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

AERODYNAMIC ANALYSIS OF AIR POLLUTANTS IN PIG FARMS USING CFD TECHNOLOGY

J-S. CHOI[1], I-B. LEE[1*], S-W. HONG[1], H-S. HWANG[1], I-H. SEO[1], J. P. BITOG[1,2] , K-S. KWON[1], S-Y SONG[1]

[1]Department of Rural Systems Engineering and Research Institute for Agriculture and Life Sciences, College of Agriculture and Life Sciences, Seoul National University, 599, Gwanakno, Gwanakgu, 151-921 Seoul, Korea Tel: +82-2-880-4586 Fax: +82-2-873-2087, * iblee@snu.ac.kr
[2]Department of Agricultural Engineering, College of Engineering, Nueva Vizcaya State University, 3700 Bayombong, Nueva Vizcaya, Philippines

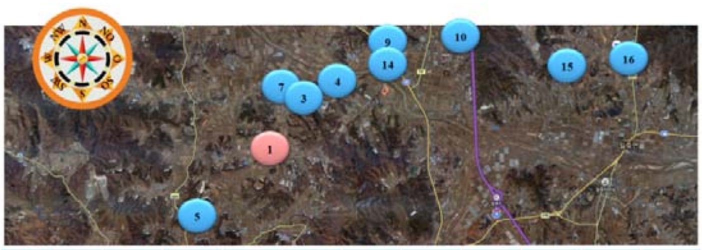
CSBE100888 – Presented at Section II: Farm Buildings, Equipment, Structures and Livestock Environment Conference

ABSTRACT In Korea, the number of large scale productions for livestock especially in the pig industry is continuously increasing. This requires proper understanding and adequate knowledge of the environmental condition inside and outside the production facilities to ensure comfort for the pigs as well as protection against diseases. In large production systems, air pollutants including viruses are one of the major modes of diseases spread. The spread depends greatly on the airflow characteristics which are highly affected by the topography. In Korea, approximately 65% of the country has a mountainous terrain. Investigating the spread of diseases as well as other air pollutants through field experiment is very challenging because of the unstable and unpredictable weather conditions. However, this can be done through computational fluid dynamics (CFD) for fluid flows where air flows inside and outside the pig production facilities can be investigated. The calculation of the flow was made by the FLUENT program which is the main module used in the study. The simulation model was developed using a T-grid and Gambit software with consideration of the available geographic information system (GIS) data. Furthermore, post processing of the simulation results allows visualization of the flow characteristics as well as the extent of the pollution. It is expected that proper ventilation system inside the production facilities as well as appropriate arrangement of the facilities were very critical in preventing and blocking the spread of livestock diseases and other pollutants.

Keywords: Computational fluid dynamics (CFD); livestock; spread of disease; topography

INTRODUCTION Recently, pig disease has occurred in Korea and the extent of the spread of the disease has increased due to collective practice of raising the pigs. The World Organisation for Animal Health (OIE) has reported that animal diseases caused direct and indirect economic losses estimated at 20% of the gross livestock production. The disease occurs when multiple factors interact such as host, pathogens, propagation path, and environmental factors. It can be analyzed due to direct contact with the infection and spread in the air caused by the indirect spread of infection. Korea's mountains are approximately 65% and approximately 54% of the farms that are close within 500m. So, the risk of disease spread through air is very high. Considering the factors involved in the spread of the disease, the terrain and topography can be a very important factor. Also, if significant amount of dusts are present in the farms, pathogens and other virus can be attached to the dusts and are diffused to other farms making more access for the spreading of the disease. In many papers, the possibility of disease spread in the air has been investigated (Gloster et al., 1983; Stark et al., 1999; Weber et al., 2008).

In Korea, the Foot and Mouth disease (FMD) occurred in May 2002. Many farms were concentrated nearby the first FMD occurred farm (Fig. 1). Many kinds of animal have been slaughtered at that time; 158,708 pigs, 1,372 cows, 42 goats, 33 dear. Economic losses caused around 125 million dollar as compensation costs for the animal growers. At that time, the disease occurred across province of Gyeong-gi. Many of farms were located intensively in the An-seong and Yong-in areas.



Order of occurrence	1	3	4	5	7	9	10	14	15	16
Report Date	5/2	5/10	5/10	5/10	5/12	5/18	5/19	6/7	6/10	6/23

Fig.1. Time table for the outbreak of the Foot-and-mouth disease in 2002, An-seong, Gyeong-gi province, Korea

Recently, modeling studies to the air flow considering the spread of the disease caused by the terrain and amenities are being attempted. KDC Strark (1999) investigated about the spread of pig infectious diseases due to air. The study have shown that spreading the virus in the air can cause the spread of the diseases through, air route, the generation of pollutants, and inhalation. In addition, for the prevention of the spreading of the disease, some kind of measures has been proposed such as air filters and dust reduction. In Brockmeier (2002) study, ventilation structure was connected without direct contact between objects. The experiment focused to determine the spread the virus from an object through the air. Some studies being performed consider the terrain and the air flow on the spread of the disease. In addition, many attempts have been made to do simulation and numerical analysis. Mayer (2008) performed simulation using the Lagrangian particle model for the spread of foot-and-mouth disease (FMD) considering a very complex terrain. Thousands of particles in the ground were calculated by tracing the trajectory of the concentration distribution. Also, the accuracy at 2.8km was improved using interpolated resolution of meteorological data from the ground at 400m. As a result, the spread of the virus seemed to be dominantly influenced by local wind. However, in the mathematical model, there are some limitations on how to express of implementation of the particles such as the virus. That process should consider several environmental factors.

Likewise, the assumption of the probability of the spread of the virus should be appropriate.

In this study, the development of CFD models focused on improvement the high accuracy of air flow. Qualitative and quantitative analysis on propagation mechanism of the primary air flow were done. The result of data on field experiments and simulations were compared considering the environmental factors. To present the criteria about the attempt to minimize the spread of disease, aerodynamic flow analysis were performed on the perspective of air pollutants over the pig farm.

MATERIALS AND METHODS A Field experiments was performed following the formation of the air flow between the farm buildings and the atmosphere. However, field experiments have some limitations. For example, it gives limited data because of limited measuring points. Also, it is difficult to maintain the same environmental conditions. These problems can be overcome using the CFD simulations. This simulation can be adjusted artificially to adopt the structure and the environmental conditions can be controlled and varied. The purpose of the simulation is to visualize the air flow using the obtained data through field experiments.

In addition, the simulation model between the farm and corresponding areas large area was designed to measure the extent of the spread of the virus. This would also be used in further field experiments to check the reliability of the model.

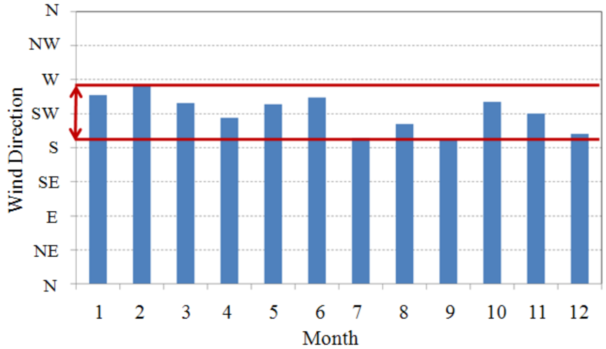
Field Experiment

1. Selection of measurement points

Prior to performing field experiments, Meteorological data in this area were analyzed. The wind direction was generally west, South-west, and south regardless of the season. In addition, when the FMD occurs in 2002, the primary wind was South-west. The initial air pollution emissions from farms have shifted along the main direction of the wind. And then, the aspects of the spread were moved to the other farm that is located near the northeast side. KDC Strark (1999) presented the environmental conditions that the virus can be very active. The virus are known to be most active less than 25℃ of temperature and approximately 60% of humidity. When the FMD occurred, the environmental factors in this area were investigated. The temperature was 20.3℃, and the humidity was 64%. So, the appropriate weather conditions were shown to provide environment for the virus.

Considering that this study is underway, 5 field experiments were performed during June-December in 2009. The Chosen farm was XP-BIO for the field experiment, which is located in Hwa-gok-ri, Il-juk-myeon, An-seong, Gyeong-gi (Fig. 2a; 37°07’09.9’’N of latitude, 127°27’53.3’’E of longitude).

The farm is surrounded by mountains. Thus, it could affect less other livestock farms. The farm has different ventilation methods depending on the by the age of pigs. In case of weaner’s house, forced ventilation structure is used while the rest of house use natural ventilation.

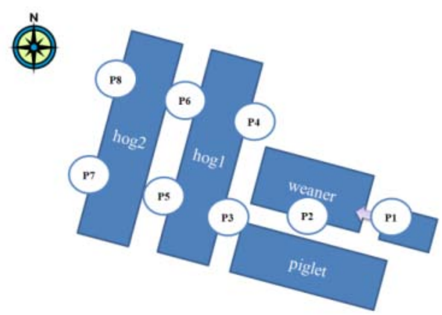


The average wind speed	1.4 m/s
Maximum wind speed	5.7 m/s
Most often the wind	SW
Average Temperature	20.3 ℃
Average humidity	64%

Fig.2. Monthly wind directions and weather condition at the period when the FMD occurred.

Measurement points were selected for to measure sample of suspended particulate matter using air pump as shown in Figure 3. In case of forced ventilation building (point 1•2), Inlet and outlet point are distinct. Pumps were installed easily at that location capture. But, to select the measurement point for the analysis were difficult at the natural ventilation building. So, trapping points at the windward and leeward were selected by considering the main wind direction. After it had been through a lot of trial and error, the sampling points have several modifications. Total of eight points were selected to perform the experiment.

(a) Experimental pig farm - XP bio



(b) Sampling points for virus test using air sampler with Teflon filters

Fig.3. Location of measurement points inside the production facility.

2. Method of measurement

Economic and temporal conditions were considered to efficiently analyze for presence of the virus floating in the air by trapping pollutants. Mini Sampler (Gilian Pump, SENSIDYNE) was installed on a small cassette to enable simultaneous capture in many locations. In the cassette, the filter is installed. That material was Teflon and size of filter was 37mm. After the collected samples, cassette with the filters is separated for existence and nonexistence of virus test. The filter was sent to the National Veterinary Research & Quarantine Service. The viruses of PRRS and PCV2 were determined and with strong possibility to be spread in the air. The dangers of the disease spread were determined through viruses test. The concentration of dust particles were measured with Dust mate instrument. The particle size concentration was analyzed from the suspended particulate using Potable aerosol spectrometer equipment. Various data measurements were planned for the further analysis of the virus and the weather conditions and the particle size distribution based on their interrelationships.

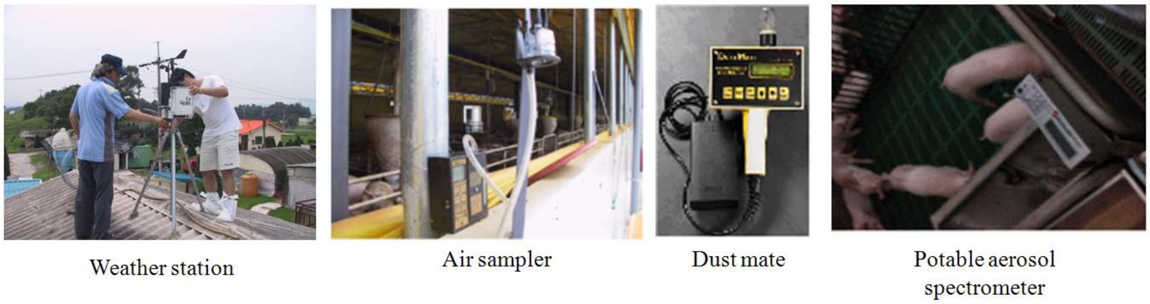


Fig.4. Instrument used the field experiment.

Computational Fluid Dynamics (CFD)

Model Design

The air flow model was designed based on GIS satellite data in conjunction with the local meteorological data measured by field experiments. To simulate the design, using the Arc GIS program was necessary to extract the needed data. Editing was done with Auto-cad program. Next, the 3-dimensional shape of the terrain was made from two-dimensional contours of the lines using Sketch-up program. This is followed by generating the base terrain by splitting regions using the Rhinoceros program. The process of grid design was focused on the appropriate design to express fine-grained flow. Three-dimensional grids were made from Gambit and T-grid program. Finally, the three-dimensional design model was created as the final volume of grid. The spreading operation was performed using Fluent simulation software. Variety of environmental conditions such as the main wind direction from the field experimental data was being considered. The flow visualization and data analysis were performed using Ensight program. The diffusion model was developed to relate to data gathered from field experiments. In addition, the spread between the farm and the farm was designed through the wider region.

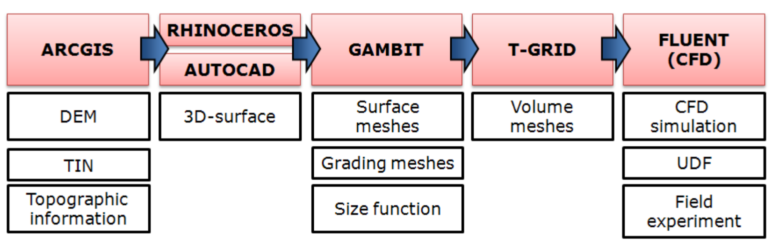


Fig.5. Flow-chart for CFD modeling.

RESULTS AND DISCUSSION

Field Experiment

20 years of the meteorological data from 1988 to 2008 provided by the I-cheon weather station were analyzed and presented in Fig. 6 below.

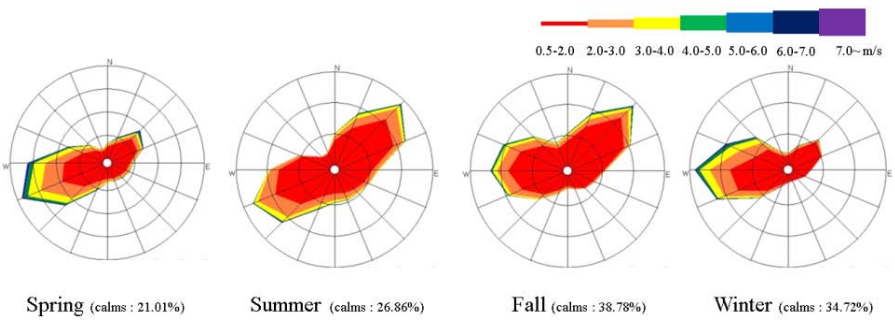


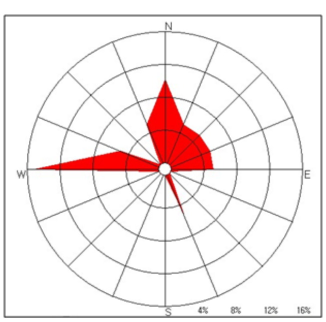
Fig.6. Wind condition per season for the last 20 years.

The main wind direction was West-South West (WSW) and northeast (NE). Approximately 30% of wind was very calm with less than 0.5 m/s wind velocity. The wind velocity was typically less than 3 m/s in the summer and autumn which is classified to as weak. In case of winter and spring, the direction is west with primarily in 4 ~ 5 m/s wind velocity which is classified as strong winds. Two very significant representative result of the field experiment is presented in Figs. 7 and 8.

The main wind direction was northeast and west wind on the 9th of October in 2009. The actual experiment was conducted from 10am to 12 noon. The observed wind direction during the times was northeast and southeast.

Detecting the virus was predicted at the points 3 and 4 where southeast and northwest was the wind direction. However, the virus was only detected in point 3 because the average of wind velocity was 0.6 m/s which very low. This explained why the virus was not detected at the leeward of hog building.

Based on the result measured on the 30th of October in 2009. The main wind direction was south. The virus was assumed to reach at the wind ward in front of the pig's house at first. But, the amount of dusts that are coming directly to the pig's house was low. In this case, the exhaust air was considered to spread more towards the top. So, the spread of the virus can determine the possibility of differences in aspect due to wind direction and wind speed.

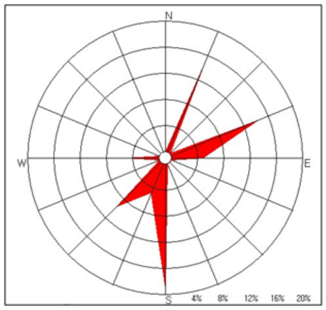


(a) Frequent wind direction.

Point	Result
1	positive
2	positive
3	-
4	positive
5	positive
6	positive
7	-
8	-

(b) Locations where the PCV-2 viruses were detected.

Fig.7. The result of field experiment of October 9th, 2009.



(a) Wind direction frequency

Point	Result
1	positive
2	positive
3	-
4	-
5	positive
6	positive
7	-
8	-

(b) Locations where the PCV-2 viruses were detected

Fig.8. The result of field experiment of October 30th, 2009.

Additional experiments were performed on the September 17, 2009. The concentration based on particle size distribution are classified as: TSP (Total Suspended Particulate), PM10 (Particulate Matter), PM2.5, PM1. The maximum measured value from different measuring locations in the pig room is shown in Table 1.

In case of natural ventilation, dust concentration was higher at the inlet point than the outlet point. The exhaust air from forced ventilation was considered to flow toward natural ventilation point. Also, the natural ventilation structure is difficult to distinguish the inlet and outlet. It means that scattering of particles will be easy better than forced ventilation. Thus the spread can be easily changed depending on the wind direction.

Table 1. Concentrations of the fine particles XP-bio farm on September 17, 2009.

Measurement locations	TSP($\mu g/m^3$)	PM_{10}($\mu g/m^3$)	$PM_{2.5}$($\mu g/m^3$)	PM_1($\mu g/m^3$)
Forced ventilation in pig room	6,420.6	6351.0	72.2	34.9
Forced ventilation in hallway	165.9	92.2	46.0	25.4
Natural ventilation Inlet	680.2	221.5	47.9	25.2
Natural ventilation Outlet	315.8	114.3	41.7	22.4

In further studies, to measure the correlation between the elements will be held based on results of field experiments. Field experimental data is applied in the simulation model then it will be compared to field data to validate the simulation results.

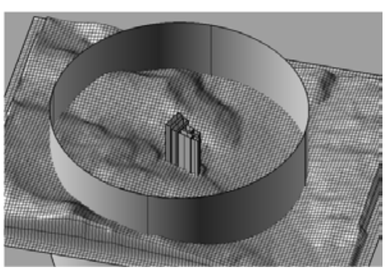
Computational Fluid Dynamics (CFD)

1. Modelling the experimental farm

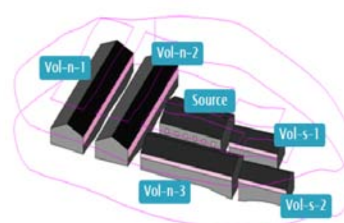
The terrain of XP-bio farm with a size of around 500m was designed. Buildings that can affect the airflow pattern were considered in details. The source of air pollutants was assumed to be the building and therefore named as the source. Both walls were assumed to occur in the exhaust. In the model, the terrain was designed with all farm buildings simultaneously. The important things considered are how to reduce computation time and elevating the accuracy of the model. When a single model was connected, some problems occur in the grid size of the terrain. If the size of farm grid is designed sparsely as same size of terrain gird, the accuracy of air flow is significantly lower. Otherwise, if the size of terrain gird is designed densely as same size of farm grid, a number of grid will be increased. Also, this problem is associated with the operation time. In this study, interface connection skill was used effectively. It can improve the precision of the grid. The densely grid was designed near the critical farm. And then, the grid of the other part was designed sparsely. The model that save the computation time while ensuring accuracy was effectively designed.

The following are the results of the simulation. The analysis of air flow was conducted by using the main wind direction which is west and northeast. To know the details of the changes in weather conditions around the farm, the result obtained from the weather stations installed were analyzed. In the early morning, the wind direction is observed mainly northeast. In the afternoon, the wind direction is observed is usually west and Southwest. During the field experiment from 10am to 12 noon, the wind direction was south east and east south east (ESE). In general, the main wind direction was determined to be SSE, SES, NE, and W which is investigated in the simulation. Wind velocity was applied the same from the measured velocity which is 1.4m/s. As a result, the assumed air pollutant was generated in the forced ventilation building of the weaner regardless of the wind direction. The influence significantly presented toward the farm (vol-n-3) located south part. In case of hog's houses (vol-n-1. vol-n-2) using natural ventilation, the result of simulation was different according to the wind direction.

The suspended particulate matter at the source was assumed at 100%. In the simulation with the south-southeast wind direction, approximately 10.5% particulate of the total amount was confirmed in the hog house as shown Fig.11. As the result of field experiment on 9th October, the virus was not detected at the hog house at point 4. In the simulation, the dust concentration near the hog house had been identified. Certainly, the amount of dust was reduced as compared with generated one. The simulation result was different with the field experimental data. It means that the dust concentration can be different depending on air flow.



Separating the area using Rhino ceros program



Designing and naming of the pig houses and its naming

Fig.9. Some results of the simulation process

2. The degree of the spread of the virus between the farms

The method of the design is similar with the method as discussed above. Farm zone was considered to generate in small volume. The grid near the farm was designed to be compact. The grid size was changed as sparser as farther away from the farm. The point of contamination was assumed by windward at the west part. The result of simulation is presented in Fig.12. The main wind directions of Southwest, westerly, north-westerly were considered. The result of the wind direction of west is presented in Table 2. The suspended particulate matter is assumed at 100% in farm 1. However, only 2% of the suspended particulate matter reached farm 3. As this result, it seems it is likely to spread to a distance more than 800m. The analysis of more data will be secured through a variety of future research based on wind direction and wind speed. This farm was chosen for the test model. The other farm is located in a triangle shape near that origin farm toward the west side. So, that is suitable for analysis of the spread by tracking the main wind direction. Specially, this farm is appropriate to analyze the impact by flat site because there is no a large the mountains near the farm. The spread of the particles were proved through the development of simulation. It is expected to improve the appropriateness and feasibility by comparing the simulation results of the model through further field experiments.

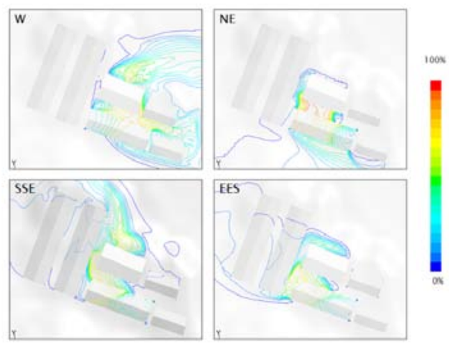
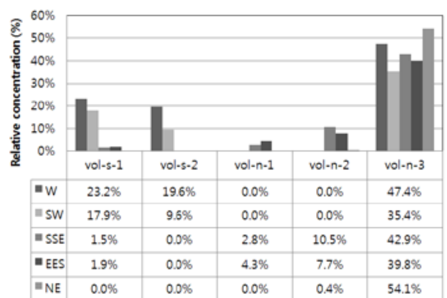


Fig.10. Concentrations of the air contaminants generating from the forced ventilated pig house at the 2m height according to the wind direction.



	vol-s-1	vol-s-2	vol-n-1	vol-n-2	vol-n-3
W	23.2%	19.6%	0.0%	0.0%	47.4%
SW	17.9%	9.6%	0.0%	0.0%	35.4%
SSE	1.5%	0.0%	2.8%	10.5%	42.9%
EES	1.9%	0.0%	4.3%	7.7%	39.8%
NE	0.0%	0.0%	0.0%	0.4%	54.1%

Fig.11. Influx rate of contaminants according to pig houses based on the wind direction.

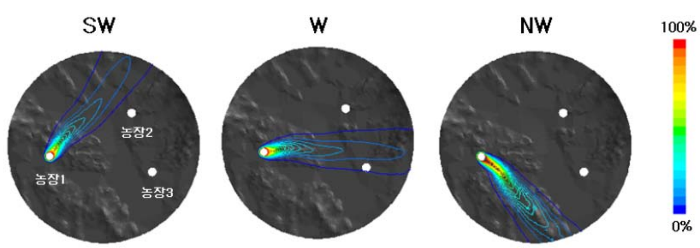


Fig.12. The dispersion of the air contaminant from the pig farm according to the wind direction.

Table 2. Influence of the suspended microorganism to other near pig farms.

Wind direction	Farm 1	Farm 2	Farm 3
SW	100%	< 0.1%	< 0.1%
W	100%	< 0.1%	2%
NW	100%	< 0.1%	< 0.1%

CONCLUSIONS

The two type of research were conducted. First one is spread virus between buildings in the farm and second one is the spread between farms. In between buildings, the influence on the other buildings depends more to the wind direction. Therefore, the damage scale will be varied by the changing formation of turbulence due to ventilation position or the structure of the farm.

In the second experiment, direct verification was very difficult. This is because of the complex environmental conditions which is too wide. Therefore, in the further study, the change of measurement points should be considered according to the main direction of the wind. The research should be performed into the site of farm rather than at boundaries at the farm. Then, the air flow pattern will be propagated through field experiments.

The field experiments have some limitations because such as the difficulty of maintaining a constant flow of air. To compensate these problems, The CFD techniques were used by changing environmental conditions. As a result, field experiments were able to observe a similar pattern with simulation. In the further study, the verification process of simulation will enhance the accuracy. It will be able to provide criteria for location of the farm or its design. Through this study, early protection measures can be expected to provide in terms of aerodynamic conditions. Furthermore, it can be possibly used to minimize the damage by establishing early protection measures.

REFERENCES

Claudia M.F. Amaral Doel, John Gloster and Jean-Francois Valarcher, 2009, Airborne transmission of foot-and-mouth disease in pigs: Evaluation and optimisation of instrumentation and techniques, Veterinary journal, 179(2009), 219-224

Kristensen C, S, A. Botner, H. Takai, J. P. Nielsen and S. E. Jorsal, 2004, Experimental airborne transmission of PRRS virus, Veterinary microbiology, 99(2004) 197-202

Mayer. D., J. Reiczigel and F. Rubel, 2008, A lagrangian particle model to predict the airborne spread of FMD virus, Atmospheric environment 42(2008) 466-479

Mikkelsen. T., S. Alexandersen, P. Astrup, H. J. Champion, A. I. Donaldson, F. N. Dunkerley, J. Gloster, J. H. Sorensen and S. Thykier-Nielsen, 2003, Investigation of airborne foot-and-mouth disease virus transmission during low-wind conditions in the early phase of the UK 2001 epidemic, 3, 677-703

Stark K.D.C., 1999, The role of infectious aerosols in disease transmission in pigs, The veterinary journal 158, 164-181

Susan L. Brokmeier and Kelly M. Lager, 2002, Experimental airborne transmission of porcine reproductive and respiratory syndrome virus and bordetella bronchiseptica, Veterinary microbiology 89, 267-275

Thomas P. Weber and Nikolaos I. Stilianakis, 2008, Inactivation of influenza a viruses in the environment and modes of transmission: A critical review.