Comparison of a pneumatic conveyor and a bucket elevator on an energy and economic basis

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Rothwell, T.M., Vigneault, C. and Southwell, P.H. 1991. **Comparison of a pneumatic conveyor and a bucket elevator on an energy and economic basis.** Can. Agric. Eng. **33**:395-397. In a series of tests made in a feed mill to reduce energy consumption, a pneumatic conveyor and a bucket elevator were compared on both an energy and economic basis. The tests showed that a bucket elevator is far more efficient than a pneumatic conveyor on an energy consumption basis and it should be considered in the design of new feed mills. In existing mills, the economic analysis suggested that a bucket elevator be considered if there are problems with the pneumatic system already in place or if the capacity of the mill needs to be increased.

Un convoyeur pneumatique et un élévateur à godets ont été comparés au point de vue énergétique et économique. Les tests ont démontrés que l'élévateur à godets était beaucoup plus efficace que le convoyeur pneumatique. Ce système devrait être fortement envisagé dans la planification d'une nouvelle meunerie. Dans le cas d'une meunerie existante, le remplacement d'un système pneumatique par un élévateur ne devrait être envisagé que s'il est désuet ou de capacité insuffisante.

INTRODUCTION

According to the Canadian Feed Industry Association (CFIA 1978), most Canadian feed mills still employ bucket elevators or inclined screw conveyors to elevate ground products. The CFIA also estimates that only 15% of Canadian feed mills are equipped with pneumatic conveyors and these mills are mainly the newer ones.

The main advantage of pneumatic conveyors over bucket elevators is their flexibility. The conveying pipes can be installed and moved in any direction, whereas bucket elevators require a straight and unobstructed vertical passageway. This advantage, however, is of little importance to feed mill managers, because most grinding and conveying systems configurations are permanent. Two important aspects of comparing between any types of conveyors are the power requirements and the energy consumption. Power requirements can be obtained from either equipment specifications available from the suppliers or publications from associations involved in the feed industry. For example, the CFIA indicates that 39 kW are needed for pneumatic conveying of 21 $t \cdot h^{-1}$ of corn from a hammermill, while only 10 kW are required for mechanical conveying under the same conditions (CFIA 1978).

As far as conveying energy consumption is concerned, no actual measured data could be found in the literature. These data are important for a good comparison between pneumatic and mechanical conveying systems. The data available on the motor nameplate are not a reliable indicator of the actual energy consumption while conveying. For example, pneumatic conveyor power requirements are determined on the basis of the volume of air being moved through empty conveying pipes. When solid material is introduced into the air stream, the energy consumption is reduced as indicated by a decline in the current needed for the motor.

The levels of loading for the motor of the bucket elevating systems in steady-state operation could not be found either. It is conceivable, however, that motor sizing is, at least partially, based on start-up requirements or that some over power allowance is made for clearing blockages.

The objective of this project was to compare a bucket elevator and a pneumatic conveyor on both an energy and economic basis, while conveying ground products away from a hammermill.

MATERIALS AND METHOD

The tests were performed at a commercial feed mill in Elmira, ON, between November 1984 and December 1986. At this feedmill, the replacement of an existing pneumatic conveyor had been planned in order to increase the capacity of the grinding/conveying system. It was decided that the existing pneumatic conveyor would be replaced by a bucket elevator. This presented a good opportunity to compare both conveyors and to measure power and energy requirements on operating conveyors. The pneumatic conveyor was monitored before replacement and the bucket elevator was monitored after its installation.

The 37 kW pneumatic system was used to move ground product away from a 93 kW Schutte 1080 hammermill. The product was conveyed vertically to a turn head distributor located 18.3 m above the hammermill. The pneumatic system consisted mainly of a three-stage Kice model ZSP-16 turbine. This turbine was located between a centrifugal separator, into which the product was drawn, and a downstream bag house which filtered the air before ejection to the atmosphere. This system was monitored in three separate tests. The quantity of whole corn to be ground was weighed for each test. The time taken for the grinding and conveying operations was measured using a stop watch. The power factor was determined using both a kVA and a kW meter. In the second test, a clamp-on kW meter was used to measure electrical power input to the turbine motor while conveying product. This permitted computation of the power and the energy consumption based on current readings taken with a clamp-on ammeter. Dividing the power required by the measured rate yielded the specific conveying energy value for each test.

Upon completion of the pneumatic conveying tests, the bucket elevating system, specified in Table I, was installed. After performing one conveying test, the aspiration fan was adjusted. This system was monitored in six separate tests. Two tests were performed using approximately the same conveying rate as for the pneumatic system and four tests were performed using the conveying rate corresponding to the maximum grinding capacity of the hammermill operated under different conditions. The procedure for testing the bucket elevator was similar to the one used for the pneumatic system. As grinding proceeded, elevator motor current values were continuously recorded and the aspiration fan current was measured at a regular interval.

For practical purposes, the following parameters were used to represent the economic analysis:

Production of manufactured feed	50 000 $t\cdot y^{-1}$
Quantity of material ground	35 000 $t\cdot y^{-1}$
Hammermill average grinding rate	8.5 $t\cdot h^{-1}$
Hours of hammermill operation	4 120 $h\cdot y^{-1}$

These numbers represent a medium capacity mill, as Canadian feed mill capacities range from less than 10 000 $t\cdot y^{-1}$ to more than 100 000 $t\cdot y^{-1}$ (Rothwell et al. 1986).

Table I. Specifications of the bucket elevator tested

Bucket size	203 mm x 127 mm
Spacing	254 mm
Headpulley diameter	610 mm
Headpulley speed	60 rpm
Belt velocity	1.9 $m\cdot s^{-1}$
Feed location	on down-side
Drive motor	3.7 kW
Aspiration fan motor	3.7 kW
Nominal maximum capacity	29 $t\cdot h^{-1}$
Elevation distance	18.3 m

RESULTS AND DISCUSSION

Energy significance

Two advantages are associated with the bucket elevator, namely, lower energy consumption as well as lower maximum power demand, which consistently reduce capital needs. As shown in Table II, the pneumatic conveyor required a power of 27.5 kW and an energy of 4.77 $kWh\cdot t^{-1}$ whereas the bucket elevator required power of 4.7 kW and an energy of 0.88 $kWh\cdot t^{-1}$ when these systems had approximately the same conveying rate of ground product. The conveying energy dropped further, to a low of 0.41 $kWh\cdot t^{-1}$ when conveying about 12.7 $t\cdot h^{-1}$ or total power of 5.2 kW. Furthermore, it should be noted that the conveying energy values for the bucket elevator also included the energy used to drive the aspiration fan. This indicates that the bucket elevator conveying ground product to the height of 18.3 m was much more efficient. For both the bucket elevator and the pneumatic conveyor, higher material flow rates resulted in reduced specific conveying energy requirements.

Although corn was used as the grinding material in the conveying trials, the maximum conveying and grinding rates, for corn were not attained in all instances. Therefore, in the case of a feed mill having a hammermill average grinding rate of 8.5 $t\cdot h^{-1}$ some 4.1 $kWh\cdot t^{-1}$ of energy could be saved, by replacing a pneumatic conveyor with a bucket elevator, and a corresponding 22.3 kW reduction in peak power demand would also result. Based on the annual conveying of 35 000 t, the hypothetical mill would save 143 500 kWh.

Economic significance

The comparative capital costs for a 37 kW pneumatic conveying system and a 3.7 kW bucket elevating system, including aspiration fan, are estimated to be \$20 000 and \$30 000 respectively, including motors, starters, electrical and millwrighting labor. Assuming 4 120 h of operation annually, 10% interest and a straight line 15 years depreciation, with no salvage value, the hourly fixed costs of operation are then \$0.81 and \$1.21 for the pneumatic and bucket conveyors, respectively. At a conveying rate of 8.5 $t\cdot h^{-1}$, the corresponding fixed costs are \$0.095 and \$0.142 per tonne of material elevated, and hence, the bucket elevating system entails a \$1 645 annual fixed cost premium over its pneumatically-driven counterpart. However, it must be recognized that, in this particular instance, the maximum capacity of the bucket elevator is 29 $t\cdot h^{-1}$, thus more than three times that of the pneumatic conveyor. Consequently, the bucket elevator system allows for increased production rates arising from expanded grinding capacity, at little additional cost.

In terms of maintenance requirements the systems were roughly equivalent, according to maintenance personnel at the feed mill where the research was conducted. Partial wearing of either conveyor type causes a corresponding partial reduction in capacity. For example, worn pipes and worn buckets, which may leak, both result in lower work rates. It can be argued that bucket elevator work rates are more easily adjusted by simply changing belt speed but there is a limited belt speed range, outside of which proper discharge of material cannot be accomplished.

The financial costs for conveying energy are:

Pneumatic system:

$$4.77\ kWh\cdot t^{-1} \times 35\,000\ t\cdot y^{-1} \times \$0.05\ kWh^{-1} = \$8\,350\ y^{-1}$$

Bucket elevator:

$$0.88\ kWh\cdot t^{-1} \times 35\,000\ t\cdot y^{-1} \times \$0.05\ kWh^{-1} = \$1\,540\ y^{-1}$$

Saving $= \$6\,810\ y^{-1}$

Virtually all feed mills, in addition to paying for electrical energy consumption, also pay a monthly (peak) demand charge, the cost of which depends on the supplier, but which usually ranges between \$3.72 and \$4.60 kW^{-1} for any excess over 50 kW. Consequently, assuming a demand cost of \$4.00 kW^{-1}, it can be seen that the bucket *elevating system*, in lowering electrical power demand by 22.3 kW, provides a further monthly saving of \$89.20. The combined *annual en-*

Table II.Comparison of energy requirements for a pneumatic conveyor and a bucket elevator.

	Test no.	Quanity of corn (t)	Rate ($t\,h^{-1}$)	Motor Loads motor (A)	fan (A)	Total (kW)	Conveying energy ($kW\,h\,t^{-1}$)
Pneumatic conveyor	1	6.9	5.1	-	30	28.3	5.55
	2	5.6	5.7	-	30	28.2	5.05
	3	7.9	6.5	-	27	26.0	4.00
	Avg.		5.8			27.5	4.77
Bucket elevator	4	16.7	5.3	2.7	2.4	4.8	0.91
	5	15.1	5.3	2.5	2.3	4.5	0.85
	Avg.*		5.3			4.7	0.88
	6	7.3	8.5	2.8	2.5	5.0	0.59
	7	8.7	11.5	3.0	2.6	5.3	0.46
	8	16.9	9.7	2.8	2.4	4.9	0.51
	9	18.8	12.7	3.0	2.5	5.2	0.41
	Avg.**		10.6			5.1	0.48

*Average of the tests that correspond to the range of rates as for the pneumatic conveyor tests.
**Average of the tests conducted at maximum rate of the hammermill.

ergy and power cost savings for the sample mill amount to \$6 810 + \$1 070 = \$7 880, which is equivalent to the monthly electricity costs for a typical 50 000 $t \cdot y^{-1}$ mill.

CONCLUSIONS

Both, the energy and power requirements for conveying ground feed with a bucket elevator were 18% of that of a pneumatic conveying system.

Taking the fixed and maintenance costs of both systems, electrical energy savings amounting to 143 500 $kWh \cdot y^{-1}$, coupled with a 22.3 kW reduction in power demand are possible for a typical feed mill using a bucket elevator.

An economic saving associated with a bucket elevator of some \$6235 y^{-1} means that a conversion cost of \$30 000 would be recouped in less than 5 years based on energy demand and fixed cost. In the case of new installations, the \$10 000 premium paid for a bucket elevator, as opposed to a pneumatic system, would be repaid within the two first years.

In those feed mills where no increase in conveying capacity is anticipated and in which the existing pneumatic system functions adequately, changing this system for a bucket elevator system might be considered depending on the energy price and the specific requirement of the feed mill. But if either the capacity of the hammermill needs to be increased or problems occur with an older installation and changes are required, then a bucket elevator should seriously be considered.

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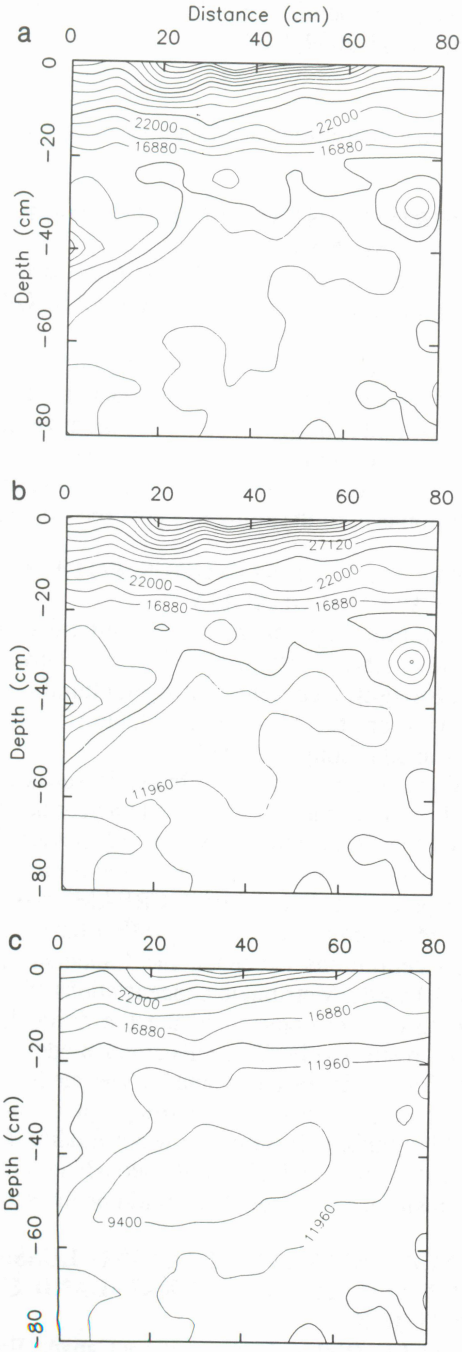
ERRATUM

Page 30, Volume 33, No. 1, January 1991 was missing. It is printed below.



'ig. 3. The gamma-ray counts per minute contour map of an undisturbed soil block: (a) air-dry soil - run 1, (b) air-dry soil - run 2, (c) after application of 15 cm water.

iden on the top because of the packing material.

The precise movement of the scanner is due to the conver- on of analog movement to step-wise. The resolution of the ovement could be changed by changing the number of fer- us plates on the position disk. The almost identical gamma unts of the air-dry soil for two different runs not only dicated reproducibility of the gamma counting but also indi- ctly indicated the reproducibility of scanning movement.

The overall performance of the system was satisfactory. The program was menu driven and user-friendly, requiring about 5 minutes for familiarization with the operation of the program. There was no detectable amount of accumulated errors after the scanner travelled a distance of 2587.7 cm. The coefficient of variation (CV) of the radiation counts of the soil was less than 6%. This indicates that the automated gamma scanner is precise on both scanning movement and radiation counts. The system as a whole is flexible and easy to use, and permits a wide range of studies related to water movement and uptake with minimum labor. This system can be improved by adding a second radiation source such as Cs to measure soil water content and bulk density simultaneously.

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