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Effect of Auger Speed and Air Flow on Discharge Rate of Bagasse

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Abstract: Bagasse as a by-product of sugar mill factories is a good resource in agricultural industries. It is used as fuel, Cellulose, livestock feed and fertilizer resources in most countries that produce sugarcane. The sugar manufacturing plants in Iran use cheap mazut as fuel. A reasonable application of bagasse in Iran is to incorporate it deeply in soil to improve its physical properties and also to overcome the problem of disposal and environmental pollutions which is burned today. To fulfill the objective of this task, a special new machine is needed to inject bagasse in soil. As a result, a bagasse discharging prototype machine was fabricated and the effects of machine parameters were studied. The results of experiments showed that the machine parameters had significantly direct effect on discharge rate, but the effect of moisture content of bagasse was indirect. The conclusion from this study is the first step in design of a new machine for injecting bagasse in deep layers of soil.

Key words: Bagasse % Auger speed % Air flow % Soil organic materials % Discharge rate

INTRODUCTION

Bagasse as a fibrous material is one of the main by-products of sugarcane manufacturing plant which is obtained after the sugar juice is leached out of sugarcane. It is a low density material with very wide ranges of particle size and high moisture content of around 50-52% as it leaves the milling process in almost all sugarcane industries [1]. The dried bagasse consists of 38-40% Cellulose, 25-28% Hemicellulose, 20-22 % Lignin, 2-3% Sucrose and 7-10 % of ash [2,3]. It is important to characterize flow ability of bagasse since it is necessary to apply normal design procedures for mechanical or pneumatic conveying, fluidization, drying and combustion of this by-product. Terminal velocity and drag coefficient of bagasse fibers has been reported by Nebra and Macedo [4]. They found that the terminal velocity of bagasse fibers is between 2 to 4 m/s. The physical properties of bagasse were studied by Rasul *et al.* [1] and by Ponce *et al.* [5]. They developed a technique for determining physical properties of major components of bagasse named pith, fiber and rind.

In most countries that produce sugarcane, bagasse is used as; fuel resource (usually in the same sugar extraction factory), Cellulose resource for Cellulosic industries (for making fiberboard, paper or cardboard), livestock feed and soil fertilizer in both forms of composted or non-composted. Almost 30 to 35% of harvested sugarcanes are transformed into bagasse from each hectare of sugarcane farms as a by-product of sugar [2]. Annual global production of bagasse is estimated around 410 million tons. Share of Iran is 2.8 million tons of bagasse annually [6].

Globally, almost half of the surplus bagasse is burned in sugar manufacturing plant as fuel. In a well-balanced raw-sugar factory, the quantity of final bagasse is usually more than sufficient to supply all the fuel required, leaving a surplus to be disposed of. In such cases, where no secondary outlet for the material exists, its disposal often offers troublesome problems and heat efficiency is sacrificed so that a greater quantity than actually required to be burned in the boiler furnaces. The bagasse surplus to fuel requirements may be as much as 25 percent or more of the total quantity available. So the surplus is often more than enough to provide the energy requirements for distillation of alcohol, rum made from molasses and for other ancillary services provided by the sugar factory, including the generation of electric power, the bagasse is exceeded and other usages should be employed [2].

Because of the cheep mazut in Iran, sugar-manufacturing plants are designed to use mazut as fuel of boilers instead of bagasse. Due to the needs of cellulosic

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industry to large investment which in the meantime is not possible in Iran, bagasse is not used for Cellulosic products. The only MDF (Medium Density Fiberboard) manufacturing factory established in Iran utilizes annually just 100,000 tones of bagasse. Unfortunately bagasse is not considered now as a useful material and it is disposed or burned which makes the environment polluted. Thus almost all of the leftover bagasse in Iran is useless for time being. The only application could be as a soil fertilizer that improves physical properties of soil. Cellulose and Hemicellulose decompose very fast after incorporation of bagasse with soil by microbial activities, but decomposition of Lignin takes place slowly and after this process, a quietly stable organic material called humus remains in soil [7]. Humus plays important rolls on the physical properties of soil. It reduces soil bulk density and compaction by increasing elasticity and aeration of soil and also improves drainage characteristics.

All sugarcane farms in Iran are located at Khuzestan province in southwest. Inadequate drainage, dispersed and compacted soil and low organic material content (around 0.5%) are the main challenges of these sugarcane farms [3]. Incorporation of bagasse to deeper layers of soil is not possible with plowing. Furthermore, since sugarcane is a perennial crop, the incorporation should be done between the crop lines or before planting. This task needs a special machine capable of carrying and injecting bagasse between the rows. Consequently, this machine should be equipped with subsoiler shanks to open narrow furrows for injecting bagasse. A complete review of literatures indicates that such machine has not been designed before. In sugarcane farms of Iran, for ratooning operation, special subsoilers are used once a year after the sugarcane is harvested. The main challenges of this machine should be injecting quietly large amount of material deeply in soil. In addition to the general characteristics of farm machines such as: safety, simplicity, stiffness, low production cost, good maneuverability and simple power transmission, this machine should also fulfill the following goals; (1) carrying a reasonable amounts of bagasse, (2) adjustability for both discharge rate and injection depth, (3) less sensitivity to bagasse moisture content (4) simple control on injection process and (5) simple adjustability for transport. Since such machine has not been designed so far and does not exist in market, therefore it is reasonable to start the design process by studying the mechanisms through a prototype machine.

The objective of this task was to design and fabricate a prototype machine for studying the effects of machine parameters and bagasse properties in order to offer a complete injection machine for injecting bagasse in deep layers of soil used in sugarcane farms.

MATERIALS AND METHODS

To accomplish the objective of this study, it is necessary to design and develop a prototype machine so that the effects of auger speed and air flow on discharge rate of bagasse with different moisture contents could be investigated. For the intention, a prototype machine was fabricated as shown schematically in Fig. 1. The overall construction of the completed prototype machine was made of following three parts and assembled on a chassis bolted to floor. The overall size of the prototype machine is 370 cm in length, 100 cm in width and 140 cm in height.

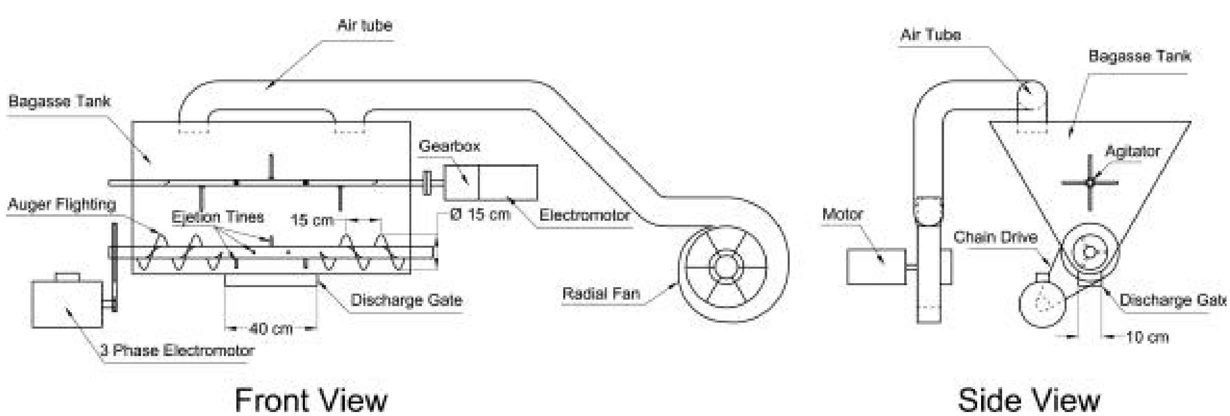

Fig. 1: Schematic drawing of the prototype machine (chassis not shown)

Sealed tank assembly: A sealed tank with a screw conveyor and agitator was built by light and firm plastic sheet (6 mm thick). Due to large capacity and discharging characteristics of wedge shape containers [8], the sealed tank was made in that shape. This tank has a capacity of 0.4 m^3 for bagasse storage. A double sided auger was built and fitted inside the tank and mounted on two bearings from the ends of auger shaft to push the bagasse toward the middle of the tank. The theoretical maximum throughput of an auger conveyor would be obtained if the conveyor is running full with the particulate material moving purely in the axial direction and the throughput of the conveying material is directly proportional to the auger speed, pitch length and the central shaft diameter [8-10]. The auger is 15 cm in diameter with three screw pitches of 15 cm and chock length of flighting 45 cm, since a chock length of up to three screw pitches may be required at high speeds [8]. Five tines with 10 cm in length were mounted in a spiral pattern at the middle of auger shaft spaced 5 cm equally which rotate by the auger shaft to help feeding of material through the discharge gate. The discharge gate is positioned underneath and at the middle of sealed tank along to the auger shaft. It is necessary to have an agitator above the auger to break any bridge built by bagasse above the auger to help a better discharging. The chassis of the tank was made of L – shape profile and walls were formed of light and firm plastic sheets. On the top of the sealed tank, a cover door was installed so it can be easily opened or closed (Fig. 1).

Air blower: A 0.75kW – 2800 rpm single phase electromotor coupled with a radial flat-blade fan was provided from market and connected to the sealed tank by a flexible tube with 12.5 cm in diameter in a form that the tube was divided into two separate outlet to give the best air distribution in the tank. As shown in Fig. 1, ends of the outlet tube were connected to the sealed tank beside the top cover door. Although in the proposed injection machine, a lobe type blower (or may called Roots blower) should be used to keep the air pressure and air flow rate at a constant level and independent from each other [11-14]. But due to the temporary use of prototype machine and since, the possibility of blocking the line is low, a radial fan was employed. Problems with this type of fans are that the air pressure and air flow are variable and depends on each other. Because of small size of the prototype machine, this problem does not exist and air flow was relatively constant during the tests conducted.

Power transmission system: The auger and agitator are driven by two separate 3-phase electromotors. An electromotor with 2.2kW–1400 rpm drives the auger shaft via a reducing chain drive system. The speed of this electromotor is controlled by an inverter from Zero to 1.2 times of maximum motor speed. So the auger could run from Zero to 500 rpm. The other electromotor with 0.75kW-1400 rpm which drives the agitator, is equipped with a 1:20 reduction gear to reduce the speed of motor from 1400 to 70 rpm. All three parts of the prototype machine were fixed by a chassis bolted at 6 locations to floor in laboratory.

RESULTS AND DISCUSSION

To study the effects of auger speed and air flow on discharge rate of bagasse at different moisture content levels, a sealed tank prototype machine was fabricated. The dependent variable considered in this study was the discharge rate of bagasse.

Test procedure: The developed prototype machine was used in the laboratory for conducting experiments under different operating conditions and moisture content levels for bagasse. Two series of experiments were conducted to study the effects of air flow, auger speed and moisture content on discharge rate. The results obtained under normal discharging (no air injected in the sealed tank) were compared to the results of experiments conducted with air injected into the sealed tank. The discharge rate was calculated by dividing the amounts of discharged bagasse to the time of discharging since the observations showed that not all the bagasse in the tank is fully discharged.

Data analysis and results: In Fig. 2, the regression trend lines showing the effects of air flow, auger speed and moisture content on discharge rate of bagasse from the prototype machine are presented. The overall trend in Fig. 2 shows that, the discharge rate increases as the auger speed is increased while injecting air in the sealed tank, but with the increase of moisture content, the discharge rate is decreased. The results are as expected, since when the auger speed is increased, more bagasse is fed by auger flighting into the discharge gate. Also, it is a fact that injected air would pressurize the sealed tank and it helps the bagasse to exit the discharge gate faster. In opposition, as the bagasse moisture content increases, the discharge rate is decreased. The reason beyond this justification is, as the moisture content of bagasse

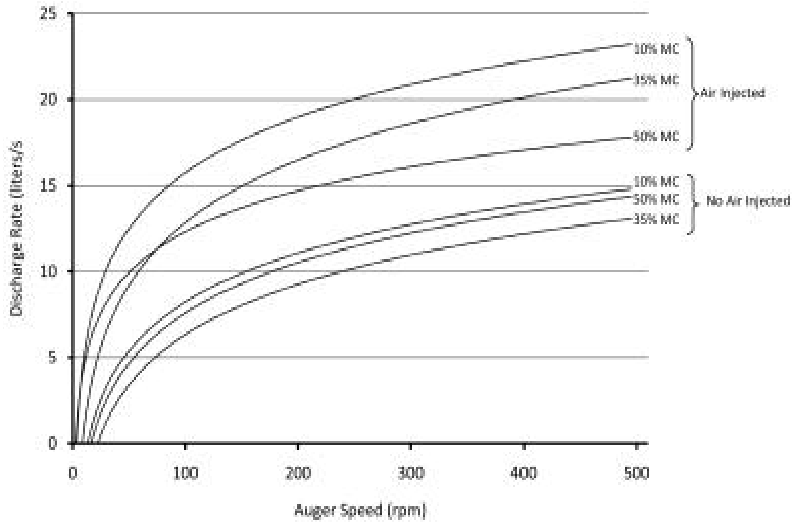

Fig. 2: Effects of auger speed, moisture content and air injection on discharge rate of bagasse (the lines are logarithmic regression trend lines)

increases, the adhesion of bagasse particles increases and therefore the auger flightings could not work at full capacity.

The statistical experiment design chosen for this study was split-plot where the main plots consist of air injected and no air injected cases. Sub-plots in factorial arrangement with two factors were moisture content at three levels (10%, 35% and 50%) and auger speed at five levels (100, 200, 300, 400 and 500 rpm). All the tests were conducted with three replications. The statistical analysis of variance was employed to investigate the effects of air flow, auger speed (AS) and moisture content (MC) on discharge rate of bagasse. This analysis was performed by SAS software [15]. Table 1 shows the analysis of variance for the experiments at 1 and 5% probability levels. The F-values were calculated as the sum of squares of the corresponding factors being divided by sum of squares of error terms.

Table 1: Analysis of variance of the effects of air, auger speed and moisture content on discharge rate of bagasse

Source	DF	Mean Square	F Value	Pr > F
REP	2	0.2162	0.21	0.8141ns
AIR	1	937.0240	894.50	0.0001**
REP*AIR	2	1.6189	1.55	0.2222ns
MC	2	62.4820	59.65	0.0001**
AS	4	137.0832	130.86	0.0001**
AIR ×MC	2	48.3618	46.17	0.0001**
AIR×AS	4	0.7275	0.69	0.5989ns
MC×AS	8	2.5202	2.41	0.0262*
AIR×MC×AS	8	1.8790	1.79	0.0977ns

** and * significant at 1% and 5% levels respectively and ns for not significant

DISCUSSION

Table 1 shows the means of bagasse discharge rate for two cases of air injected and no air injected at different moisture contents and auger speeds. A fact is revealed from Table 2 that the higher R^2 belongs to the cases when the moisture content of bagasse is lower and air is injected into the seal tank. As mentioned before, the bagasse particles at low moisture content are less adhesive and therefore, air injected in the tank helps the bagasse to discharge faster and more evenly.

Table 2: Means of three replications for discharge rate (liters/s) at different moisture contents and auger speeds

	Moisture Content (Wet Based)	Auger Speed (rpm) 100	200	300	400	500	Trend Line Equations*	R^2
No air injected	10 %	7.65	11.84	13.29	13.69	14.31	y = 4.101ln(x) - 10.65	0.927
	35 %	6.71	8.66	10.73	12.35	13.38	y = 4.219ln(x) - 13.10	0.960
	50 %	7.28	10.44	13.63	12.76	14.05	y = 4.227ln(x) - 11.88	0.865
Air injected	10 %	15.35	19.68	20.78	22.37	22.88	y = 4.668ln(x) - 5.757	0.927
	35 %	12.21	17.09	19.56	20.03	20.44	y = 5.242ln(x) - 11.29	0.918
	50 %	12.07	14.87	16.95	16.13	17.96	y = 3.424ln(x) - 3.455	0.857

* x and y in the equation are auger speed and discharge rate respectively

Table 3: Duncan's multiple range tests for variables

Auger speed (rpm)	Means*	Moisture content (%)	Means*	Air injected	Means*
500	17.1917^a	10	16.2970^a	Yes	17.8896^a
300	16.0400^b	35	14.1287^b	No	11.4362^b
400	15.9828^b	50	13.5630^c		
200	13.8906^c				
100	10.2094^d				

* Means (liters/s) with the same letter are not significantly different at 5% probability level

The effects of air injection, moisture content and auger speed were statistically significant at 1% probability level (Table 1). In addition, the interaction of air injection and moisture content was significant at 1% level. The interaction of moisture content and auger speed was only significant at 5% probability level. There was no significant different for the interaction of air injection and auger speed.

The Duncan's multiple range tests were conducted as shown in Table 3. The comparison for means of discharge rate for all values of variables showed significant effect on dependent variable except for the auger speeds at 300 and 400 rpm. Since the difference between the two means is 0.9428, this could be due to the operator's error in the experiments or an unexplained event through out the experiments.

CONCLUSION

To fulfill the objective of this study, a prototype machine was fabricated and the effects of machine parameters (air flow and auger speed) and moisture content of bagasse were studied. The results of experiments conducted showed that the effects of air flow, auger speed and moisture content were significantly different at 1% probability level. Also the Duncan's multiple range tests showed that the means of discharge rate for all values of variables were significant on the dependent variable. The results obtained from the developed prototype machine, is an earnest effort toward the design of a complete injection machine. By design and fabrication of such machine and injecting the bagasse in deep layers of soil, the problem of huge amounts of disposed bagasse as surplus material is solved in the developing countries that produce sugarcane.

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