XVII^th World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010

FLUSH SYSTEMS FOR DAIRY MANURE REMOVAL: THE ALLEY ROUGHNESS VALUE

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CSBE100442 – Presented at Section II: Farm Buildings, Equipment, Structures and Livestock Environment Conference

ABSTRACT The note proposes an hydraulic approach to the flush system for removing manure from alleys in dairy freestall barns. The flushing flux is able to transport manure along the alley flooring, depending on hydraulic flux parameters. Chezy formula has been commonly used to calculate the mean flow velocity, assigning a constant value to the roughness Manning coefficient. Attention is posed on the variability of that coefficient, depending on both the flooring material and the type and quantity of material lying on the floor. Trials in three barns, located nearby Reggio Emilia in the North of Italy, which have been using the flushing system for some years, have been performed to calculate the Manning coefficient n values once it was known the flow flush velocity. The obtained n value for the clean alley, concrete floored with grooves, differently increases depending on the alley use, feeding or freestall, because of the type and quantity of bedding materials present only in the freestall alley. N-values close to 0.02, as suggested in literature, are found only for the freestall alleys. As a consequence of using a constant roughness value for both the alleys, the flow velocity results under estimated in the feeding alley and over estimated in the freestall one.

Keywords: Flushing, Dairy freestall, Manure removal, Manning's coefficient, Roughness.

INTRODUCTION Flushing is becoming an accepted system for removing animal manure from dairy freestall barns also in Italy. The removing action is given by the flushing of a re-circulating fluid maintained in a reservoir after the solids have been separated. A flush system, correctly designed, is able to ensure a sufficient flow velocity with an acceptable depth to maintain the alleys free of animal manure and guarantee a satisfactory degree of cleanness (Elder, 2003). Flushing systems may be easily automated reducing the operating costs. Mechanical scrapers or scraping with a tractor are still widely utilized in Italian dairy farms, especially when bedding materials are used. In the designing of new freestall barns, both the hydraulic systems realized in the channels below slatted floors and on the full concrete alleys should be taken into consideration due to the attitude of water for removing solids and odour. Among the hydraulic systems, the evacuation of manure by flushing of recycled slurry is expanding (Barbari et al., 2004). Scraping requires more manpower and greater handling of material than flushing and it has, therefore, typically been used only for management of manure from areas that cannot be effectively flushed, such as flat barn and driveways. Some advantages of flushing dairy facilities, compared with scraping, may be seen in terms of lower cost of manure removal for large herds (Barbari et al., 2007), cleaner facilities and less emission of ammonia and greenhouse gases from the surface of the feeding and freestall alleys. The appropriate design of the alleys is crucial to ensure an efficient removing action of the flush flow. Some drawbacks of the flushing system are related to the recurrent waste of clean water to flush the alleys when the storing pits are totally emptied (not more than 2-3 times per year), the investment and maintenance costs of the mechanical separator and the hydraulic devices (pumps, piping, valves, etc.). Some US experiences showed that the Chezy formula for open channels (Chow, 1954) can be applied for dairy flushing (Fulhage, 1993). The present note shows the first results coming from an experimental study on the different velocity values reached in feeding and freestall alleys, depending on their different roughness degree.

MATERIALS AND METHODS The experiment was carried out in three different dairy freestall barns, located nearby Reggio Emilia in the North of Italy, producing milk for Parmigiano Reggiano cheese. Repeated trials have been made in the freestall barn, called barn 1, whose functioning scheme is constituted by a vertical propeller pump, collecting pipes, 3 flush valves, three 1.65% sloped alleys (a feeding alley, a two rows "head to head" freestall alley and a single row freestall alley), a crossing gutter, a below-ground manure transfer pit equipped with lift pump, a press screw separator, two tanks for storing the liquid manure and a concrete slab as a storage for manure solids. Longitudinal grooves, 0.02 m wide and deep at a distance of 0.1 m, are able to control the slipperiness when the alley flooring is wet. Freestall are bedded with 1.5 kg/d per stall of chopped straw. The liquid fraction, coming from the manure removal and re-used for flushing, is collected in an excavated tank and then pumped through the propeller pump and diverted into the alleys through the flush valves. At the exit of each alley, the flushing liquid is collected into the crossing gutter which is connected to the transfer pit by pipe line and then sent to the separator. The solid fraction is stocked in a concrete platform whereas the liquid fraction is collected in the first tank, overflowing into the other adjacent tank. The propeller pump, powered by a 22 kW electric motor, generates a flush flow rate of 0.22 m^3/s to clean the sloped alleys three times a day, by opening the flush valve in each alley for 60 s.

As regards the freestall barn 2, the functioning scheme and the type of surface in the alleys are essentially the same of barn 1, except for some differences about the number of alleys (two feeding alleys including one row of freestalls and two single row freestall alleys) and a less use of chopped straw (1.1 vs 1.5 kg/d per stall).

The flushing system of barn 3 differs from the previous ones, described above, because it does not include a flush pump as the flush flow comes from the base of an elevated tank which is connected with the three flush valves through a pipeline. The three alleys are 2.8% sloped and the longitudinal grooves are 0.01 m wide and deep and 0.04 m spaced. The flush flow rate is 0.755 m^3/s and the energy is given by a hydraulic head of 8 m; the flush valve opening time is 12 s and two flush operations are carried out per day. Litter of chopped straw is used with a daily amount of 0.5 kg/stall.

The main design parameters of the three barns are shown in table 1.

Table 1. Description of the three freestall barns.

	Barn 1		Barn 2		Barn 3	
Alley	Feeding	Freestall	Feeding	Freestall	Feeding	Freestall
Number of cow places	105	70	85*	38	79	76
Length (m)	73	58	60	60	55	55
Width (m)	3.3	3.14	4.2	2.4	3.9	3.14
Slope (%)	1.65	1.65	1.7	1.7	2.8	2.8

* plus 44 freestalls

In the present study the Chezy's formula, including the Manning expression for the Chezy coefficient to calculate the mean flush flow velocity under uniform flow conditions, is used as suggested by Fulhage (1993). The attention has been focused on the value to be attributed to the alley roughness given by an intrinsic value depending on the alley roughness flooring, for example concrete, and groove type, and its covering conditions due to litter material and manure quantity lying on the floor itself.

Experiments were carried out using an image recording system and photo cameras to collect digital movies and pictures to be analyzed by means of an image software. Repeated trials were made on the feeding and freestall alleys of the barn 1, in different months in the period 2005-2007. The same tests were carried out with and without the presence of manure to investigate the floor intrinsic roughness. Tests of flushing in the clean alleys were carried out to evaluate the roughness value of the alleys depending only on the material (concrete) and on the groove presence. Further tests in the dirty alleys covered by manure and litter (in case of the freestall alleys) were conducted to estimate the increased roughness depending on the material lying on the alleys. The liquid depth in the alleys was measured through vertical graduated segments, located in three different sections along the alley and the mean value was calculated.

To better visualize the movement of the wave flux running over the alley, lime has been put on the alley floor, on lines normal to the longitudinal flow, at a distance of 5 m. Image analysis has been made to take the flush discharge time when intercepting the back sight of the lime line. Flush liquid velocity is then calculated as the ratio of the alley length and the mean flush time. The roughness coefficient is determined through the Chezy formula substituting the previous obtained velocity. Different values of the obtained roughness coefficient may be justified through the different materials lying on the alley flooring depending on feeding and freestall type. In fact, on the freestall the litter material is also present together with the manure.

Figures 1 and 2 show the movement of the flush wave on the freestall alley flooring, for the barn 2. It clearly appears how the front wave is moving regularly on the clean floor compared with the wave flow along the dirty floor of the alleys. The roughness obtained values justify this behavior.

Figure 1. Flush wave on the clean freestall alley (barn 2).

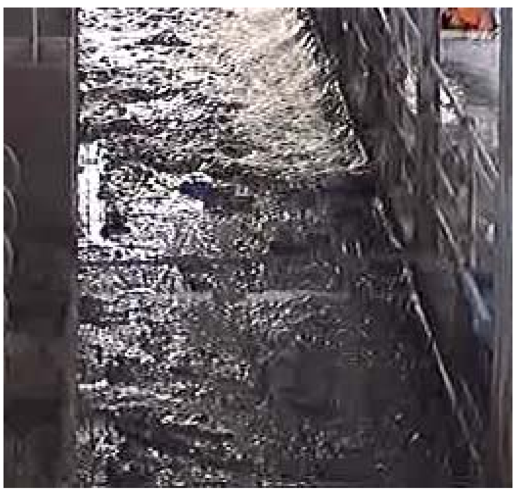

Figure 2. Flush wave on the dirty freestall alley (barn 2).

RESULTS AND DISCUSSION The values of the Manning coefficient *n* are obtained from the Chezy formula substituting the measured velocity and the surveyed flow depth for each trial. Data elaboration has been made both separately for each freestall barn and then grouped for alley type. The barn 1 and 2 have in fact the same alley grooves. In figure 3, *n* values for the barn 1 are shown, with the reference value of 0.02 as suggested in literature, separated between feeding and freestall alley types. The repeated trials on the clean alley of both types show comparable values included in the interval 0.010-0.013, thus a value of 0.01 (cut at the third digit) may be considered as the typical roughness number for an alley made of concrete with longitudinal grooves, 0.02 m wide and deep and 0.1 m spaced. As regards the feeding alley, the range is 0.014-0.017, showing an increase of 27% compared with the *n* value for the clean alley. The freestall alley presents values in the interval 0.022-0.024, showing an increase of 46% compared with *n* value for the clean alley. The higher value calculated for the freestall alley, compared with the value obtained for the feeding alley, may be justified by the presence on the alley of both manure and litter material. From the graph, it is clear how all the values are under the 0.02 line with the exception of values for the freestall alley.

With reference to the barn 2, the roughness values for the clean alleys are 0.012 and 0.011, confirming the previous values calculated for the alleys of barn 1, presenting similar groove type. For the freestall alley, the obtained *n* value is 0.018 representing an increase of 39% with respect to the clean situation. This percentage is lower than that one obtained for the same type of alley of barn 1, but it may be justified by considering that the presence of litter (type and quantity) influences the roughness. In barn 2, the feeding alley presents some differences in comparison with barn 1 as it is wider (4.2 vs 3.3 m) and gives access to a single row of freestalls. The obtained value for the roughness is equal to 0.027, showing an increase of 52% with reference to the clean value. It is obvious that this value cannot be compared with any other among those belonging to the other freestall barns. It can be observed that this roughness value is the maximum obtained and it may be justified by the fact that the amount of manure present will be greater. As regards the barn 3, the 0.017 *n* value for the feeding alley is comparable with the previous ones.

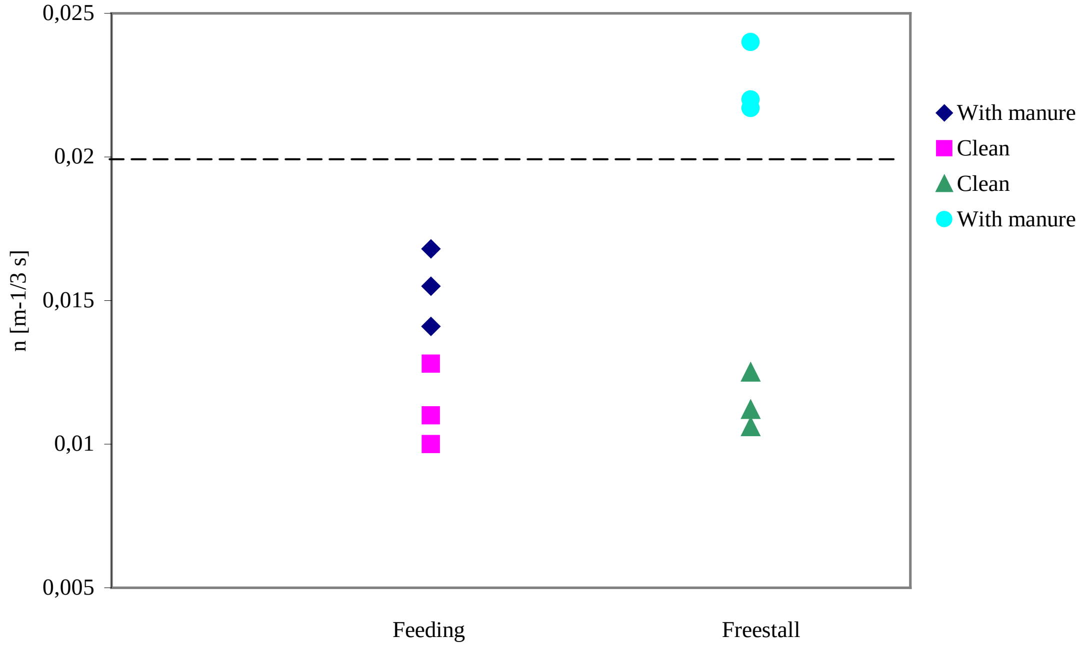

Figure 3. Manning coefficient (*n*) for the different alleys under normal and clean conditions for the freestall barn 1 (dash line represents the *n* value equal to 0.02 as suggested in literature).

In figure 4, the velocity values, calculated with the Chezy formula using a *n* value equal to 0.02 and the measured ones, are reported for all the investigated barns. Points close or on the straight line are those whose calculated and measured velocity values are similar, resulting in *n* values close or equal to 0.02. All the points are above the line with the exception of those corresponding to the freestall alley for barn 1. For those points, the *n* value equal to 0.02 would result into a weak over estimation of the velocity. The value of *n* equal to 0.02 may be considered representative for a situation which is not the current one in the surveyed barns. The only point belonging to the freestall alley over the straight line is for the barn 2 and this may be justified by observing that the freestall alley may be strongly influenced by the litter type and quantity. In this case, the obtained *n* value is less than 0.02. For the other freestall points, the obtained *n* value is bigger than 0.02.

As regards the feeding alley, it clearly appears that the *n* value equal to 0.02 involves an under-estimation of the velocity value. The value far from the other three corresponds to the barn 3, which was characterized by a different type of grooves compared to the other two, thus influencing the roughness value both for the clean and the dirty conditions.

As regards the clean alley case, all the points are far from the line resulting in higher measured velocity than those calculated with the 0.02 *n* value. The under estimation may be strong for this situation and *n* value equal to 0.02 is too high for that situation.

In table 2, the mean and standard deviation values for the Manning roughness coefficient *n* are reported, considering all the surveyed barns grouped by alley type. With sufficient reliability, it can be stated that for alley concrete flooring with longitudinal grooves 0.02 m wide and deep and 0.1 m spaced, the clean and the feeding alley would have respectively a *n* value equal to 0.012 and 0.016.

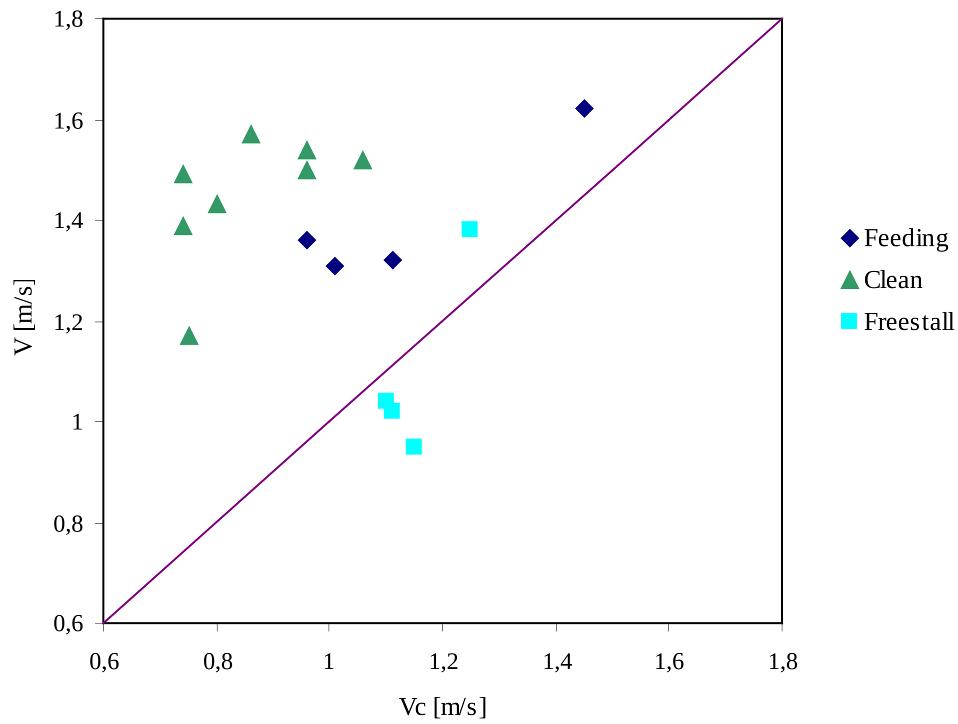

Figure 4. Measured velocities (V) and calculated velocities (Vc) for different alleys.

For the freestall alley, the value of 0.022 would be acceptable only for alleys characterized by similar grooves, type and quantity of litter and managed like barn 1.

Table 2. Manning coefficient (*n*) mean values.

Alley	Feeding	Freestall	Clean
Mean ($m^{-1/3}$ s)	0.016	0.022	0.012
Standard deviation ($m^{-1/3}$ s)	0.0016	0.0026	0.0014

CONCLUSION Flush systems for removing the manure from the feeding and the freestall alleys of three dairy barns, located nearby Reggio Emilia in the North of Italy, were experimentally investigated aiming at the characterization of the alley roughness. Measured flush velocity values were compared with those obtained by the application of the Chezy formula, for uniform flow conditions, using a constant value of the Manning roughness *n*, suggested in literature equal to 0.02 and then the corresponding *n* values calculated. The *n* value 0.02 seems to weakly represent the regular conditions of manure presence on both the feeding and freestall alleys in the experimented dairy barns. The obtained values for clean alleys (barn 1 and 2), representing then the intrinsic roughness depending on the material (concrete) and groove type, is 0.012. For the feeding alley that value undergoes to an increase of 27% (barn 1) which may be considered as due only to the presence of manure. As regards the freestall alley, the increase may be influenced by type and quantity of litter on the floor, so the obtained value is more dependent on the management of the barn itself. An increase of 47% may be considered applicable for other freestall barns having similar management conditions as those resulted in barn 1.

The obtained *n* values are always lower than 0.02 except for those calculated for the freestall alleys. Then, the application of the Chezy formula with a constant *n* value equal to 0.02 may result into an under-estimation of the real flush velocity in the feeding alley and an over-estimation in the freestall ones, influencing the cleaning action of the flush system on the alleys in the analyzed freestall dairy barns. From a design point of view, the use of the constant *n* value of 0.02 may induce variations on the geometric characteristics of the alley to obtain bigger velocity values.

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