Belt separation system under slat in fattening pig housing: Effect of belt type and extraction frequency

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A B S T R A C T

The efficiency of manure separation by a conveyor belt under a partially slatted floor for fattening pigs was determined for two types of belts, a flat belt with an incline of up to 6° transversely and a concave belt with an incline of up to 1° longitudinally. A 31.20% and 23.75% dry matter content of the solid fraction was obtained for the flat and concave belt, respectively. The flat belt was more efficient at 6° than other slope angles. The residence time of the manure on the two belt types influenced the separation efficiency from a live weight of 63.00 kg upwards. The quantity of residue produced with this system was reduced to 25–40% with respect to a pit system under slat. This could mean a remarkable reduction in costs of storage, transport and application of manure.

Keywords:
Environmental
Swine
Manure
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Belt

1. Introduction

Some regions of Spain (Cataluña, Murcia, etc.), are home to a dense concentration of intensive pig fattening facilities (MAPA, 2006). In these areas it is important to separate feces from urine to obtain solid manure that can be composted for used as organic fertilizer and be transported, stored and applied less expensively than slurries. Such composted manure can be applied more precisely and thus contamination of both soil and sub-soil with excessive nitrogen and phosphorus can be avoided (Daudén et al., 2004).

Various types of belts below slatted floors have been proposed for the separation of feces and urine. Ogink et al. (2000) and Craig Baird et al. (2004) proposed a system based on the placement of a convex belt, while Vázquez et al. (2001) and Koger et al. (2003) proposed a flat belt with adjustable longitudinal and transverse angles and a gutter for removing separated liquid fractions. Lachance et al (2005) compared five separation systems, one of which a flat belt with 4° of transverse slope.

The aim of this study was to determine the efficiency of the system proposed and patented by Vázquez et al. (2002). This system uses a flat belt with transverse slope angle and a concave belt with a longitudinal slope angle. The amounts of dry matter solid fraction collected from both belt types according to the frequency with which they were emptied and the separation efficiency of the flat belt at three different angles (2°, 4° and 6°) are presented. The mass balance of the system and the quantity of residue generated is compared to that of a traditional slurry pit below slats.

2. Methods

2.1. Facilities

The experiment was carried out in the Pig Welfare Laboratory of the Universidad Politécnica of Madrid, a facility for fattening pigs with four independent rooms with six equal size pens per room. Each pen has a dimension of 2.40 m by 3.10 m with 40% slatted floor surface (1.20 m wide), one wet/dry feeder placed on the concrete floor, and two drinking troughs placed at 30 cm above the slats.

A manure separation system with a belt under slats was installed in each room. All rooms have a mechanical exhaust ventilation system with the fans located under the space occupied by the animals; as such the ventilating air circulates over the belt separation system (Ovejero et al., 2004). The flow ventilation rates were regulated according to the desired temperature (20–24 °C) during the entire fattening cycle, and since the animal live weights per room were similar (initial coefficient of variation, 6.5%; final coefficient of variation, 4.5%) the flows ventilation rates were similar for all rooms.

Two of the rooms had flat belts (Fig. 1) and the other two concave belts (Fig. 2) that could be adjusted longitudinally from 0° to 2° (0–3.5% slope) (Fig. 3). They were 0.60 m wide and had deflectors that formed a continuous funnel to optimize excrement

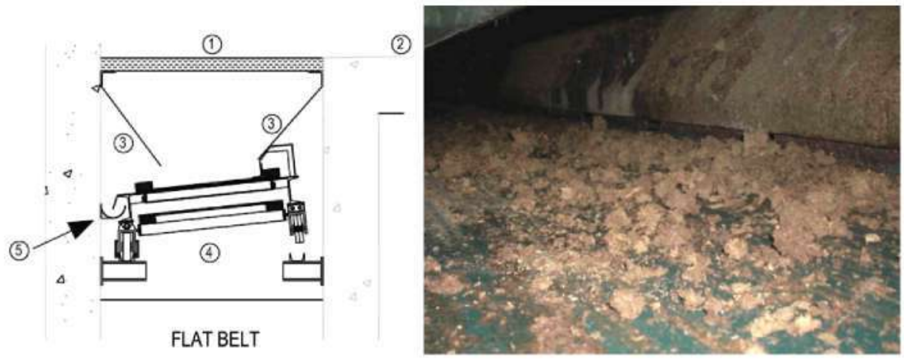

Fig. 1. Transversal section of flat belt (1, slatted floor; 2, concrete floor; 3, deflector; 4, belt; 5, gutter) and droppings clusters on the belt.

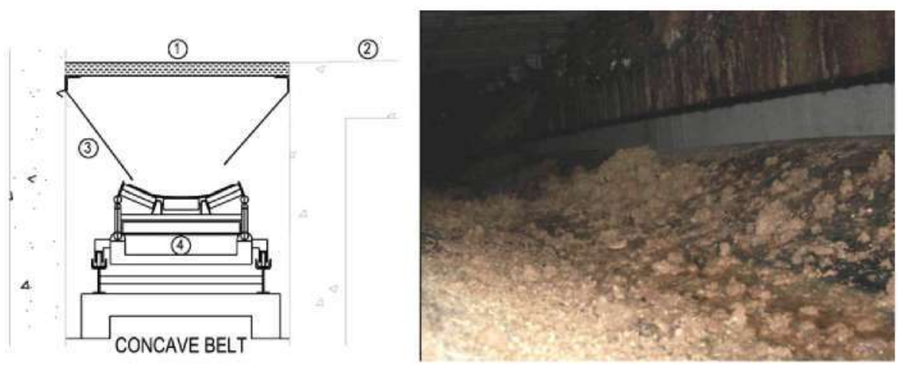

Fig. 2. Transversal section of concave belt (1, slatted floor; 2, concrete floor; 3, deflector; 4, belt) and droppings clusters on the belt.

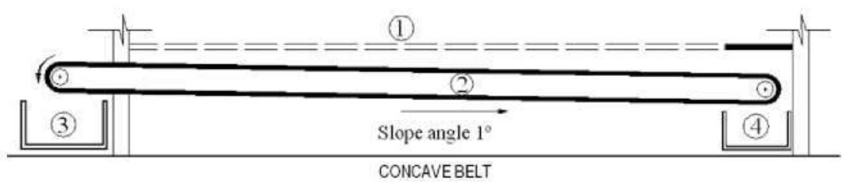

Fig. 3. Longitudinal section of concave belt (1, slatted floor; 2, belt; 3, solid fraction container; 4, liquid fraction container).

collection. The 60-cm-wide flat belts could be adjusted crossways from 0°–8° (0–14.5% slope) and were also equipped with deflectors. In the concave belts, the liquid fraction was collected by a collector situated at one end. The flat belts had a gutter on one side to collect the liquid fraction.

2.2. Animals

One-hundred-sixty-eight pigs [(Pietrain) × (Large White × Landrace) males from the same farm with an initial live weight 28.2 ± 3.9 kg] were fed *ad libitum* and fattened to a final weight of 119.3 ± 13.6 kg (seven pigs per pen, 42 pigs per room). Available surface per pig was 1.05 m^2 during the whole fattening period in compliance with European Union space requirements (Table 1). The distribution of initial weight in each room was similar.

2.3. Experimental procedure

The slope angle of the concave belts remained constant at 1° during the whole fattening period. The slope angle of the flat belts was varied during the fattening period. From the start of the fattening period to a live weight of 63 kg, both belts were at a 2° slope angle and a 4° slope angle until a live weight of 97 kg was reached. The angle was adjusted to 6° and maintained until the end of the fattening period. These angles were chosen according to the literature (Ogink et al., 2000; Craig Baird et al., 2004; Koger et al., 2003 and Lachance et al., 2005) and our previous studies (Alonso et al., 2008) and provided sufficient space between belt and deflectors to not affect flow ventilation rates.

Excretions fell onto the belts through the slats. The belts in rooms 1 and 2 were emptied once a day and in room 4 twice a day during the fattening period. The belt in room 3 was emptied twice a day from the start of fattening period to a live weight of 63 kg, three times a day until a live weight of 97 kg, and four times a day until the end of the fattening period (Table 2). Throughout

Table 1
Calculated chemical composition of the diets.

Chemical composition	Periods		
	I[a]	II[a]	III[a]
Dry matter	88.74	89.03	89.08
Crude protein	17.90	17.30	14.00
Crude fat	5.30	6.20	4.00
Crude fiber	5.00	5.30	4.50
Ash	5.30	6.00	5.30

[a] I Growing period 1: 46.50–63.00 kg live weight, II growing period 2: 63.00–97.00 kg live weight and III finishing period: 97.00–119.00 kg live weight.

the fattening period the pens were dry cleaned daily. After the animals were removed, the building was cleaned with high pressure water application after a dry cleaning (scraping). The total water consumption was considered as a low level contaminant residue with an estimated density of 1.00 kg l^{-1}. Solid and liquid fraction were stored in containers and, respectively, weighed and emptied weekly and daily. Solid fraction samples were taken weekly during the fattening cycle. Once the container was empty and after the belts were in operation, the solid fractions were homogenized and three samples were taken per room. To determine the percentage of dry matter, the samples were oven dried at a temperature of 105 °C until a constant weight was reached.

2.4. Data analysis

The results were subjected to analyses of variance by the ANOVA process of the Statgraphics Centurion. Three variance analyses were carried out to study the dry matter content of the solid fraction and another one to study the production of solid fraction per kilo of live animal mass per day.

The first model analyzed the differences in dry matter content from the flat belts according to the fattening period and numbers of extractions carried out per day. The model fits the Eq. (1).

$$y_{ijk} = \mu + P_i + ED_j + (PxEI)_{ij} + \varepsilon_{ijk} \quad (1)$$

where:

- y: data observed (dry matter content of solid fraction in %);
- μ: general average;
- P_i: effect of period (I, II, III);
- ED_j: effect of extractions day^{-1} (once vs twice);
- $(P \times ED)_{ij}$: interaction period × extractions day^{-1};
- ε_{ijk}: residual error.

The second model was used to analyze the concave belts and studied the effect of "number of extractions per day". For this model the data analysis was carried out independently by periods and fits the Eq. (2):

$$y_{ij} = \mu + ED_i + \varepsilon_{ij} \quad (2)$$

where:

- y: data observed (dry matter content of solid fraction in%);
- μ: general average;
- ED_j: effect of extractions day^{-1} (once vs twice, once vs three times and once vs four times);
- ε_{ij}: residual error.

Table 2
Experimental design in the different rooms.

Room	Belt	Slope	Periods	Slope angle (°)	Extractions (day^{-1})
1	Flat	Transverse	I[a]	2.0	1
			II[a]	4.0	1
			III[a]	6.0	1
2	Concave	Longitudinal	I[a]	1.0	1
			II[a]	1.0	1
			III[a]	1.0	1
3	Concave	Longitudinal	I[a]	1.0	2
			II[a]	1.0	3
			III[a]	1.0	4
4	Flat	Transverse	I[a]	2.0	2
			II[a]	4.0	2
			III[a]	6.0	2

[a] I Growing period 1: 46.50–63.00 kg live weight, II growing period 2: 63.00–97.00 kg live weight and III finishing period: 97.00–119.00 kg live weight.

The third model studied the effect of "belt type" on the dry matter content with one extraction per day. The model fits the Eq. (3).

$$y_{ij} = \mu + BT_i + \varepsilon_{ij} \quad (3)$$

where:

- y: data observed (dry matter content of solid fraction in %).
- μ: general average.
- BT_i: effect of belt type (flat vs concave).
- ε_{ij}: residual error.

A final model was used to study the effect of the "slope angle" on the solid fraction production per kilo of live animal mass per day with the flat belt. The model fits the Eq. (4).

$$y_{ij} = \mu + SA_i + \varepsilon_{ij} \quad (4)$$

where:

- y: data recorded (solid fraction production per kilo of live animal mass per day);
- μ: general average;
- SA_i: effect of slope angle (2°, 4°, 6°);
- ε_{ij}: residual error.

In all these models the averages were separated using the Scheffe test ($P < 0.05$).

3. Results and discussion

Table 3 shows the results of the variance analysis of the dry matter content of the solid fraction from the flat belts. No significant differences in dry matter content of the solid fractions was observed with transverse slopes of 2 and 4° but the differences were significant at a transverse slope of 6°. These results demonstrated that the flat belts separated feces and urine more efficiently with two extractions per day rather than with one (31.54% vs

Table 3
Slope angle-period and extraction per day effects on the dry matter content of the solid fraction with flat belt.

Variation factor	N	%DM
Slope angle-period		
2° Slope angle (I)	24	31.23[a]
4° Slope angle (II)	30	31.65[a]
6° Slope angle (III)	18	34.59[b]
SEM		0.502
Extractions (day^{-1})		
1	36	31.45[a]
2	36	33.54[b]
SEM		0.421
Interactions		
(I × 1)	12	31.42[ab]
(I × 2)	12	31.04[ab]
(II × 1)	15	29.77[a]
(II × 2)	15	33.53[b]
(III × 1)	9	33.16[b]
(III × 2)	9	36.04[c]
SEM		0.609
P_{period}		0.0001
$P_{extracions}$		0.0008
$P_{period \times extractions}$		0.0102

I Growing period 1: 46.50–63.00 kg live weight. II Growing period 2: 63.00–97.00 kg live weight. III Finishing period: 97.00–119.00 kg live weight. N = observations number. %DM = dry matter content of the solid fraction. SEM = standard error of mean. [a,b]Means with different superscripts are significantly different ($P < 0.05$).

33.54%).The number of extractions was not significant in growth period 1; however, it was significant in growth period 2 (29.77% vs 33.53%) and the finishing period (33.16% vs 36.04%). The dry matter content of the solid fraction of two extractions in the growth phase and one extraction in the finishing phase were similar. This result could indicate that, as the quantity of droppings increased, the number of extractions significantly affected the %DM. Also separation efficiency improved with the greater slope angle of 6°. The surface-volume ratio of droppings on the belt increased with two extractions per day in the finishing period. Therefore, smaller clusters of solids were on the belt and the possibility of water evaporation from the droppings increased (Figs. 1 and 2).With flat belts at a transverse slope of 4° and animal weights between 25 and 55 kg, Koger et al. (2003) obtained solid fractions with 48% dry matter. This result was better than that obtained with flat belts in the current study during the 1st growth period with a 2° slope for one and two extractions. These differences could be due to the lower slope angle used in this experiment.

Lachance et al. (2005) working with flat belts at a 4° transverse angle and fattening pigs up to 80 kg live weight obtained solid fractions with a dry matter content similar dry matter content to that obtained in the growth period 1, despite the lower slope angle of the belts. However, the results obtained in this study in the finishing period with two extractions per day were higher than those of Lachance et al. (2005). This outcome could have been due to the lower frequency (every two days) of extraction from the belt. Craig Baird et al. (2004) used a convex belt with a transverse slope from the centre to the sides.

The dry matter contents of the solid fractions were similar to those obtained with our flat belts at a slope angle of 2°. For the other two slope angles (4° and 6°) and two extractions per day, the %DM of manure was 15% greater in relative terms.

The effect of the slope angle on the production of solid fraction per kg of live weight and day for the flat belts for the entire fattening cycle is shown in Table 4. There are significant differences between the three angles studied. Separation was greater as the slope angle increased given that the production of solid fraction per kg of live weight and day was lower. Other studies with flat belts (Koger et al., 2003; Lachance et al., 2005) only provided results for a 4° slope angle, and the results shown in Table 4 may help to improve the adjustment of other similar systems.

Table 5 shows the effect of the number of extractions on the dry matter content of the solid fraction on the concave belts. This table includes the results of three independent analyses, one per period.

For the concave belts the number of extractions per day had a significant effect on the percentage of dry matter of solid fraction produced, both for growth period 2 (22.49% – 1 extraction vs 26.79% – 3 extractions), and the finishing period (23.42% – 1 extraction vs 26.02% – 4 extractions). These differences are more acute in relative terms in growth phase 2 than in the finishing phase (119.60 vs 111.10). Once the pigs reach a live weight of 63.00 kg and the quantity of droppings increased, it became inefficient to carry out four extractions per day. When the differences in %DM between growth phases 1 and 2 and between growth phase 2 and the finishing phase are compared, the values are 14.97% and 11.95%, respectively. This result confirms that the quantity of droppings affected the efficiency of separation. However, Aarnink and Ogink (2007), using a similar belt to that of Craig Baird et al. (2004), obtained solid fractions with a dry matter content significantly lower than that of the flat belts used in the present experiment. The %DM was similar to that obtained with the concave belts with one extraction per day. The effect on the dry matter content of solid fraction in the different belt types with one extraction per day throughout the fattening period is shown in Table 6.

The belt type had a significant effect on the dry matter content of solid fraction for the fattening cycle (31.20% vs 23.75%). These results support previous observations (Alonso et al., 2008) that demonstrated that flat belts were more efficient than concave belts for the separation of feces and urine. This difference in efficiency could be due the different paths followed by the liquid fractions on each type of belt. On the flat belts the route is short and across the belt, on the concave belts it is long and along the belt. Also, on the concave belts, the accumulated solid fraction impedes the flow of the liquid fraction to the collector at the end of the belt, so that the solid fraction retains part of the urine.

The production of solid and separated liquid fractions throughout the experiment for each of the rooms, and data on water use during cleaning are shown in Table 7. For the concave belts, the ratios of solid fraction production per kilo of live weight and day were greater than those for the flat belts. This result agrees with the higher ratios of urine production separated per kilo of live weight and day obtained with the flat belts; however, the production of solid fraction dry matter and liquid fraction separated per kg of live weight and day are not similar for the two belt types. This effect could be because the distance covered by urine in the flat belt is shorter and the slope angle is greater. The liquid fraction of the flat belt probably carried away more solids than the liquid fraction of the concave belt. The average weekly results for dry

Table 5
Effect of number of extractions on the dry matter content of the solid fraction with concave belt.

Periods	Variation factor			
	Extractions (day^{-1})	N	%DM	SEM
I[A]	1	12	26.45	0.648
	2	12	26.13	
II[A]	1	15	22.49[a]	0.379
	3	15	26.79[b]	
III[A]	1	12	23.42[a]	0.355
	4	12	26.02[b]	

N = observations number. %DM = dry matter content of the solid fraction.
SEM = standard error of mean.
[a,b]Means with different superscripts are significantly different ($P < 0.05$).
[A] I Growing period 1: 46.50–63.00 kg live weight, II growing period 2: 63.00–97.00 kg live weight and III finishing period: 97.00–119.00 kg live weight.

Table 4
Slope angle effect on the solid fraction production per kg live animal mass per day for the flat belts.

Variation factors		Period: all the fattening phase		
Belt type	Slope angle (°)	N	kg SF	SEM
FLAT	2	12	0.014495[a]	0.000578
	4	10	0.012818[b]	
	6	8	0.010675[c]	

N = observations number. SEM = standard error of mean. kg SF = solid fraction production per kg live animal mass per day.
[a,b]Means with different superscripts are significantly different ($P < 0.05$).

Table 6
Belt type effect on the dry matter content of solid fraction with once extraction per day.

Variation factors		Period		
Belt type	Extractions (day^{-1})	All the fattening cycle		
		N	%DM	SEM
FLAT	1	51	31.20[a]	0.323
CONCAVE	1	51	23.75[b]	

N = observations number. SEM = standard error of mean.
%DM = dry matter content of the solid fraction.
[a,b]Means with different superscripts are significantly different ($P < 0.05$).

Table 7
Solid fraction and liquid fraction separated production and cleaning water.

	Room 1 flat belt	Room 2 concave belt	Room 3 concave belt	Room4 flat belt
Solid fraction production:				
Kilogram solid fraction (pig^{-1} day^{-1})	0.966	1.233	1.383	0.965
Kilogram solid fraction kg live animal ($mass^{-1}$ day^{-1})	0.012628	0.017593	0.017849	0.012777
Kilogram DM solid fraction (pig^{-1} day^{-1})	0.33597	0.33247	0.39815	0.35036
Kilogram DM solid fraction live animal ($mass^{-1}$ day^{-1})	0.004368	0.004726	0.005423	0.004562
Liquid fraction separated production[a]:				
l liquid fraction (pig^{-1} day^{-1})	1.558	1.180	1.063	1.370
l liquid fraction kg live animal ($mass^{-1}$ day^{-1})	0.019897	0.014120	0.014488	0.017861
Kilogram DM liquid fraction (pig^{-1} day^{-1})	0.04198	0.04107	0.03151	0.04244
Kilogram DM liquid fraction kg live animal ($mass^{-1}$ day^{-1})	0.000507	0.00050	0.000438	0.000558
Cleaning water:				
l cleaning water (pig^{-1} day^{-1})[a]	1.290	1.203	1.588	1.248
l cleaning water kg (LW^{-1} day^{-1})	0.017492	0.017922	0.021632	0.017434

[a] Estimated urine density = 1.00 kg l^{-1}.

matter of solid fraction obtained from the beginning of the fattening period to a live weight of 55.00 kg for the flat belts were 0.235 kg DM solid fraction pig^{-1} day^{-1} in room 1 and 0.217 kg DM solid fraction pig^{-1} day^{-1} in room 4. These values are similar to those reported by Koger et al. (2003). Baird et al. (2004) obtained an average solid fraction production of 0.844 kg solid fraction pig^{-1} day^{-1} y for liquid fraction of 3.06 l pig^{-1} day^{-1}, with similar live weights at the start and finish at the start and finish of fattening to those of this study. The solid fraction results were similar to those shown in Table 6. Nevertheless, the liquid fraction production obtained by these authors was 50% higher than that of the flat belts.

The solid fraction for the concave belts was similar to that obtained by Aarnink and Ogink (2007) (1.31 kg solid fraction pig^{-1} day^{-1}); however, 80% less urine was separated. This outcome could be explained by the possible effect of the ventilation system which contributed to partial evaporation of the liquid fraction: the exhaust air temperature was lower than the room air temperature (not published data).

When taking into account the cleaning water, the average residue production was 3.76 kg pig^{-1} day^{-1}, which is 26.25% less than the average production values for slurry in fattening pigs BREF ILF (2004). Navarotto (1982) concluded that the production of slurry for every 450 kg of live weight is 29.5 kg day^{-1} and 2.7 kg day^{-1} of dry matter. These figures are 25% higher than those obtained in the present experiment. ASAE (2003) published an average value of fresh manure production per 1000 kg live animal mass per day of 84 kg. The average figure obtained in this study was 50.25 kg. This means a 40% reduction in residue. The decrease in production of fresh manure could be due to the systems of belt separation and exhaust ventilation in the building. Therefore, the moving under floor system, be it with one type of belt or another, is not only efficient in the separation of feces and urine, but it also notably reduces the quantity of residue generated.

4. Conclusion

The efficiency of manure separation depended on the type of belt, the slope angle and the frequency with which the belts are emptied. The flat belt was more efficient than the concave belt and its efficiency increased with the height of the slope angle. The length of time the manure was left on the belt had an effect on the efficiency of separation from a live weight of 63.00 kg upwards. The liquid fraction was reduced with respect to other conveyor belt systems under slat and the reduction in the quantity of residue was remarkable.

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