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Joseph P. Harner

John F. Smith

Michael J. Brouk

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Abstract

Manning's equation provides a method to evaluate the flow characteristics of a flush plume system used to move a diluted, sandladen manure stream from a freestall building to sand or solid separation equipment. Evaluation of a 16, 18, and 24-inch plume showed pipe slope is critical in maintaining a 5 feet per second water velocity through the pipe. A 24 inch or larger plume placed on a 0.5% slope is able to obtain water velocity of 5 feet per second if the pump capacity exceeds 3,600 gpm. The flow velocity never reached or exceeded 5 feet per second in a 16- or 18-inch pipe placed on a 0.5% slope, regardless of the pump capacity. A 16-, 18- or 24-inch pipe laid on a 1% slope could obtain a water velocity of 5 feet per second if the pump capacity exceeded 1,500 gallons/minute.; Dairy Day, 2007, Kansas State University, Manhattan, KS, 2007; Dairy Research, 2007 is known as Dairy Day, 2007

Keywords

Dairy Day, 2007; Kansas Agricultural Experiment Station contribution; no. 08-127-S; Report of progress (Kansas State University. Agricultural Experiment Station and Cooperative Extension Service); 984; Dairy; Sand; Plume; Flush; Sand sparation

IMPACT OF SLOPE AND PIPE DIAMETER ON FLUSH PLUME DESIGN

J. P. Harner, J. F. Smith, and M. J. Brouk

Summary

Manning's equation provides a method to evaluate the flow characteristics of a flush plume system used to move a diluted, sand-laden manure stream from a freestall building to sand or solid separation equipment. Evaluation of a 16, 18, and 24-inch plume showed pipe slope is critical in maintaining a 5 feet per second water velocity through the pipe. A 24 inch or larger plume placed on a 0.5% slope is able to obtain water velocity of 5 feet per second if the pump capacity exceeds 3,600 gpm. The flow velocity never reached or exceeded 5 feet per second in a 16- or 18-inch pipe placed on a 0.5% slope, regardless of the pump capacity. A 16-, 18- or 24-inch pipe laid on a 1% slope could obtain a water velocity of 5 feet per second if the pump capacity exceeded 1,500 gallons/minute.

(Key Words: sand, plume, flush, sand separation.)

Introduction

Sand is the preferred bedding option on many dairies in spite of the challenges with sand laden manure. The abrasiveness of the sand causes increase wear on equipment and is difficult to remove from containment structures. Many dairies are using passive (gravity) or non-passive (mechanical) sand separation systems to reduce the volume of sand entering further storage structures. Both separation systems required diluting the sand-laden manure with fresh or recycled water. A water to sand laden manure dilution ratio of 5:1 is representative of flush streams (Wedel, A.W. and W.G. Bickert. 1996. Separating sand from sand-laden manure: factors affecting the process. Paper No. 1996-4016. ASABE, St Joseph. MI.). This equates to a water:sand ratio of 20:50 depending on the sand usage in the stall and water volume per square feet of alley space being flushed. Different types of settling processes have been used to recover sand from a flush stream.

Often, existing dairies are unable to retrofit their facilities to a flush system that would enable them to recover sand. A flush plume system provides an alternative on these dairies. In this system, manure is scraped into a plume, and water from a containment structure is used to erode or move the sand-laden manure to a sand separation system. A pump is used to recycle water from a containment structure to the plume. The plume openings allow manure to drop inside a pipe but prevent the system from being pressurized. Water and sand-laden manure move through a plume via gravity to the separation or storage area. Pipe slope, diameter, and surface roughness influences water velocity and volume in open channel flow. Optimizing the plume system on existing dairies may not be practical because topography and existing building evaluations may limit pipe slope. Pipe diameter and surface roughness, however, are controllable factors even in a retrofit situation. The objective of this study was to evaluate the effect of pipe diameters and pipe slope on water velocity and volume.

Procedures

The common design equation for fluid flow in open channels and pipes is known as Manning's equation. The equation considers piping material, pipe slope, wetted perimeter, and pipe cross-sectional area. This equation is used for open channel flow in which the flow rate is controlled by gravity as compared with a pump system where head pressure forces liquid through an enclosed conveying channel.

Manning's equation is represented by:

$$Q = (1.486 \times S^{0.5} \times A^{1.667}) / (n \times P^{0.667}),$$

where

Q = pipe flow (cubic feet per second),
S = slope (ft/ft),
A = water cross sectional area (sq ft),
n = pipe surface coefficient, and
P = wetted perimeter (ft).

Normally, this equation is used for open channel or full pipe flow; however, in plume design only partial flow is considered. Geometrical equations can be used to estimate the cross-sectional area of a pipe with partial flow and the wetted perimeter based on the water depth in the pipe. The surface coefficient is a function of the type of pipe. Smooth plastic pipe has a coefficient ranging from 0.009 to 0.015. For this study, a coefficient of 0.013 was used based on earlier work (Metcalf & Eddy, Inc. 1981. Wastewater Engineering: Treatment Disposal and Reuse. New York, McGraw-Hill). Pipe slopes of 0.5 or 1% were evaluated and reflected normal construction practices. Pipe diameters selected were 24, 18, and 16 inches. In order to compare different pipes, percentage depth of water flow in the pipe was used. Water flow depths of 25, 50, 75, and 100% of pipe diameter were considered. At 100% of pipe diameter, the pipe would be flowing at full capacity.

Results

Table 1 summarizes the flow velocity (feet/second) and flow rate (gallons/minute) as a function of pipe diameter, pipe slope, and depth of flow. Recommended pipe flows are 5 to 8 feet/second in plume design with handling sand-laden manure (Wedel, A.W. 2000.Hydraulic conveyance of sand-laden dairy manure in collection channels. Paper No. 00-4106. ASABE, St Joseph. MI). Further, "a flow velocity of 5 feet/second will initiate scour." At 5 feet/second, 4 mesh grains will not be completely suspended in water but will bounce along the bottom of the plume. This flow velocity is obtainable when 18- or 16-inch pipes are placed on a 1% slope or a 24-inch pipe is used on either a 0.5 or 1% slope. Optimum flow velocity occurs when the water flow depth is 75% of the pipe diameter. The flow velocity at 100 and 50% flow depth is equal because the ratio of wetted perimeter to pipe cross sectional area is equal. Current recommendations indicate limiting pipe flow to 50% of the pipe diameter or half of the cross-sectional area. This should provide room in the pipe to temporarily store manure until the water erodes and moves the sand-laden manure to the separation system.

Table 1 also shows the flow volume necessary to sustain the flow velocity for the varying design parameters. Assuming a water flow depth of 50% and minimum water velocity of 5 feet/second, a 24-inch pipe on a 0.5% slope requires a minimum pump capacity of 3,600 gallons/minute. The pump capacity required for an 18- and 16-inch plume on a 1% slope is 2,400 and 1,700 gallons/minute, respectively. Further analysis indicates a minimum pump capacity for 16-, 18-, and 24-inch plumes is 1,500 gallons/minute if water velocity is be maintained at 5 or greater feet/second. However, the water flow depth is less than 50% of the pipe diameter if the pipe has a 1%

slope. A plume 24 inches or larger is required if the pipe slope is 0.5%. The flow volume must equal or exceed 3,600 gallons/minute to maintain a velocity of 5 feet/second if the pipe slope is 0.5%. If a 1,500 gallons/minute pump is used with a 24 inch or larger plume on a 0.5% slope, then the water velocity will range between 4 and 5 feet/second. Some coarser sand may settle causing the pipe to plug if the water velocity is less than 5 feet/second.

Manning's equation provides a method to evaluate the flow characteristics of a flush plume system used to move a diluted sand-laden manure stream from a freestall building to a sand or solid separation system. Evaluation of a 16-, 18-, and 24-inch plume showed that pipe slope is critical in maintaining a 5 feet/second water velocity through the pipe. This velocity could not be reached in a 16 or 18 inch plume if the pipe was placed on a 0.5% slope. A 24 inch or larger plume placed on a 0.5% slope is able to obtain 5 feet/second water velocity, but only if the pump capacity exceeds 3,600 gallons/minute. The design parameters indicate, if the site allows, that the least cost option is placing the plume on a 1% slope, because a pump with a 1,500 gallons/minute capacity is acceptable and the plume may be 16 to 24 inches wide.

Table 1. Flow Velocity and Flow Volume Through Different Size Plume Pipes Placed on Either a 0.5 or 1% Slope

		PVC pipe diameter					
	Water flow depth (% of pipe diameter)	24 inches		18 inches		16 inches	
Pipe slope		Flow velocity	Flow volume	Flow velocity	Flow volume	Flow velocity	Flow volume
(%)	(%)*	(fps)[1]	(gpm)[2]	(fps)	(gpm)	(fps)	(gpm)
0.5	100	5.1	7,200	4.2	3,400	3.9	2,400
	75	5.8	6,600	4.8	3,100	4.4	2,200
	50	5.1	3,600	4.2	1,700	3.9	1,200
	25	3.6	990	3.0	460	2.7	340
1	100	7.2	10,200	6.0	4,700	5.5	3,500
	75	8.2	9,300	6.8	4,300	6.2	3,200
	50	7.2	5,100	6.0	2,400	5.5	1,700
	25	5.1	1,400	4.2	650	3.9	470

*This represents the percentage of the cross sectional area with water flow. For example, if the pipe is half full, then water flow depth is 50% of the pipe diameter. The water flow depth equals 100% of the pipe diameter if the pipe is flowing full.

[1]Feet per second.

[2]Gallons per minute.