Systems Engineering for Handling and Land Application of Solid and Semi-solid Livestock Manure

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Background

Research on manure handling and land application has been recognized as a top priority by a number of national and provincial organizations across Canada as a means to increase the environmental sustainability and to improve the social acceptance of intensive livestock production. Handling and land application systems for solid and semi-solid manure (i.e. manure containing more than 10% of solids by weight) have experienced much less technical research and development efforts than comparable systems for liquid manure and slurry over the last thirty years or so. However, these types of manure management systems have been identified as potential alternatives to liquid manure systems in terms of reducing environmental and societal problems that may be associated with liquid manure management. Solid and semi-solid manure as well as organic fertilizers resulting from the combination of solid (separated or composted) manure and other materials (eg. wood chips, paper mill residues, industrial or municipal sludges, etc.) have highly variable physical and flow properties. Adapted handling and land application systems are therefore required if one wants to optimize their value as a source of nutrients for field crops while minimizing environmental and nuisance risks. The most important technical characteristics of handling and land application systems in terms of optimizing the agronomic value of manure are those related to the control of the application rate of the product and to its uniform application and distribution to the cropped land.

Table 1. Summary of least squares regression estimation analysis for the factorial designs used to evaluate the effects of the gate, the speed of the conveyor and the angle of the side walls (the cells of the table with an 'X' indicate statistically significant

	Scraper Conveyor		Screw Conveyor	
	Specific energy	Characteristic flow rate	Specific energy	Characteristic flow rate
Gate	X	X	X	X
Speed		X		X
Walls		X		
Gate x Speed Interaction				X

Objectives

The purpose of this research and development project is therefore to provide the designers and operators of equipment used for the handling and land application of solid and semi-solid manure with the engineering and technical information required to optimize the design and performance (e.g. energy requirements, uniformity of application) of that equipment. The specific objectives of the project are:

1. To determine representative ranges of values for the physical and flow properties of different types of solid and semi-solid manure that have a direct impact on the performance of handling and land application equipment: solids content, apparent density, angle of repose, coefficient of friction, particle and lump size distribution of the solid phase, shear strength.

2. To determine the efficiency of different discharge systems at providing controlled discharge rates for the different types of manure identified in 1.

3. To determine the efficiency of different distribution and land application systems in terms of uniformity of application rate and coverage for the different types of manure identified in 1.

Progress Report

<u>Objective 1: Determination of the physical and flow properties of the manure products</u>

<u>Objectives 2 & 3: Comparative evaluation of manure discharge systems</u>

The design component of this project was broken down into two "test-bench" components. The first test bench involves the main body or box of the spreader and controls the flow and movement of the material to the back of the spreader. The second test bench deals with the transverse distribution of the material across the full width of application (3 m, 10 ft). A transitional hopper between the test benches will also be designed to help facilitate flow from the back of the spreader to the transverse conveyor.

Main Test-bench

A commercial box manure spreader (New Idea, model 362) was used as the body for the main test-bench. Four load cells (Massload Technologies,

Table 2. Summary of unit energy requirements and discharge rates for tested components.

Component	Material	Unit Energy Requirement (W per kg/s)	Maximum Total Discharge Rate Achieved (kg/s)	Comments
Main test-bench (scraper)	Feedlot manure	117	10.5	
	Swine manure and straw	194	15.1	No repetitions
Main test-bench (screws)	Feedlot manure	374	47.4	
	Separated solid swine manure	212	36.9	No repetitions
Transverse test-bench (belt)	Compost	37	22	3 m span
	Sheep manure and straw	-	-	Unable to obtain results
Transverse test-bench (screw)	Compost	1,000	3.84	2.4 m span
	Sheep manure and straw	838	2.4	

model ML-100BC, Saskatoon, SK) were installed between the spreader box and frame for continuous mass measurement. The spreader box also includes inclinable sidewalls that can be lined with different types of materials for which the friction characteristics have been determined: steel (bare and painted), plastic PVC and plywood. A hydraulically actuated gate was installed at the back of the box to help control the flowrate of material into the transverse conveyor. The gate opening could be adjusted to any height between 0.0254 and 0.9144 m (between 1 and 36 inches). Two types of floor conveyors were implemented (scraper and screw conveyors) which are discussed next.

Scraper Conveyor

The scraper conveyor consisted of a traditional chain and slat device that spanned the full 1.524 m (5 ft) width and 3.05 m (10 ft) length of the box. The drive shaft was positioned at the back end of the box and the gearbox between the PTO at the front and the drive shaft at the back provided the required speed reduction from 540 rpm to 10 rpm. A torque transducer (Lebow Associates, model 1248H-20K, Troy, Michigan) and a magnetic speed sensor were positioned at the front of the spreader to monitor the PTO torque and speed for power requirement calculations.

Screw Conveyors

Four 0.3048 m (12 inch) diameter, standard pitch (2 right hand, 2 left hand flighting) screws were installed across the entire width of the floor to eliminate bridging in the hopper and to provide an even flowrate across the entire width at the back of the spreader. Stainless steel troughs were constructed to house the screws to provide stability and allow for more predictable material behaviour. The drive system included two gearboxes (one each for the right hand and left hand screws) 100-chain sprockets of varying size to achieve further speed reduction.

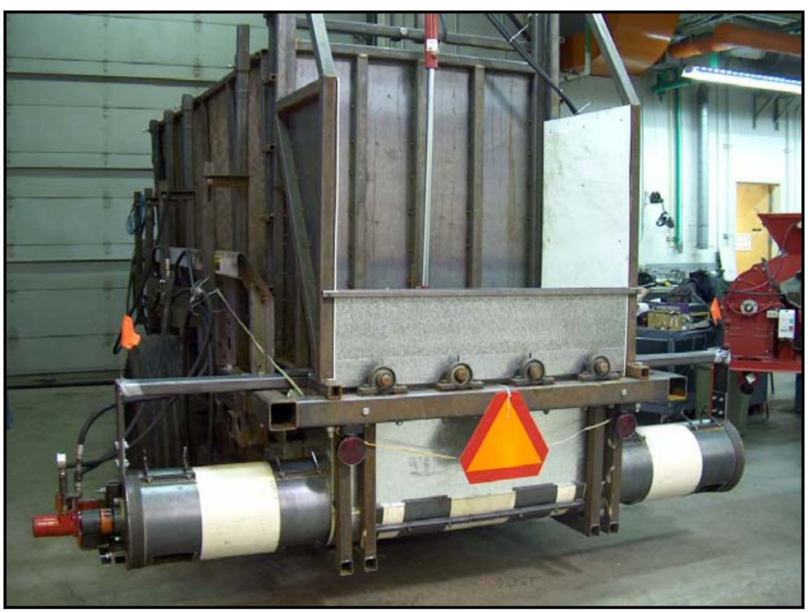


Figure 1. Prototype design for transverse distribution.

Test-bench for Transverse Distribution

Designs for the transverse distribution of solid and semi-solid manure included two types of conveyors: screw and belt.

Belt Conveyor

Specifications:

- 3.05 m (10 ft) long, 0.457 m (1.5 ft) wide belt on a trough support with rollers and idlers at each end
- 80 L (21 gallon) hopper, adjustable height
- Set of 3 dividers and gates (adjustable position and angle) to provide evenly spaced drop points (3 or 4) along length of conveyor
- Hydraulic drive system with instrumentation to measure hydraulic flow and pressure for power determination (rotational speed measured manually with digital tachometer)

Screw Conveyor

Specifications:

- 2.44 m (8 ft) long, 0.203 m (8 in) diameter standard pitch screw conveyor
- Complete, circular steel trough adapted from an auger conveyor
- 50 L (13.2 gallon) hopper
- 4 evenly spaced drops, with slide plates for drops 1, 2 and 3 to adjust opening width
- 0.0762 x 0.0254 m (3x1 inch) "paddles" welded to the flighting at each drop point to help material flow out of openings
- Apertures changed from 0.1016 m (4 in) diameter circular to 0.1016 m (4 inch) 180º rectangular openings
- Final drop point at end of conveyor completely open

Figure 2. Preliminary results obtained for banded application of chicken wastes compost (three repetitions are shown).

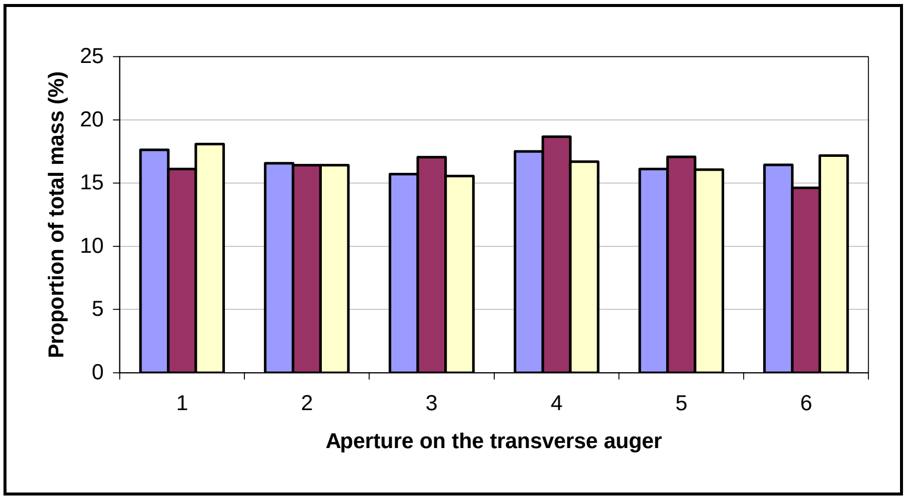
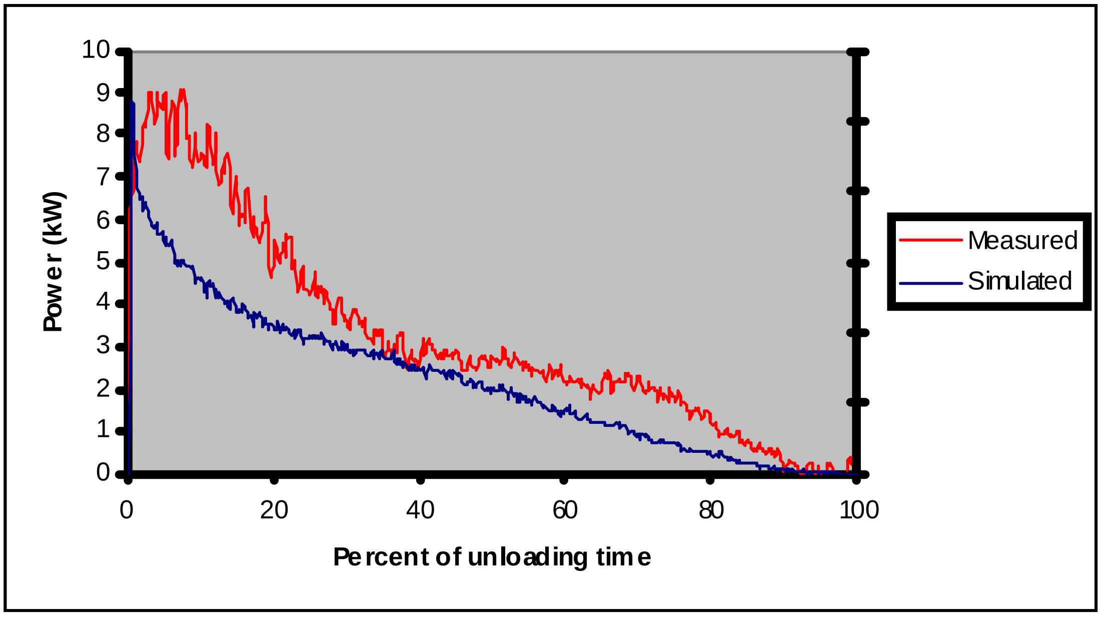


Figure 3. Comparison between results from DE model and actual testing.



- Hydraulic drive system with instrumentation to measure hydraulic flow and pressure for power determination (rotational speed measured manually with digital tachometer)

Results

The main test-bench performed well with the scraper conveyor configuration. Inclining the sidewalls to 10º from vertical significantly reduced the power requirement while using the gate increased the power requirement while helping to control the distribution pattern. Analysis of the energy requirements (power per unit discharge rate) showed no wall effect, but the energy requirements were higher when the gate was closed. Refer to Table 1 for a summary of significant factors and to Table 2 for a summary of flowrates and energy requirements.

The main test-bench with the screw conveyors was tested with composting feedlot manure and freshly separated solid swine manure. The gate height and PTO speed significantly affected the total flowrate while the wall inclination did not affect flowrate. The gate height was the only variable to significantly affect the unit energy consumption while the PTO speed and wall inclination had no effect on the unit energy consumption. Refer to Table 2 for flowrate and energy values.

The transversal distribution test-benches showed that a screw conveyor is more suited to handle the solid and semi-solid materials the unit is required to deal with. While the belt conveyor provided flexible and accurate distribution of compost, it did not perform well with the fresh manure sample. The 0.203 m (8 inch) diameter screw conveyor, while requiring more power, handled the manure samples well, but the observed flowrates did not satisfy the requirements for the expected application rates. The final prototype design will incorporate a 0.305 m (12 inch) diameter screw conveyor for the transverse distribution component. The low standard error (<20%) observed for the flowrates between each of the drop points of the transverse screw should provide the required even distribution pattern of solid and semi-solid manure.

Prototype Design

The prototype precision land applicator to include transverse distribution can be seen in Figure 1. The machine includes four 0.305 m (12 in) diameter screw conveyors (2 right hand, 2 left hand flightings), inclinable sidewalls and an adjustable gate for control of the flow to the back of the spreader. A transitional hopper leads to the transverse screw (0.305 m, 12 in diameter) which is housed in a PVC tube with 6 equally spaced, adjustable openings for banded application.

Preliminary work shows that it is possible to obtain the same flowrate from each of the drop points (Figure 2) with a unit energy consumption of approximately 520 W per kg/s. Including the energy required to run the four screws in the box of the spreader, the total unit energy requirements of the system are approximately 894 W per kg/s. More trials are required to validate the achievable flowrates and energy consumption.

Future work will also focus on adapting the prototype for broadcast application and subsurface incorporation. For the broadcast application, hydraulically powered spinners will be added to each of the drop points and soil openers and/or disks will be added to the current configuration for subsurface incorporation.

Modeling activities

Discrete element models of machine-manure interactions are being developed to better understand the flow of organic fertilizers in land application equipment. The results obtained during the spreading experiments are used to develop those models. Figure 3 presents an example of the results obtained with the DE models. The measured and simulated powers for the four augers with the gate at its lowest setting are presented. The models will need to be further refined to better replicate the properties and behaviours of manure products.

Acknowledgements

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