximum and minimum reduction in specific volume was 68% and 60% at feed rates of 1.4 and 1.2 t h^{-1} and knife speeds of 4.7 m s^{-1} and 7.9 m s^{-1}, respectively. Figure 2B indicates that the percent weight loss of fresh water hyacinth decreased at higher rates up to a feed rate of 1.2 t h^{-1}. This may be due to the fact that increased feed rates beyond this, the material thickness between the rollers increased and the tissue reabsorbs the moisture released after chopping and crushing. Analysis of variance shows that the feed rate had a significant effect on reduction of specific volume and percent weight loss of fresh water hyacinth at the 99% confidence level.

Knife speed. The average reduction in specific volume and weight loss of fresh water hyacinth at different knife speeds are shown in Figure 3A and 3B respectively. The trend of curves (Figure 3A) shows that the reduction in specific volume increased up to the knife speed of 4.7 m s^{-1} and thereafter it started to decrease up to the tested knife speed of 7.9 m s^{-1}. The maximum reduction in specific volume was 68% at a knife speed of 4.7 m s^{-1}. This may be attributed to lesser contact time between rollers, thus reduced crushing, at speeds higher than 4.7 m s^{-1}. Trends in Figure 3B show that, the percent reduction in weight of fresh water hyacinth decreases linearly with the increase in knife speeds for all feed rates.

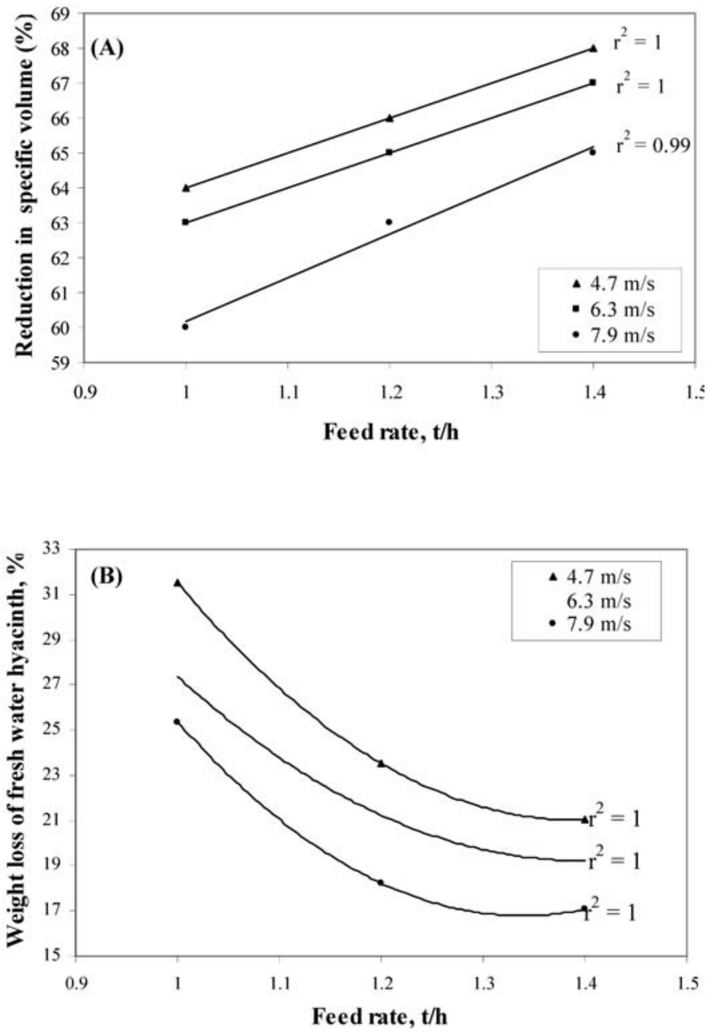

Figure 2. Effect of feed rate on chopping of water hyacinth at different knife speeds (A) reduction in specific volume, %; (B) weight loss of fresh water hyacinth, % initial specific volume of fresh water hyacinth, 8.25 m^3/t; initial weight of fresh water hyacinth sample, 15 kg.

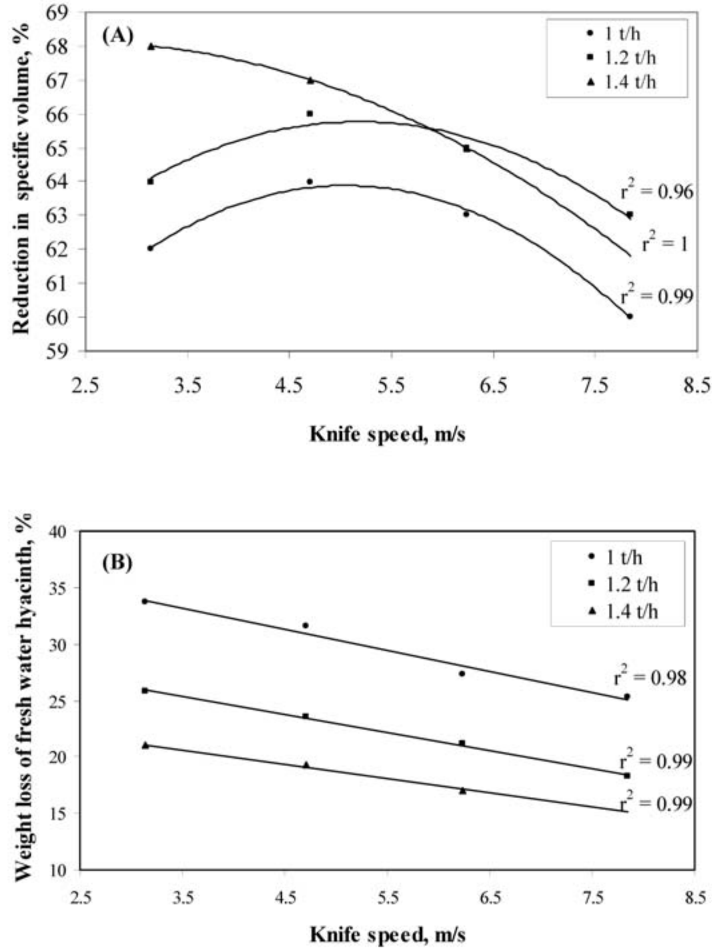

Figure 3. Effect of knife speed on chopping of water hyacinth at different feed rates (A) reduction in specific volume, %; (B) weight loss of fresh water hyacinth, % initial specific volume of freshwater hyacinth, 8.25 m^3/t; initial weight of fresh water hyacinth sample, 15 kg.

Results show that the decrease in percent weight loss increased by 31% when knife speed was increased from 3.1 to 7.9 m s^{-1}. Analysis of variance (ANOVA) indicates that the knife speed had a significant effect on the specific volume and percent weight loss at the 99% confidence level.

Combined effect of feed rate and knife speed on specific volume. Analysis of variance shows that the combined effect of feed rate and knife speed on specific volume was highly significant. Two variable interactions showing the effect of feed rate and knife speed on specific volume is presented in Table 1 and shows that increasing the feed rate from 1 t h^{-1} to 1.4 t h^{-1} decreased specific volume significantly at all knife speeds. Non linear regression was used to develop a combined relationship between feed rate, knife speed and the specific volume and is expressed as:

$$V_s = 4.71 - 0.83\,F - 0.36\,S_k + 0.04\,S_k2 \qquad (1)$$

where: V_s is the specific volume in $m^3\,t^{-1}$; S_k is the knife speed in m s^{-1}; F is the feed rate in t h^{-1}.

The higher values of r^2 (Figure 4A) between predicted and observed specific volume reflects that equation 2 predicts the specific volume with in the tested range of feed rate and knife speed.

Combined effect of feed rate and knife speed on weight loss. The combined effect of feed rate and knife speed also had a significant effect on percent weight reduction. Table of means (Table 1) presents the mean values of percent weight reduction at different combinations of feed rate and knife speeds. It also shows that the maximum percent weight reduction was achieved with the minimum feed rate and knife speed of 1.2 t h^{-1} and 3.1 m s^{-1} respectively.

A relationship was developed between the percent reduction in weight with feed rate and knife speed and found to be a second degree polynomial and can be represented by the following equation

$$W_l = 162.76 - 188.08\,F - 3.37\,S_k + 1.5\,FS_k + 65.15\,F^2 \qquad (2)$$

where: W_l is the percent weight loss.

The higher value of r^2 shows (Figure 4B) that the proposed model predicts the per cent weight loss fairly well within the tested limits.

TABLE 1. EFFECT OF FEED RATE AND KNIFE SPEEDS ON MEAN SPECIFIC VOLUME (%) AND WEIGHT LOSS (%).

Knife speed (m/s)	Feed rate (t/h) 1		1.2		1.4	
	% Volume loss	% Weight loss	% Volume loss	% Weight loss	% Volume loss	% Weight loss
3.1	62	33.8	64	28.8	—	—
4.7	64	31.6	66	23.5	68	21.4
6.3	63	27.4	65	21.2	67	19.2
7.9	60	25.4	63	18.2	65	17.1

Initial specific volume of fresh water hyacinth feed, 8.25 m^3/t.
Initial weight of fresh water hyacinth feed, 15 kg.

Machine performance parameters. The mean reduction in specific volume and percent weight loss were maximum at knife speed of 4.7 m s^{-1} (Table 1). Weight loss was maximum at the feed rate of 1 t h^{-1} while specific volume was minimum at this feed rate (Figure 5). When the feed rate was increased to 1.2 t h^{-1}, the loss in weight decreased at a faster rate (7%) and the reduction in specific volume increased by 2%. Further, when feed rate was increased to 1.4 t h^{-1} it resulted in a 3% decrease in weight and reduction in specific volume increased 2%. Therefore, it can be inferred that if feed rate is increased from 1 t $h^{-1}$to 1.2 t h^{-1}, loss in weight is greater while gain in specific volume is less. So to obtain optimum results both in terms of volume and weight reduction of freshly harvested water hyacinth, it is suggested that the machine should be operated at a feed rate of 1 t h^{-1} and knife speed of 4.7 m s^{-1}. The average power required to operate the machine was 0.1 kW at the recommended knife speed and feed rate. The output capacity of the developed chopper was 1.4 t h^{-1}.

The combination chopping and crushing by this machine will be able to reduce volume and weight (free cell water) of water hyacinth in a single operation and be helpful in reducing the cost of transportation. This machine will be able to reduce the problem of transportation of water hyacinth from city lakes. The capacity of the machine can be increased by increasing its size and feed rate or by incorporating more machines into the mechanical removal operations.

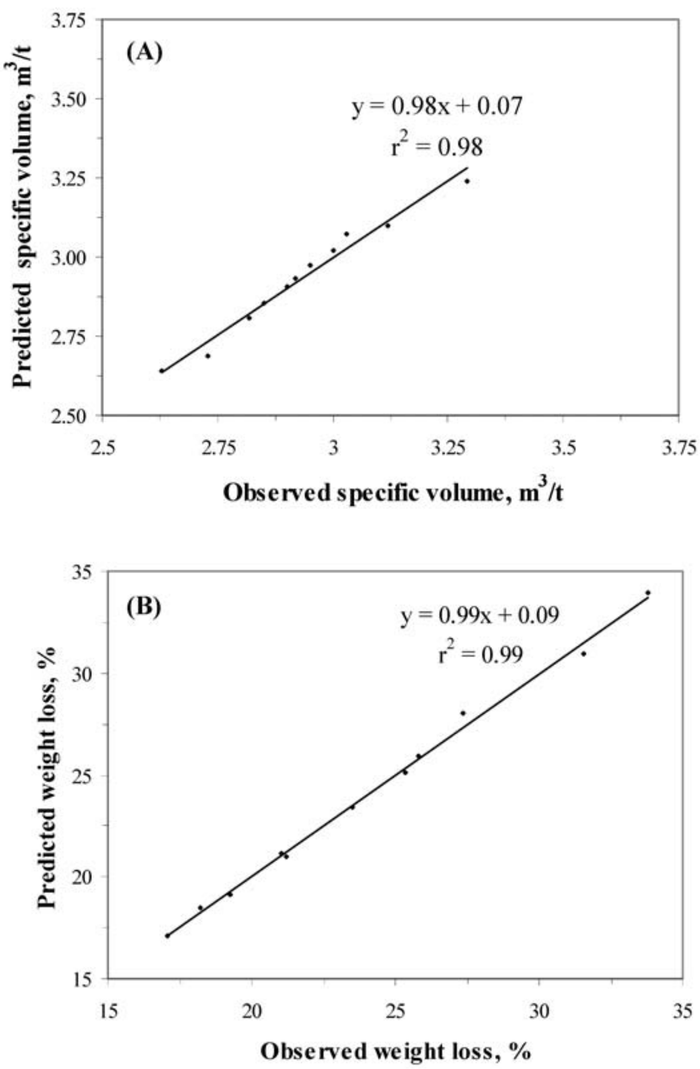

Figure 4. Correlation between observed and predicted (A) specific volume, and (B) weight loss.

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