Pipeline Transportation of Liquid Manure

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DUE to transportation costs, manures can be utilized for their fertilizer value only when the hauling distance is short. However, manure cannot be applied indefinitely to a limited land area close to the manure production site without creating problems of water pollution (Patni and Hore, 1978) and excessive nutrient and salt accumulation in the soil. Therefore, using manure for crop production on large integrated farms requires a practical and economic method for long-distance transportation of manure. For liquid manure, pumping under pressure through a pipeline holds promise. The objective of this work was to develop and study a pumping system for transporting relatively thick dairy cattle liquid manure from the barns to a remote field storage. The manure was later plowed under in surrounding fields. The operational experience, operating problems, pumping suitability and pressure drop data are given here.

PREVIOUS STUDIES

Pressure drops during flow of various manure types (species and solids concentration) in 50 mm to 150 mm dia pipes of various materials of construction have been reported by Hart et al. (1966), Staley et al. (1971, 1973), Rolfes et al. (1977), and Howard (1979). Rheological properties of various manure types and semi-theoretical relationships for pressure drops have been proposed (Sobel, 1966; Grimm and Langenegger, 1971; Kumar et al. 1972; Staley et al., 1973; Chen and Hashimoto, 1976; Hashimoto and Chen, 1976; Bashford et al., 1977). Manure pumps have also been evaluated for pumping different manure types by Hart et al. (1966) and Carson et al. (1978).

The above studies have limited application for the design of a farm-scale pumping operation because of non-typical farm conditions such as: pumping in a closed loop system; pumping for short periods of time; pumping data based on small volumes of manure; determination of manure rheological properties on screened manure samples; short test sections; small pipe diameters; etc. Dougherty and Broughton (1969) described operational experience with pumping hog manure at an operating farm. Holjewilken (1976) described a large installation on pipeline transport of manure without giving any data.

The use of trade names used in this article implies no endorsement of the products named nor any criticism of similar products not mentioned.

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SYSTEM DESCRIPTION AND OPERATION

The land recycling system for manure at Agriculture Canada's 1130 ha Animal Research Institute Greenbelt Farm has been described by Turnbull et al. (1971). Every year, about 34,000 m^3 of liquid manure are hauled in 4.5 and 9 m^3 tankers for rapid plowdown in selected fields to minimize complaints about odor from the surrounding urban areas and to conserve manure nutrients. To reduce time and resource requirements for hauling to distant fields, a preliminary system was set up to pump dairy cattle manure from the barn site to a remote storage via a high density polyethylene pipeline, which was 900 m long and 100 mm in dia (Fig. 1).

Liquid Manure

Liquid manure beneath slatted floors in a free-stall dairy barn for 240 lactating cows was mixed by circulation using a Clay Equipment Corporation (Georgetown, Ontario) chopper-agitator pump, after adding the minimum necessary dilution water. The manure was then transferred to one or more of six outdoor concrete storage tanks, each 13.3 m X 6.7 m X 3.0 m deep. Manure 'as available' from this outside storage was used without any adjustment for solids content. About 8 percent of the solids was due to wood shavings used as bedding.

Pipeline

The polyethylene pipe (Sclairpire®, Du Pont Canada Inc.) was rated for continuous service at 550 kPa; it was laid about 1 m below grade using a drainage-tile machine. Control valves, bypass lines and stand pipes to protect against hydraulic transients were also installed as shown in Fig. 1.

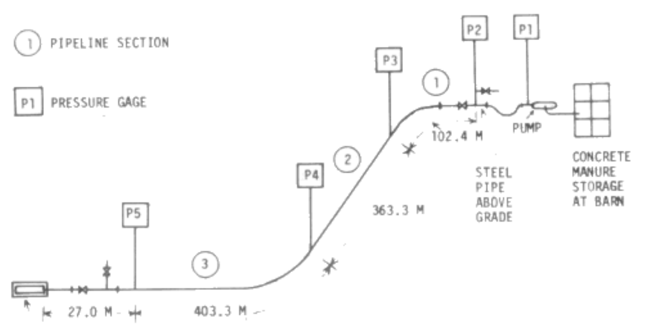

FIG. 1 Schematic plan view of buried pipeline. Pipeline relative elevation was 6.12 m at P2, 2.73 m at P3, 1.67 m at P4, 0.46 m at P5, and 0.0 m at lagoon inlet.

Pumps

Table 1 gives information on the four centrifugal PTO pumps used and pumping conditions. The Gorman-Rupp pump was serviced at the Farm before use, but the other three pumps were used `as supplied' by the dealers.

Remote Storage for Manure

The remote storage, to which manure was pumped, was plastic-lined and covered; it has a capacity of 950 m3 (`Controliner' Model 360, supplied by Environetics, Inc. of Bridgeview, IL). The 2.3 m deep storage had sloping sides and the top dimensions were 48.8 m X 15.2 m. Pumped manure entered one end of the storage 0.2 m above the floor. Vacuum tankers were used to remove manure from this storage via three 100 mm dia agitation-removal hoses.

EXPERIMENTAL PROCEDURE AND MEASUREMENTS

Pumping and Flow Measurement

Manure was mixed for 60 to 180 min before pumping, unless it had been freshly transferred from the barns to the outside storage. A 4.5 m length of 100 mm or 150 mm dia hose was used on the pump suction side. A 6 m length of 1030 kPa pressure hose connected the pump discharge to the pipeline. About 15 min of pumping of manure usually established steady-flow conditions. A 50 mm water line from the barns supplied water at 410 kPa pressure for flushing the pipeline after pumping manure. Flow rate was measured using the rate of drop of manure level in the concrete storage tank whose cross-sectional area was known. An electric level sensor was used.

Pressure Measurements

Pressure at pump discharge and at four known points in the pipeline was measured using pre-calibrated oil-filled bourdon gages (Marsh P0148 and E0152, Marsh Instrument Co., Skokie, IL) which were separated from the manure by a diaphragm seal (Marsh Type DA). Plugging was prevented by mounting the pressure gage and its associated seal on a vertical standpipe. In computing pressure drops due to friction, allowance was made for elevation difference and the manure column in the standpipe. Calibration of the gages was rechecked after pumping. Pump suction pressure was measured using a mercury manometer or a pre-calibrated vacuum gage.

TABLE 1. PUMPS USED AND PUMPING CONDITIONS

Pump make, model and type	Footnote	Average total solids, %	Average flow rate L/s	(U.S. gpm)	Pumping duration, min
1. Gorman-Rupp Model 14C11	0	0.1	14.8	(234)	97
(Gorman-Rupp of Canada Ltd.,	†	8.5			
St. Thomas, Ontario)		4.8	13.8	(219)	60
Priming: self		6.1	14.8	(234)	90
Chopper: yes		5.6	12.9	(204)	300
Size: 100 mm X 100 mm		4.8	13.1	(208)	135
		6.1	13.0	(205)	120
		6.3	12.3	(195)	270
	†	8.0			
2. Wright Rain Model H3LM	‡	7.3	8.1	(128)	30
(Wright Rain Ltd., Ringwood,	‡	7.3	5.9	(94)	30
Hampshire, U.K)		5.3	13.1	(208)	240
Priming: manual		6.1	11.5	(183)	220
Chopper: no	†	8.0			
Size: 100 mm X 75 mm					
3. Parma High Pressure Slurry	§	5.5	22.7	(360)	75
Pump (Parma Division,		8.7	18.3	(289)	240
Agri-Lines Corporation,		8.0	18.2	(288)	75
Parma, Idaho)		9.7	15.7	(250)	100
Priming: manual		6.4	21.1	(335)	150
Chopper: no		5.7	21.1	(335)	210
Size: 100 mm X 100 mm					
Suction hose: 150 mm reduced					
to 100 mm at pump intake					
4. Better-Bilt High Pressure		6.2	18.7	(297)	265
Pump (Pearson Bros. Co.,	†	9.1			
Galva, Illinois)					
Priming: manual					
Chopper: no					
Size: 150 mm X 150 mm					
Discharge: 150 mm reduced to					
100 mm					

* Test-run with water; † No flow, line blocked; ‡ Intake to aluminum pipe on suction side partly plugged; replaced in other tests by open hose.

§ Under-capacity operation: To protect 550 kPa rated pipeline, pump was operated at 800 rpm at PTO instead of 1000 rpm, which gave a pressure of about 860 kPa at pump discharge.

TABLE 2. PRESSURE DROP DUE TO FRICTION IN DIFFERENT SECTIONS OF 100 mm DIA PIPELINE

Manure total solids, %	Flow rate, L/s	Pressure drop due to friction, m water column		
		Section 1*	Section 2 †	Section 3 ‡
0.1	14.8	7.8	12.0	19.1
4.8	13.8	7.8	11.3	16.2
6.1	14.8	10.6	17.6	21.3
5.6	12.9	10.6	14.1	18.6
4.8	13.1	7.8	14.1	18.6
6.1	13.0	8.5	13.4	17.8
6.3	12.3	12.1	14.2	17.1
7.3	8.1	9.8	23.2	33.1
7.3	5.9	12.7	18.2	30.2
5.3	13.1	14.8	23.9	33.1
6.1	11.5	12.7	21.8	30.2
5.5	22.7	21.1	24.5	37.6
8.7	18.3	21.1	23.8	37.5
8.0	18.2	20.4	29.4	38.8
9.7	15.7	17.6	35.9	35.9
6.4	21.1	21.1	24.5	40.2
5.7	21.1	20.4	23.1	38.8
6.2	18.7	10.6	21.8	28.8

* Section 1: Steel pipe 6.7 m long with 22.5 deg elbow + polyethylene pipe 95.7 m in length with a long bend + one gate valve + three flanged connections.

† Section 2: Straight polyethylene pipe 363.3 m long.

‡ Section 3: Polyethylene pipe, 311.9 m straight and 91.4 m in a long bend.

Power

Mechanical power was computed for one pump from torque and pump speed measurements. Torque was measured with a strain gage dynamometer on the tractor PTO shaft, a portable signal conditioner, and recorder. Pump speed was measured using an optical tachometer. Fuel consumption data were obtained in two instances.

Manure Properties

One-liter manure samples were collected at the time of pumping to determine temperature, specific gravity, and average total solids content. Later, additional 5-L samples were collected to determine particle size distribution. Temperature was determined with a mercury-in-glass thermometer, specific gravity with a hydrometer, and manure total solids by oven drying at 103 ºC. Particle size distribution of washed and unwashed manure solids was determined using a Fisher Scientific Co. sieveshaker modified for wet sieving.

Wood Shaving Characteristics

As wood shavings constituted about 8 percent of the total solids in manure, particle size distribution of wood shavings was determined by dry sieving.

RESULTS AND DISCUSSION

Pumps

The flow rates and pumping duration for each trial for manures with different total solids (TS) contents are shown in Table 1. All the pumps tested were able to pump manure with up to about 6.4 percent TS, but only the Parma High Pressure Slurry Pump could handle manure with 8 percent TS. The latter pump, which could develop a discharge pressure of 1100 kPa, was operated at a discharge pressure of 860 kPa or less by reducing the pump speed, in order to protect the pipeline which was rated for continuous use at only 550 kPa. This pump also gave discharge rates greater than other pumps, and these rates would have been higher still, had the pump operated at its full rated speed.

Difficulty in priming the pumps was experienced with every pump except the Gorman-Rupp, which was the only self-priming pump, and also the only one with a chopper. In a farm operation, the other three pumps would require an auxiliary chopper pump if the manure to be pumped contained large pieces of solid materials. Entry of manure into 100 mm dia suction hoses of the Gorman-Rupp and Wright Rain pumps had to be facilitated by a 200 mm long, 200 mm X 100 mm reducing cone at the manure inlet end of the hose. Restricted entry into the suction hose was noted otherwise. This was not a problem when a 150 mm dia suction hose was used with the other two pumps.

The efficiency of the Parma pump, determined from the pump pressure head, discharge rate and brake horsepower measurements, was 36.1 and 36.2 percent at discharge rates of 17.7 and 16.7 L/s respectively. Better efficiency would have resulted had not the pump been operated at reduced speed for the reason noted above. Using the same tractor in tests one week apart, 80 L of diesel fuel was required to pump 370 m^3 of liquid manure (5.7 to 6.4 percent TS) in 4.9 h using the Parma pump, and 89 L was required to pump 290 m^3 (6.2 percent TS) in 4.3 h by the Better Bilt pump.

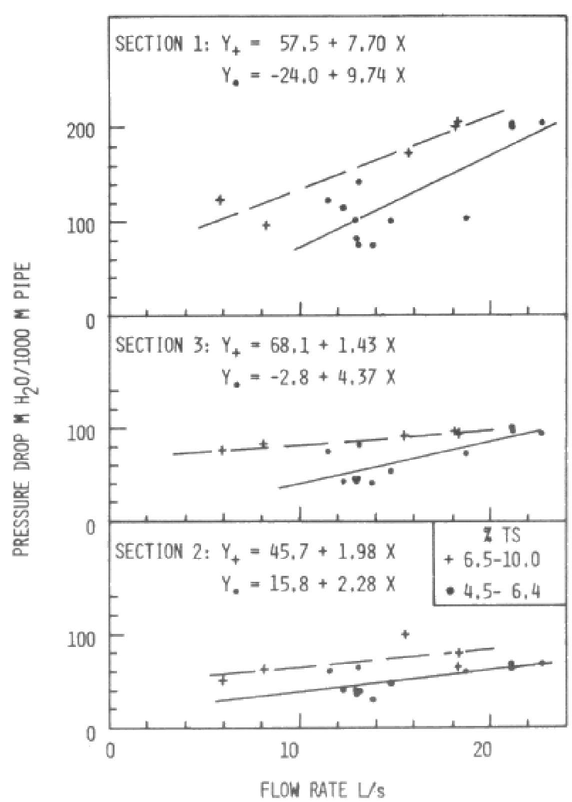

FIG. 2 Pressure drop due to friction in different sections of the pipeline. Section 1 - pipe with joints and fittings. Section 2 - straight pipe. Section 3 - straight pipe and long bend.

Pressure Losses

Pressure loss due to friction in three sections of the pipeline at different flow rates are listed in Table 2 for different manure solids concentrations. One initial pumping was done using water to confirm that the observed pressure drop through the straight section of the pipeline checked against the expected pressure drop indicated by the pipe manufacturer. In each section, the maximum pressure drop observed was about three times the minimum pressure drop, and this maximum corresponded to different flow rate and solids concentration in each case, conceivably due to a different action of slurry solids flowing in a straight pipe compared to a non-straight pipe. For comparison, data of Table 2, converted to meters of water column per 1000 m of pipe length are plotted for each section in Fig. 2, with the realization that for practical use such transformation of data for non-straight pipeline sections should be used with caution. Scatter of data reported in other studies mentioned earlier is also evident in Fig. 2. The pressure loss for the straight pipe (section 2) during flow of manure with 6.5 to 10.0 percent TS was about twice that reported by Rolfes et al. (1977) for flow of beef cattle slurry under similar conditions in 15.24 m long polyvinylchloride pipes. Increased contribution to pressure drop caused by a long bend (section 3) and joints etc. (section 1) can be estimated from Fig. 2. This increased contribution was greater as the solids concentration increased from the 4.5 to 6.5 percent range to the 6.5 to 10.0 percent range.

Particle Size Distribution

Fig. 3 shows the particle size distribution for washed and unwashed manures, coarse and fine wood shavings used in barns, and plug material removed from the blocked pipeline on one occasion. The term particle size here refers to the material retained on a given size of sieve opening. During wet sieving of manure without washing, large and small slurry particles balled up together due to a glue-like action of some undetermined component in manure, once the liquid fraction was shaken out. Particle size distribution of washed manure, which represents the actual distribution, was considerably below that of unwashed manure. This property of unwashed manure particles sticking together makes it essential that manure pipelines be flushed with water immediately after pumping is stopped and before the liquid fraction drains out. Wood shavings used in the barns as well as the pumped manure had a much smaller proportion of large solids compared to the material that formed the plug in the blocked pipeline. On each occasion when the pipeline was blocked, the plug was located 600 m or more from the inlet to the pipeline. The location of the plugs and the particle size distribution of the plug material suggest that a small but differential rate of movement of fine and coarse particles occurred during flow, which resulted in an increasing proportion of coarser particles in manure as it moved down the pipe till such time when the concentration of coarse particles became large enough to cause the plug.

Remote Storage

Manure was hauled rather than pumped to this storage in winter. However, low temperatures (- 15 ºC) for a few days were enough to freeze manure in the agitation-removal hoses and this prevented further use of the storage in winter. Without a snowcover, manure also froze in the inlet pipe. Vacuum tankers used to haul the manure away required more than twice the time to fill up at this storage which had 100 mm dia manure removal hoses compared to 150 mm dia hoses used at the concrete storage tanks. Increasing the diameter of manure agitation-removal hoses at the storage could possibly result in inadequate mixing due to reduced velocity when manure is discharged back from tankers into the storage for agitation, leading to a sludge build-up.

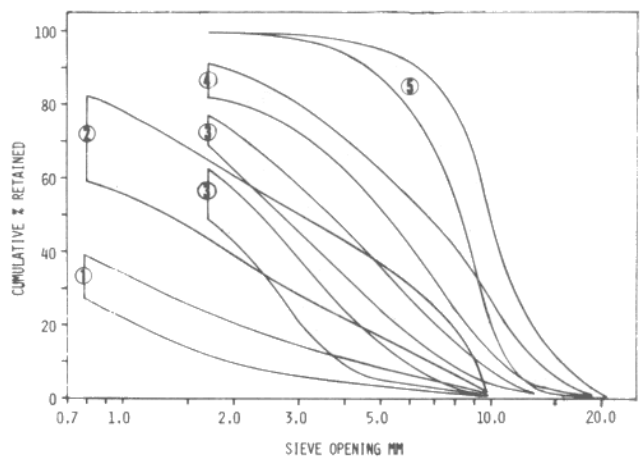

FIG. 3 Particle size distribution in (I) washed manure (2) unwashed manure (3) `fine' wood shavings (4) `coarse' wood shavings and (5) plug from blocked pipeline, oven dry basis.

Pumping versus Hauling

In these trials, manure was transported in a pipeline over a distance that was equivalent to 1 km by road travel, at the rate of 40 to 80 m^3/h (higher rates were possible with one pump). Assuming a tractor speed of 24 km/h for tanker-hauling, a 2 km travel on road would take 5 min. Not considering other factors, 54 m^3 and 108 m^3 manure respectively would be moved per hour using a 4.5 m^3 and 9.0m^3 tanker. Thus, short-time volumetric rate of manure transport is nearly same by pumping or hauling. However, considering factors such as fuel and equipment requirements, ability to transport manure continuously for several hours, release of manpower for other pressing needs, and greater possible utilization of manure for crop production, pumping of manure would be advantageous compared to hauling particularly when large volumes have to be hauled. Pumping systems require higher capital investment and more involved technical operation.

SUMMARY AND EQUIPMENT REQUIREMENTS

Pumping of thick manure slurries was tested in a field application for extended periods. Of the four pumps tested, only one was able to pump manure with 8 percent or more total solids over a distance of 900 m. High pressure pumps with better priming, chopper attachments, and easy servicability are required.

Pressure drops due to friction for flow of dairy cattle liquid manure in a 100 mm dia polyethylene pipe were greater than published values for similar conditions. Pressure losses increased considerably with introduction of joints, bends, etc. in the line.

Use of pipeline with a higher pressure rating (1400 kPa) and smooth inside bore at joints is indicated.

With reasonable care, pumping of thick manure slurries over long distances is possible, but a reliable system for immediate flushing of the pipeline with water, when manure pumping is stopped, is essential for practical trouble-free operation. Manure used for pumping should be free of excessive bedding material, and aging it for as long as practical makes pumping easier. Pumping would be advantageous for large-volume utilization of manures for crop production, particularly at large integrated farms, but plastic-lined and covered, remote storages of the type described here were found to be unsuitable for use in very cold weather.

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