

ASSESSMENT OF DUST CHARACTERISTICS BY CYCLONE

DEDUSTER IN PIG HOUSE

Running Head : **DUST CHARACTERISTICS IN PIG HOUSE**

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ABSTRACT : This study compared the dust, bioaerosol and gas characteristics dynamics inside a pig barn with or without cyclone deduster (CD). The detection of inert minerals and heavy metal contamination was also done for both feed and dust. During a 24-hour monitoring at 30-minute interval, the peak level of dust concentration in the control was recorded at 20:00 with $6,763 \mu\text{g}/\text{m}^3$ for Total Suspended Particulate (TSP), $2,966 \mu\text{g}/\text{m}^3$ for Particulate Matter 10 (PM diameter $<10 \mu\text{m}$) at 19:00 and $2851 \mu\text{g}/\text{m}^3$ for PM 2.5 at 9:30. With the aid of CD, the average removal efficiency for the 1st and 5th week monitoring for TSP, PM10 and PM2.5 was 36.1 %, 43.6 % and 23.9%, respectively. The volumetric distribution at 4.65 % of TSP ($> 23 \mu\text{m}$) was detected in the test room and was lower than the TSP ($>37.29 \mu\text{m}$) found in the control room at 5.1 %. Moreover, the CD was effective in reducing the bacterial count, NH_3 and CO_2 levels for 3 weeks. An analysis on the heavy metal contamination of the dust showed that Pb had the highest concentration at 5,695 ppm followed by Cr, AS Cd and Hg at 3,455, 1.3, 0.33 and 0.015 ppm, respectively. The above findings proved that the CD can mitigate the harmful effects of dust and bioaerosols to animals and livestock farmers.

Keywords: Cyclone deduster, dust characteristics, heavy metals, dust density

INTRODUCTION

- Livestock farming emissions such as dust, odorous gases, microorganisms and heavy metals are detrimental to both humans and animals (Van Wicklen and Yoder, 1988). As a result, modern pig-housing facilities should be based on proper waste-cleaning strategies particularly, in confined spaces (Lavoie et al., 1995). Presently, distribution characteristics of these dust on a periodic monitoring basis inside livestock house is scarce. There are various ways to improve animal performance by modifying the environment inside livestock confinement housing. One of these strategies is the wet pad forced ventilation system (WPFV) as confirmed recently by Chiang and Hsia (2005). However, this system is more focused on providing cooler environment inside the house rather than assuring maximum collection of dust. Investigations then on the combined use of WPFV and cyclone dedusters in poultry and livestock buildings would be valuable for both animal husbandman and environmentalist.. Dust in livestock buildings is almost entirely organic and originates from feed, skin, feathers, bedding and dried faeces (Harry, 1978). Several airborne contaminants in livestock houses are known to be detrimental to humans and animal productivity. While air quality is commonly related to ambient temperature and relative humidity, it is also a function of the concentration of gases and airborne particulate matter. Aerosol particles, with a diameter between 0.5 to 5 μm , are known as respirable aerosol particles. Respirable dust can

reach the lower respiratory system, which can be harmful as they transport odor, pathogens, diseases, and irritate the respiratory system (Van Wicklen and Yoder, 1988). High concentration of respirable dust in pig house may also create environmental and health problems for both the animal (De Boer and Morrison, 1988) and for the worker (Donham et al. 1989). In this study, dust characteristics and collection efficiency of the cyclone deduster were periodically monitored in a building for 3 - wk old weanlings during spring time. While there is still a limited knowledge among raisers on the hazards brought about by dust concentrations inside livestock barns, the valuable data generated in this study will serve as a basis for modifying housing structure, feeding management and ventilating systems without compromising animal performance. Finally, this study compared the dust, bioaerosol and gas characteristics dynamics inside a pig barn with or without cyclone deduster (CD).”

MATERIALS AND METHODS

Dust particle analysis

The collected dust particles were analyzed for chemical composition following the procedures prescribed by AOAC 1990. The feed dust however, was not analyzed for heavy

metals. The heavy metals investigated were classified as inert minerals such as Ca, P, K, Na, Mg, Fe, Mn, Zn, Cu, F and toxic metalloids such as Pb, Cd, As and Hg. The total suspended particulate (TSP), particulate matter < 10 μm (PM10), and particulate matter (PM2.5) < 2.5 μm were measured using Fh62 -2 dust detector (ESM Eberline Co. Germany) at 30-minute interval. Other sizes of dust particles were monitored using Master Sizer Microplus Ver 2.18 (Malvern Instruments Co. UK).

Housing and Management

The experiment was conducted in a weaner house of a private farm in central Korea. Six enclosed pig rooms were used. Three rooms were installed with CD mounted on the center at a height of 2.0 m while the remaining rooms were used as the control in the experiment. All rooms were ventilated under negative pressure by a variable speed fan installed under slat for pit ventilation. Each room (L x W x H = 8.4m x 9.8m x 2.4m) with a concrete slatted floor, were further subdivided into 8 pens with 40 heads of 18 day-old weaners (Landrace x Yorkshire X Duroc) weighing 5.4 kg. The total weaners in the entire swine confinement house was 320. All weaners were fed a 22.1% crude protein, corn-soybean meal based diet according to NRC, 1998 nutrient requirement recommendation and dry fed by automatic feeder with bite-type nipple drinker.

Dust collector installation

The dust collector (Fig 1) used was a cyclone-type (Dyne Engineering, Daejon, Korea) classification powered by a 205 watt/hr capacity with a flow rate of 1, 200 m³/hr. The CD used in this study has the unique feature of being equipped with a booster sucking block found before the motor driven exhaust fan that allowed the effective release of purified air. Prior to the expulsion of the filtered air, it was recirculated through a cyclonic flow. The diameter of the CD is 290 mm and a length of 1,000 mm. A motor driven sirocco fan that is capable of recirculating polluted air in a cyclonic flow is located behind the inlet air passage. The dust collection box found at the bottom of the air outlet passage has a volume of 1.9 liter and was utilized to quantify the weekly dust collection for 5 wks. In Fig 2, scanning electron micrographs at 370 x and 740 x magnifications of dust particles were collected from cyclone deduster in a swine growing building for subsequent chemical analysis.

Measurement of Bacterial Colony Forming Unit Particle

To determine the number of suspended bacterial particles in the air, a nutrient agar concoction (Biolife, Italy) was prepared. The powder was mixed with a distilled water and continuous stirring was done to prevent sedimentation at the bottom. After cooling, it was then dispense to the petri disc and placed for one minute at 3 different sites in the pig house. After incubating the agar at 37 °C for 24 h, manual reading was done for bacterial colony forming unit particle.

Measurement of NH₃ and CO₂

The NH₃ and CO₂ levels were measured by the user-friendly and quick detector or reaction tube method. The detector tube for NH₃ was No. 3 L (0.5 to 78 ppm, GASTEC, Model GV-100, Japan while that of CO₂ was No. 2LL (300 to 5000 ppm). To trap the gases two different calibrated detector tubes containing inert support granules were mounted on the tip of the suction gun. Collection of the gases was done in 3 different sites of the house at pig nose height level. Around 100 ml of gas was collected after pulling the suction gun's plunger. Finally, direct reading on the colorimetric detector tubes of NH₃ level was done according to color intensity change from pink to yellow while that of CO₂ was white to purple.

RESULTS

Effect of CD on dust distribution

Hourly variations in dust density in the weaner building is shown in Fig. 3. These measurements revealed that dust concentration varied greatly in time. There were two peaks of high dust concentration, during the morning and afternoon.

Effect of CD on dust particle size distribution

The dust distribution size related to size is shown in Fig.4. The particle size of dust ranged from 0.745 to 1.08 μm . . Particle sizes ranging from 0.745 to 1.08 μm which are alarmingly

considered as respirable dust were effectively reduced to 53.5 % as compared to the control which is 55.27 %.

Influence of CD on NH₃, CO₂ and bacterial count

In Table 4, during a 3-wk monitoring period, the level of NH₃ at wk 3 was reduced from 6.3 ppm, to 5.0 ppm, when the CD was installed in the weaner house. Although the level of NH₃ for both the test and control rooms are below the limit, the measurement of NH₃ was done in younger pigs hence a higher concentration can be expected in older animals. In our result, the microbial count was much lower for both the test and control houses. The test house, however, has a substantially lower bacterial count throughout the 3-week monitoring period (1.5 to 2.2 x 10³ CFU/m³), indicating the effectiveness also of the CD in flushing out these microbes.

Comparative contaminants of dust and feed

As shown in Table 5, the crude protein of feed was 19.8%, while that of dust was 25.9-32.7%. An analysis on the heavy metal contamination of the two dust particles showed that Pb had the highest concentration at 5,695 ppm followed by Cr, AS Cd and Hg at 3,455, 1.3, 0.33 and 0.015 ppm, respectively.

DISCUSSION

Effect of CD on dust distribution

These measurements revealed that dust concentration varied greatly in time. Dust concentration tends to be higher during the daytime because of the pig's increasing activity towards this period. The peak level of TSP concentration in control pig room was $5,322 \mu\text{g}/\text{m}^3$ (09:00~10:00) and $6,763 \mu\text{g}/\text{m}^3$ (19:00 to 20:00). However, the CD decreased it to $3,299 \mu\text{g}/\text{m}^3$ (08:00) and $3,473 \mu\text{g}/\text{m}^3$ (18:30). During the 1st wk, the average dust concentration classified as TSP, PM 10, and PM 2.5 in the control pig room were $3,614 \mu\text{g}/\text{m}^3$, $1,584 \mu\text{g}/\text{m}^3$, $486 \mu\text{g}/\text{m}^3$, respectively. With the CD, this was substantially reduced to $2,230 \mu\text{g}/\text{m}^3$, $1,069 \mu\text{g}/\text{m}^3$, and $380 \mu\text{g}/\text{m}^3$, respectively. The suction reduction rate which ranged from 21 to 38 % was considered exceptional. These measured dust densities are very important because Donham et al. (1989) claimed the presence of respiratory ailments among pig workers exposed to a dust density of $3,800 \mu\text{g}/\text{m}^3$. Conversely, in broilers, as observed in or previous study, dust concentration was evident throughout the day because of their constant feeding and movement. The suction reduction rate of the CD was very relevant as the resulting dust density for the respirable dust (PM10) at $1,069 \mu\text{g}/\text{m}^3$ in the building was lower than the exposure limit to animals (24 h, continuous) which is $1700 \mu\text{g}/\text{m}^3$ as specified by CIGR, 1992. During winter, the daily average of the total dust concentration in the buildings of growing-finishing house varied between 1300 to $6300 \mu\text{g}/\text{m}^3$ (Gustafsson, 1997).

He also investigated the mass balance of dust in houses for pigs and chickens and proved that the generation of dust was related to the number and weight of the animals. Based on the above values for dust density, it clearly shows that the lesser dust concentration was obtained because younger pigs were used. Moreover, the restricted and dry feeding system adapted by the pigs was a contributory factor in the reduced level and this corroborated with the findings of Robertson (1999). The average dust density of building after dedusting was $1226.33 \mu\text{g}/\text{m}^3$ and this did not have a large difference to that obtained by Takai et al. (1986), which was $1,800 \mu\text{g}/\text{m}^3$ in dry fed pigs. On the other hand, Wathes et al. (2002) found out, that pigs exposed to dust concentration of $5100 \mu\text{g}/\text{m}^3$ to $9900 \mu\text{g}/\text{m}^3$ had depressed growth rate. Similarly, Donham (1991) stated an increase in mortality and reduced gain among piglets exposed to dust concentration higher than $5200 \mu\text{g}/\text{m}^3$ while in fatteners, levels above $3,700 \mu\text{g}/\text{m}^3$ resulted to elevated mortality and prevalence of pneumonia. However, air quality because of dust levels can deteriorate with bigger and more animals inside a building. (Cargill et al., 1996, Gustafsson, 1999). Therefore, the dust density data in the present study for weaner pigs can be a basis for formulating simulated models on the relationship of dust characteristics to animal performance at varying stages of growth. With this development, measures to reduce the contamination of air in swine houses is urgent to livestock raisers.

Effect of CD on dust particle size distribution

The data in Fig. 4 demonstrated the effectiveness of CD in reducing the dust distribution relative to size in the weaner house. Apparently, the result in this study varied greatly when it was compared to the investigation of Van Wicklen and Yoder (1988) who reported 64.5% for 0.3 to 0.5 μm while Nicks et al (1993) claimed that 82% of the aerial particles were in the size range 0.3 to 0.5 μm . As dust particle sizes increase, suction ability of the deduster also became more effective. This was demonstrated in the present study when the aerial dust particle size ranging from 1.19 μm to 2.5 μm had a distribution rate of only 23.14 % as compared to 47.92 % to the control. Likewise, there was an abrupt drop in the dust distribution rate beyond 1.19 μm for both the control and test room with the latter being more pronounced. There was no dust recovery anymore in the test room for particle size > 44.92 μm . whilst in the control room, dust particles up to 49.31 μm were still detected. This indirectly justified the removal efficiency of the CD for very minute particle size of dust. Apparently, the accessory block located just before the exhaust fan of the deduster contributed to this extra suction effort. Moreover, Nicks et al. (1993) reported a < 1% distribution of dust particle > 5 μm , the present study recorded almost the same value at < 1 % (Fig. 5), which could indicate the reliability of the cyclone model deduster used in this study. Therefore, the above dust particle dynamics of this study confirmed that the cyclone dust collector was able to trap most of the bigger dust particles in the pig room.

Dusts in livestock buildings are complex substances, not only made up of several constituents, but also particles of a wide size range, typically from less than 1 μm to visible particles up to 100 μm . The particles are often irregular in shape, many of them may be generally classified as flakes, fibres, spheres or cubes. In the present investigation, the consistency of CD was proven when the cumulative distribution rate of aerial dust particles ranging from 30 to 40 μm that were left in the control room was 20.1 % and more concentrated than the test room having only 16.27 %. The study also observed that the aerial dust having a diameter of 1.19 to 2.5 μm was less concentrated in the test room as compared to the control. Airborne bacteria that can cause respiratory diseases usually attached themselves to dust with $> 20 \mu\text{m}$. Moreover, correlation of total dust and total airborne bacteria, total dust and ammonia, and total dust and odor were shown statistically significant by Choi et al. (2005). Therefore, there is an added advantage for the use of CD especially at prolonged period.

The summary of the particle size distribution of both the control and test rooms is presented in Table 1. It can also be an indirect measure of the suction efficiency of the deduster. It is interesting to note that the two rooms followed a uniform ratio of approximately 60:30:10 distribution rate. This indicated a reliability on the suction efficiency of the CD.

The removal efficiency of the CD, as shown in Table 2, apparently indicated that the PM10 was the most preferred particle to be sucked by the CD. This is because there were more TSP concentration during the same period than the PM10. Further, it seemed that this is attributed

to “volume - mass - air pressure interaction” and this has to be verified in subsequent studies. This claim is valid because in Table 1 of this study, the PM 10 in the test room had the lowest distribution rate over the control indicating better suction effect was done. This finding is relevant as PM10 is a respirable dust.

There was no definite trend in the moisture content and weight of dust collected in the dust collector relative to collection period as demonstrated in Table 3. Other factors that resulted to this observation are therefore to be investigated. This data provides a valuable information to predict concentration of dust pollutants through simulation models given varying conditions in terms of management, pig density, types of building and others.

Influence of CD on NH₃, CO₂ and bacterial count

The emission of NH₃ from agriculture and livestock farming as claimed by Kim et. al. (2004) has not been estimated in Korea, but could be equal or surpass that of Europe. Awareness then on the inventory of NH₃ should be done so that a nationwide estimate can be done in the future at least for livestock houses. In the present study, the CD was able to effectively reduced NH₃ inside the house and therefore the rate of decrease that was quantified can serve as a basis for estimating the gas should there be a widescale use of dedusters in the future. Moreover, NH₃ is an irritant to the respiratory tract, therefore its concentration has to be monitored in livestock house. Murphy and Gargill (2004) reported an NH₃ concentration of 3 to 20 ppm in pig farms.

For pigs exposed to 50, 100 and 150 ppm NH₃ for 4 wks, growth rates were reduced by 12, 30, and 29 %, respectively (Drummond et al. 1980). Moreover, pigs exposed for short period of NH₃ above 35 ppm can result to inflammatory changes in the wall of the respiratory tract. Although the NH₃ level for both the test and control rooms is way below the 35 ppm level, this is attributed to the fact that younger pigs has been used in this study, therefore the use of CD should not be ignored. Likewise, there was a 9 % reduction in the 3-wk average value of CO₂ in the test room. At a CO₂ concentration of 967 ppm in the test room on the 3rd wk, this was already lower than 1500 ppm which was claimed by Donham et al. (1989), to be the level associated in the reduction of growth rate and increased prevalence of respiratory diseases in pigs. Accordingly, recommended levels for CO₂ vary and a good target is usually less than 1500 ppm with 3000 ppm being the absolute maximum (Pointo et al., 1989). CIGR (1992) on the other hand, suggested that the maximum allowed CO₂ concentration for animals is 3000 ppm while for workers is 5000 ppm.

Donham et al. (1989), in Sweden, have reported average concentrations of bacteria at 1.4×10^6 CFU/m³ and Crook et al. (1991) in their survey of six pig-housing facilities in the United Kingdom, observed concentrations of total bacteria of $3-80 \times 10^5$, $2-60 \times 10^5$, $2-20 \times 10^3$ CFU/m³, and 1.4×10^6 CFU/m³ in samples incubated at 25°, 37, and 55°C. Donham (1995) recommended a level for viable airborne bacteria in pig CFU/m³ to be 1.0×10^5 . Moreover, Donham (1986) reported an average total bacteria concentration of 3×10^6 CFU/m³ and a statistically significant association between exposure to concentrations of at least 1.4×10^6

CFU/m³. Clark et al. (1983) reported that the concentration of airborne endotoxin found in swine units is 0.12 µg/m³. Other workers found out that a high concentration of gram negative bacteria in swine confinement buildings (4.7 x 10² to 0.9 x 10³) resulted to acute and chronic respiratory symptoms and ventilatory capacity reductions in swine farmers (Zuskin et al., 1992a,b). In our study, the level of bacteria of the test room was more than the above range therefore, more dedusters with higher suction efficiency per room should be considered in swine buildings

Airborne bacteria which are usually 1 to 2 µm can cling to inert host dust particles with 10-20 µm in diameter (Dyment, 1976). On the other hand, Curtis et al. (1975) detected a concentration of around 28 to 31 % of the microbial population to be bacteria colony forming particle with diameter < 4.7 µm. Because of the accuracy of dedusters to measure airborne bacteria, microbiologist can work with livestock men and investigate whether the increase in size of bacteria was made possible inside a confined livestock environment and further determine its pathogenicity. In this way, adjustment on biosecurity measures and health protocols will be considered by the livestock farmers. This can be a subject for our future investigation as we did not take into account the particle size distribution of the bacteria.

Comparative contaminants of dust and feed

The relatively high protein level suggests that the main source of dust was from the livestock, specifically materials from the skin and feathers. Crude fat of dust also was higher compared

with that in the feed. This indicated that dust is basically of animal origin and confirmed the findings of other workers wherein they found out that dust from livestock buildings showed to be largely of organic sources like feed, skin, feathers, bedding, and feces and has not been changed as indicated in the review covering 3 decades (Grub et al, 1965; Bundy, 1984). Likewise, Nilsson and Gustafsson (1987) also claimed that pig house dust contained 87% dry matter, 24% crude protein and 4% fat. The average of 2 dust particles recorded a higher Ca, P, K concentration than the feeds. The CD, therefore has to significantly reduce these inert minerals as the threshold limit value (TLV) for total mineral dust for humans is $100 \mu\text{g}/\text{m}^3$ (Carpenter, 1986), while the US EPA, 1999 recommended a limit for TSP to $150 \mu\text{g}/\text{m}^3$. The size of the inert mineral dust detected in this study can fit well under TSP category. Subsequent studies should therefore investigate the removal efficiency of CD for these specified classification of minerals. . It is expected that these contaminants are evident in most livestock houses since Ko et al. (2004) detected these metals in swine manure at higher levels. The heavy metals were Cr, As, Cd, Cu, Zn and P with zinc having the highest concentration at 425.77 ppm and cadmium the lowest at 1.51 ppm.

IMPLICATIONS

The study proved the importance of CD, particularly this new model that was capable for sensitive detections. It was able to relate how dust can bring adverse effects to both the stockman and animals. The CD reduced the number and density of dust particles as well as bacterial and gaseous contaminants in the pig house. The unique feature of the cyclone

deduster used in this study is the presence of a block that improved its suction efficiency and was well elucidated by the detailed and exhaustive detection monitoring of the particulate matter distribution. While ventilation systems can control the concentration of microorganisms, gram negative bacteria were still above recommended limit. In this study, the cyclone deduster was able to detect microbial load below the tolerable level. Since this was done to weaning pigs during spring time, it is postulated however, that detection can vary under different growth cycles, seasons and management systems. Therefore, data generated in this investigation can be utilized as a basis for simulation models and regression correlation analysis for future workers. Finally, this will also provide technical input on further improvement on design and suction efficiency of cyclone dedusters should there be linear increase in indoor area of building and concentration of dust relative to varying piggery management conditions and climatic patterns.

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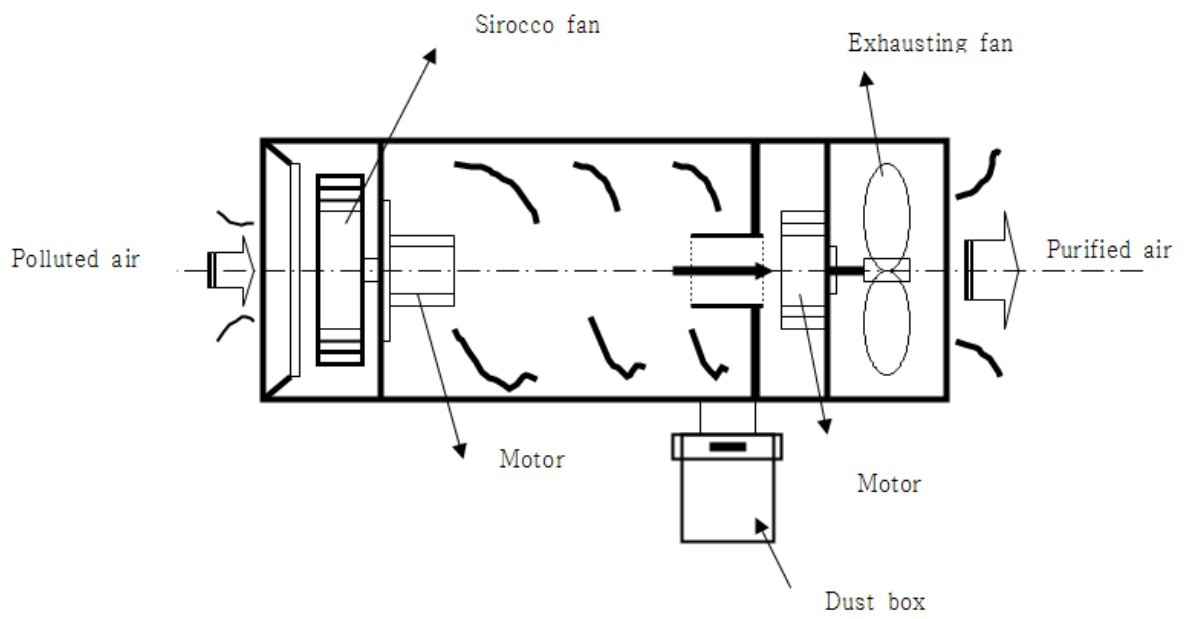
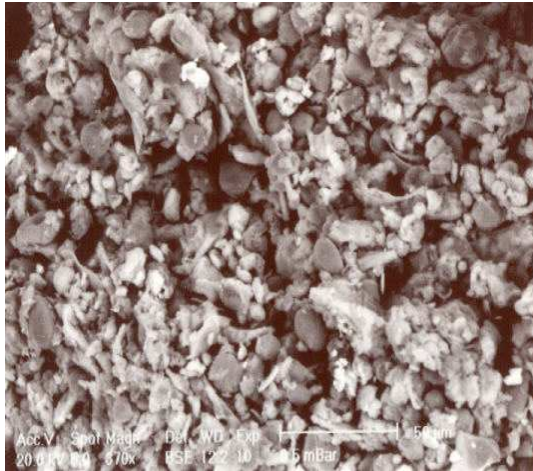
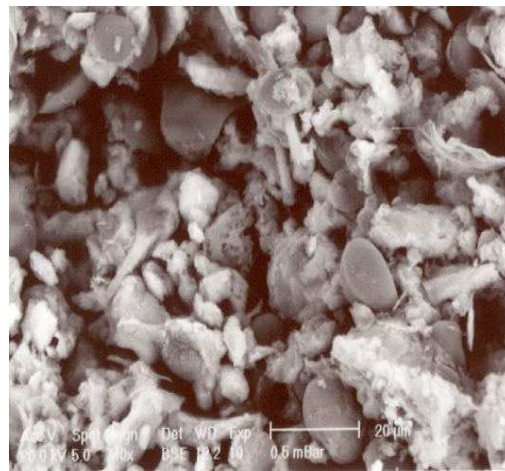


Fig. 1. Schematic of the cyclone-type deduster



(370 x)



(740 x)

Fig 2. Scanning electron micrographs of dust particles collected from cyclone deduster in swine growing building

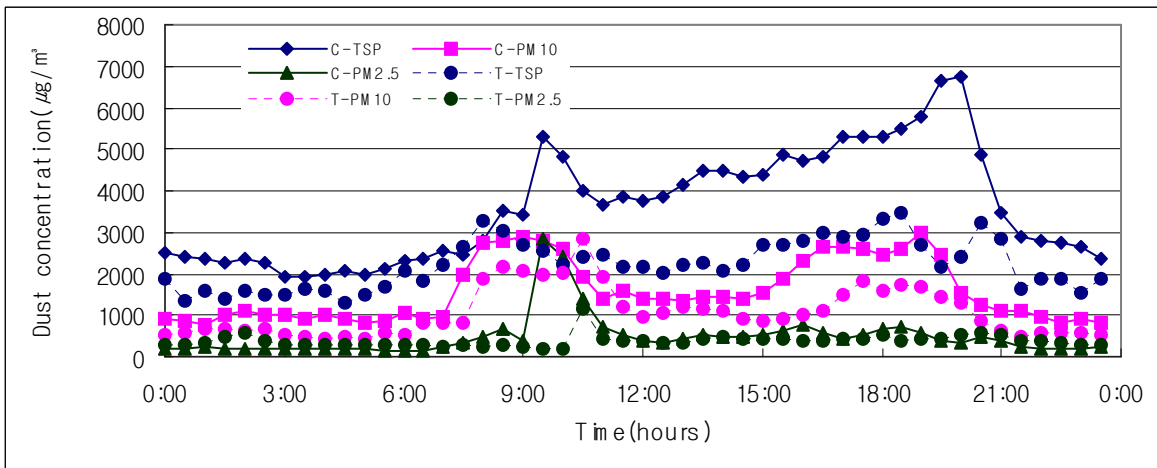


Fig. 3. Comparative dust concentration in building for weaned pigs at 3 wks of age

TSP -Total Suspended Particulates without CD.

TSP - Total Suspended Particulates with CD

PM10- Particulate Matters < 10µm without CD

PM10 - Particulate Matters < 10µm with CD

PM2.5- Particulate Matters < 2.5µm without CD.

PM2.5 -Particulate Matters < 2.5µm with CD

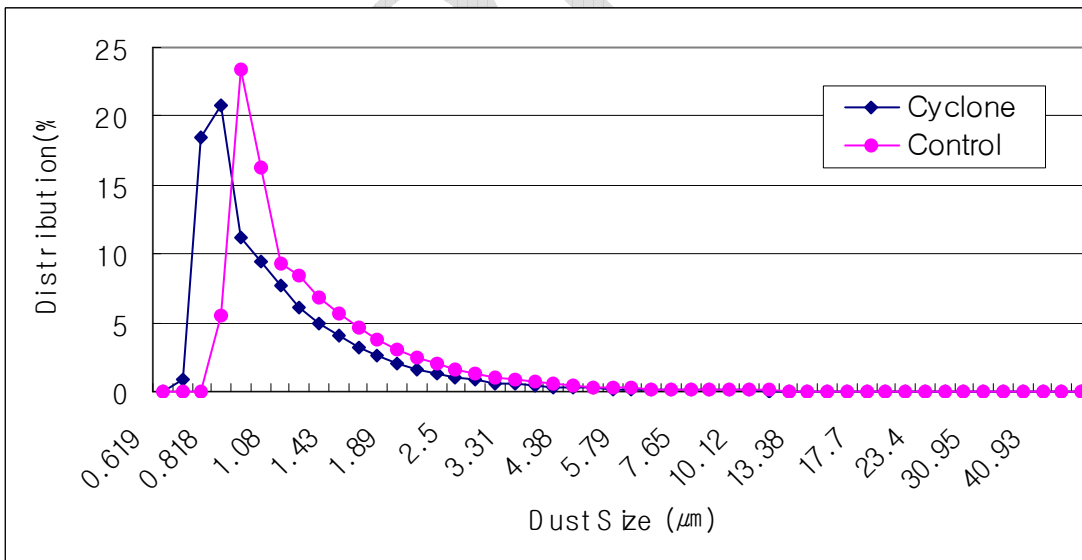


Fig. 4. Particle size distribution of aerial dust in weaned piglet building by number basis

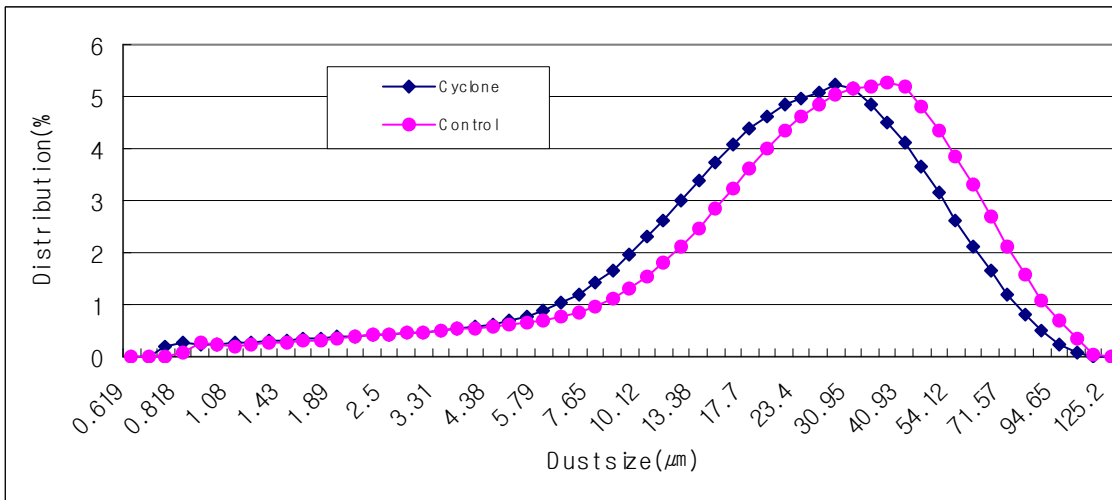


Fig. 5. Particle size distribution of aerial dust in weaned piglet building by volume basis

Table 1. Comparative particle size distribution of dust in a weanling pig house

Item	Control			Test			
	TSP	PM10	PM2.5	TSP	PM10	PM2.5	
1st wk	$\mu\text{g}/\text{m}^3$	3,614.8	1,583.7	486.4	2,229.5	1,069.3	380.4
	%	63.0	28.0	9.0	61.0	29.0	10.0
2nd wk	$\mu\text{g}/\text{m}^3$	1,978.0	1,014.8	261.0	1,342.5	305.5	188.5
	%	61.0	31.0	8.0	65.0	16.0	19.0
Mean	$\mu\text{g}/\text{m}^3$	2,796.4	1,299.2	373.7	1,786.0	732.4	284.4
	%	63	29	8	64	26	10

Table 2. Removal efficiency of dust using cyclone deduster

Item	TSP			PM10			PM2.5		
	C	T	(%)	C	T	(%)	C	T	(%)
1 st wk	3,614.8	2,229.5	38.3	1,583.7	1,069.3	32.5	486.4	380.4	21.8
5 th wk	1,978.0	1,342.5	32.1	1,014.8	395.5	61.0	261.1	188.5	27.8
Mean	2,796.4	1,786.0	36.1	1,299.3	734.2	43.6	373.8	284.5	23.9

Table 3. Weekly weight of dust collected in the deduster bin

Item	1 st wk	2 nd wk	3 rd wk	4 th wk	5 th wk
MC ^a (%)	10.2	7.8	5.6	8.5	6.8
FM ^b , g	96.1	121.4	110	104	84.5
DM ^c , g	86.7	112.0	103.7	95.2	78.8

^a Moisture Content

^b Fresh matter basis

^c Dry Matter basis

Table 4. Comparative evaluation of the bacterial and gaseous concentration of the test and control house

Item		1 st wk	2 nd wk	3 rd wk
Bacteria (CFU/m ³)	Test	2.2 x 10 ³	1.5 x 10 ³	1.9 x 10 ³
	Control	2.3 x 10 ³	2.6 x 10 ³	3.3 x 10 ³
NH ₃ (ppm)	Test	9.2	9.6	5.0
	Control	9.6	11.6	6.3
CO ₂ (ppm)	Test	1,827	2,633	967
	Control	2,183	2,580	1,167

Table 5. Proximate analysis, mineral and heavy metal concentration of feed and dust.

Items	Feed ¹	Dust Particle ¹	Dust Particle ¹
Crude Protein, %	19.8	32.7	25.9
Crude Fat, %	8.3	11.8	9.1
Crude Fiber, %	1.6	0.14	0.15
Crude Ash, %	6.9	15.5	14.9
Salt, %	0.98	1.05	0.82
Ca, %	0.75	0.51	2.09
P, %	0.58	0.51	1.63
K, %	0.78	0.83	2.02
Na, ppm	0.21	0.15	0.43
Mg,ppm	0.12	0.15	0.68
Fe,ppm	325	10,479	2632
Mn,ppm	69.2	345,	245
Zn,ppm	971	2017	316
Cu,ppm	83.5	389	209
F,ppm	85.5	548	109.9
Cr,ppm	1.07	3.5	3.41
Pb,ppm	2.98	6.71	4.68
Cd,ppm	0.13	0.58	0.08
As,ppm	0.80	1.73	0.87
Hg,ppm	0.00	0.02	0.01
S,%	0.12	0.26	0.29
SiO ₂ ,%	0.19	0.7	0.76

¹ Mixed feed and not in dust particle form.