Using Zinc Oxide Nanoparticles to Control Emissions - Pig Performance, Manure Properties, and Production Cost

Predicala, B. and A. Alvarado

B.ernardo Predicala

Alvin Alvarado

SUMMARY

The impact of pig performance, manure nutrient characteristics and cost of production was evaluated with several mixing and filtration methods using zinc oxide (ZnO) nanoparticles to control hydrogen sulphide (H2S), ammonia (NH3) and odour emissions from commercial swine facilities. Conditions represented conventional swine production. Results indicate the application of mixing and filtration treatments had no significant effect on pig performance and manure nutrient characteristics. The cost analysis revealed that employing air filtration in a 100-head grow-finish room amounted to around 3.8% of the average total cost of production, while the mixing method was found to be cost prohibitive at about 40.2% of the average total production cost.

INTRODUCTION

Our previous work demonstrated that mixing and filtration methods using zinc oxide (ZnO) nanoparticles were effective in controlling hydrogen sulphide (H2S), ammonia (NH3) and odour emissions from swine facilities (PSC Annual Report 2010, pp. 16-18). In order to assess the feasibility of its application in commercial swine facilities, the impact of these two treatments approach on pig performance and manure nutrient characteristics as well as on the cost of production was carried out.

METHODOLOGY

The effectiveness of mixing and filtration methods using ZnO nanoparticles was evaluated in room-scale tests under commercial barn conditions. The experiment was conducted in two environmental chambers at PSC with each chamber housing 8 pigs at an average weight of 29 kg at the start of the trial. One chamber was configured as a normal swine room (Control) and the other one as a treatment room. Aside from monitoring odour and target gases (with results presented in PSC Annual Report 2010 pp. 16-18), the effect of the treatment on pig performance such as average daily gain and feed intake, manure production rate, water usage, and manure characteristics were also assessed.

Cost analysis of the application of nanoparticles in a typical swine operation was undertaken after the room-scale experiments. The analysis was carried out with the assumption that the treatment was applied at the grow-finish stage of production. Thus, all the expenses incurred for one complete growth cycle in a grow-finish room including the purchase of material (nanoparticles) and equipment, and labour and operating costs were estimated. The total cost associated with these gas and odour control techniques was then compared to the overall cost of production.

"Mixing Zinc Oxide to Reduce Hydrogen Sulphide Amounted to 40.2% of the Average Total Cost of Production while Filtering Zinc Oxide Amounted to Only 3.8% of the Total"

RESULTS AND DISCUSSION

Impact on pig performance and manure nutrient properties

During the entire 30-day trial period for both mixing and filtration tests, the average daily water usage and manure production rate of pigs in the control chamber were not significantly different (P>0.05) from the treatment chamber as shown in Table 1. Furthermore, the average daily feed intake (ADFI) and average daily gain (ADG) of the pigs in the treated chamber were not significantly different (P>0.05) than those in the control chamber. Thus, these results indicated that the application of mixing and air filtration methods

Table 1. Daily water usage, manure production rate, average daily gain, and average daily feed intake of pigs in the control and treated chambers during room-scale tests.

Hog Performance Parameters	Mixing[1]		Air Filtration[1]	
	Treated	Control	Treated	Control
Avg daily water use (L day^{-1}-pig^{-1})	2.2±0.8	2.4±0.1	2.4±0.7	2.1±0.4
Avg daily manure production (L day^{-1}-pig^{-1})	2.28±0.24	2.33±0.15	2.09±0.05	2.07±0.12
Avg daily feed intake, ADFI (kg day^{-1}-pig^{-1})	1.70±0.19	1.74±0.14	1.70±0.13	1.68±0.20
Avg daily gain, ADG (kg day^{-1}-pig^{-1})	0.79±0.03	0.82±0.05	0.81±0.06	0.80±0.07

[1]Mean (±SD) of 3 replicates, representing a total of 48 pigs for each treatment.

with ZnO nanoparticles had no significant adverse or beneficial effect on pig performance.

Table 2 shows the results of physical and chemical analyses conducted on the manure samples collected from each chamber. As expected, the installation of a filter system with ZnO nanoparticles in the treated chamber had no measurable impact on the characteristics of the manure in the tub. On the other hand, the addition of ZnO nanoparticles into the manure slurry (mixing) had caused a significant increase in the amount of zinc by 1,654 mg kg-1 ($P<0.05$); all other physico-chemical characteristics were not significantly different from the control ($P>0.05$). In spite of the increase, the zinc content of the treated slurry was below the toxicity limit (2,800 mg Zn kg-1) set by the U.S. Environmental Protection Agency (USEPA, 1994) for biosolid applications. With this preliminary assessment, the treated manure is not expected to result to adverse effects when subsequently applied to crop lands but this would need to be verified by conducting a full evaluation of the land application of the treated manure.

Assessment of economic feasibility

A cost analysis was conducted based on the

Table 2. Characteristics of manure samples collected from each chamber during room-scale tests.

Parameters	Mixing[1]		Air Filtration[2]	
	Treated	Control	Treated	Control
Moisture (%)	86.40±3.58	89.00±4.56	84.95±5.02	87.15±3.46
Total Solids (%)	13.60±3.58	10.99±4.57	15.05±5.02	12.85±3.46
Conductivity, EC (uS cm^{-1})	17020±9960	24330±1460	18350±11240	23200±4670
pH (pH)	7.27±0.21	7.09±0.04	6.86±0.21	7.01±0.01
Total Kjeldahl Nitrogen (mg kg^{-1})	9400±2200	8400±1700	12800±3300	12000±2600
Ammonia as N (mg kg^{-1})	5700±1400	5500±1100	7400±1300	7000±1100
Calcium, Ca (mg kg^{-1})	2400±1200	1700±700	3300±400	2700±200
Copper, Cu (mg kg^{-1})	50±28	38±15	74±13	65±14
Iron, Fe (mg kg^{-1})	294±131	223±127	346±25	284±4
Magnesium, Mg (mg kg^{-1})	1600±500	1200±400	1700±400	1500±300
Manganese, Mn (mg kg^{-1})	90±32	69±24	115±22	97±13
Phosphorus, P (mg kg^{-1})	3000±1200	2300±900	3600±800	3000±300
Potassium, K (mg kg^{-1})	4800±1100	4300±900	5100±200	4700±300
Sodium, Na (mg kg^{-1})	1400±300	1300±200	1300±100	1300±200
Sulfur, S (mg kg^{-1})	1600±400	1300±100	1500±400	1300±300
Zinc, Zn (mg kg^{-1})	**1848**±708	**194**±82	327±35	307±30

[1]Mean (±SD) of 3 samples; one sample per trial

[2]Mean (±SD) of 2 samples collected on Days 0 and 15 of the third trial

Manure samples collected from the manure tub of each chamber during room-scale tests. These samples were sent to a commercial laboratory for analysis.

assumption that the treatment was applied to a 100-head grow-finish room (20 – 110 kg) for one complete growth cycle of about 16 weeks. Using the application rate used in the room-scale experiments (PSC Annual Report 2010, pp. 16-18), the total amount of ZnO nanoparticles required in the room for a 16-week growth cycle was 68.67 kg for mixing method and 4.1 kg for air filtration test. As summarized in Table 3, the total cost associated with the application of mixing method with ZnO nanoparticles in a grow-finish stage of operation was around $67.2 (CAD) per finished pig while the total cost of operating a filtration system with ZnO nanoparticles was about CAD$6.3 per finished pig.

Table 3. Parameters used in the calculation of the total cost of applying ZnO nanoparticles in a grow-finish swine production barn.

Operational information and associated cost	Deployment Technique	
	Mixing	Filtration
Application rate	3 g L^{-1}	1.8 g in^{-2}
Frequency of application per cycle	5	4
Total amount of ZnO applied per room, kg	68.8	4.1
ZnO unit price per kg[1]	87.7	87.7
ZnO cost per pig, $	**66.2**	**4**
Number of hours to apply treatment per cycle, hr	7.5	4
Labour cost per hour, $/hr	13	13
Labour cost per pig, $	**1**	**0.5**
Total costs for required equipment, $	370	5930[2]
Estimated life span, yr	5	5
Total cost of required material per pig, $	-	1.66
Capital cost per pig, $	**0.01**	**1.77**
Estimated energy consumption per year, kWh	-	1871
Energy cost per kWh[3], $	-	0.1
Operating cost per pig, $	**-**	**0.2**
Total cost per pig	67.2	6.3

[1]based on the current price of NanoActive ZnO (www.nanoscalecorp.com)
[2]includes estimated cost of installation ($4000)
[3]SaskPower rate

The result of the cost analysis revealed that the total cost associated with mixing and filtration methods with ZnO nanoparticles was about 40.2 and 3.8%, respectively, of the estimated total cost of $167.15 (CAD) for the grow-finish stage of production (MAFRI, 2010). The total cost was relatively high especially for mixing because the assumptions used in the cost estimates were based on the findings from the room-scale experiments which were conducted with measures to intentionally produce extreme high levels of the target gases, i.e., if the treatment was found to be effective under these extreme conditions, then it would work as well under typical barn conditions with lower levels of the target gases expected.

Some considerations may be applied in order to lower the cost without substantially affecting its effectiveness in reducing the target gases. In mixing method, the total cost could be lowered by reducing the ZnO cost per pig which constituted about 98% of the total cost ($66.2 of $67.2). ZnO cost is dependent on the application rate, and frequency and time of application prior to each pit-pulling session. Thus, by lowering the application rate, for instance, to 1.5 g L-1 which also showed considerable reduction on H2S and NH3 levels, and applying the treatment 3 times per cycle, the total cost would be reduced from CAD$67.2 to $20.4. The same applies to filtration method; if the frequency of filter installation is reduced to 2 times (i.e. on the 1st and 10th week of the cycle) instead of 4 times, the total cost can be reduced from CAD$6.3 to $4.1. It should be noted as well that that the ZnO nanoparticles used in this study were experimental materials purchased at an extremely high unit price; it has been documented recently that when wider applications were developed for certain nanoparticles, this allowed manufacturers to produce them in bulk quantities, thus the unit price for these nanoparticles were drastically reduced. Hence, it is anticipated that the total cost for this treatment could still go down significantly as new uses for nanoparticles are discovered.

CONCLUSIONS

Room-scale experiments revealed that the pig performance and manure nutrient characteristics were not adversely affected by either mixing or filtration using ZnO nanoparticles. Cost analysis for a typical 300-sow operation (7,500 finished pigs per year) using current cost estimates and application parameters indicated that the implementation of filtration treatment with ZnO nanoparticles would amount to about 3.8% of the total production cost, which was economically more feasible than incorporating ZnO into the manure slurry.

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