Better Housing for Effective Pig Production[a] - Review -

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ABSTRACT : Air quality in confinement pig houses is important to production and health. Mechanical ventilation and confinement is known to be the most practical tool for maintaining adequate air quality in pig houses through extensive researches since Millier (1950) invented the 'slotted inlet' ventilation system. A variety of mechanical ventilation systems have been applied to confined nursery pig houses in Korea without scientific verification of their ventilation effectiveness. Ventilation systems with three feasible combinations (NA, NB, and NC) of inlets and outlets in a confined nursery pig house were tested to evaluate their ventilation efficiency, of which the one with the best performance was supposed to be taken as a standard ventilation system for nursery pig houses in Korea. Field data of air velocity and temperature fields, and ammonia concentration with three ventilation systems were taken and compared to determine the best system. The air velocity and temperature fields predicted by the PHOENICS computer program were also validated against the available experimental data to investigate the feasibility of computer simulation of air and temperature distribution with an acceptable accuracy in a confined house. NC system with duct-induced in-coming air, performed best among the three different ventilation systems, which created higher velocity field and evener distribution (2.5 m/s ± 0.3 m/s) over the space with a Reynolds number of 10^4. The experimental data obtained also fitted well with the simulated values using the modified PHOENICS, which suggested a viable tool for the prediction of air and temperature field with given calculation geometries. *(Asian-Aus. J. Anim. Sci. 1999. Vol. 13, No. 1 : 1310-1315)*

Key Words : Air Flow, Turbulence, Velocity Field, k-ε Model, Ventilated Space, PHOENICS, Confinement

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INTRODUCTION

Air quality in confinement animal housing is important to production and health. Obstacles play an important role in determining air flow directions and velocities, and air mixing. Since a typical agricultural building will have obstacles of significant sizes, their effects on air velocity fields must be determined to predict the ventilation dilution effect via mixing. Numerous studies have described the modeling of air flow in a ventilated space with no obstructions. Examples include: Nielson et al. (1971), Murakami et al. (1987), and Choi et al. (1989), each of whom applied the k-ε method of attaining closure in the solution of the turbulence transport equations. In contrast, Timmons et al. (1980) modeled the distribution of vorticity within a ventilated space as an alternative to predicting air flow directions and velocities. These researchers, and numerous others, have achieved significant success in developing models are able to predict air flow patterns, especially in spaces with no obstructions. Choi et al. (1989) provided the details of modifying the k-ε based TEACH-T computer model (Gosman and Ideriah, 1976) for the prediction of air velocities and the results were compared with data available in research literature. Reasonably good agreement was found, which is a testament to the applicability of the technique to the problem of determining the effects of obstructions within a ventilated air space.

Years of research in Computational Fluid Dynamics (CFD) have resulted in the creation of several commercial CFD codes. Among them, 「PHOENICS, FLUENT, FLOW3D, STAR-3D and CONDUCT」 are a few examples. In recent years, there has been a perceptual change among specialists of different fields with regard to using and modifying commercial CFD software to simulate their problems in question, Commercial CFD codes are widely accepted by general engineers if they analyze the result with uniqueness and creativeness because developing their own code is difficult, time-consuming and sometimes even misleading due to incorrect result.

For this study, PHOENICS with extensive modifications was used to explore the flow and temperature fields arising in different types of ventilation systems applied in a nursery pig house, and the computed results were validated against the measurements to assess the practicability of using

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PHOENICS for simulating the flow under consideration. A rectangular air space with round ducts hanged on the ceiling was chosen as the calculation domain to approximate the shape of many agricultural buildings and rectangular obstructions were assumed for computational ease in solving the governing differential equations.

MATHEMATICAL MODEL

Standard equations for flow continuity and momentum transport were used. See Choi et al. (1989) for a more complete development. Turbulent stress was expressed with tensor notation as (Rodi, 1980)

$$-\langle u_i u_j \rangle = \nu_t \, [U_{i,j} + U_{j,i}] - 2/3 \; k \, \delta_{i,j} \qquad (1)$$

and the turbulent kinematic viscosity was determined by local values of k and ε,

$$\nu_t = c_\mu k^2 / \varepsilon \qquad (2)$$

The turbulence kinetic energy and its rate of dissipation, k and ε, were derived from their respective transport equations (Rodi, 1980). At boundaries, no-slip and zero normal flux conditions were specified as appropriate. A uniform velocity profile was imposed at the inlet in the direction of entry (U component), with zero velocity in the V direction. Similar conditions were imposed at the outlet. Standard values of coefficients were used in the turbulence equations: $c_\mu=0.09$; $C_D=1.0$; $c_{\varepsilon 1}=1.44$; $c_{\varepsilon 2}=1.92$; $\Phi_k=1.0$; and $\Phi_\varepsilon=1.3$. On solid surfaces, the wall function method of Launder and Spalding (1974) was employed. The numerical values, $\kappa=0.4$ and $E=5.1$ as recommended by Monin and Yaglom (1971), were used.

In general, equations for velocities, turbulence kinetic energy of the fluctuating motion, and the rate of turbulent energy dissipation obey a generalized conservation principle. For steady state flows, if the dependent variable of interest is denoted by ϕ the generalized differential equation in vector form is

$$\mathrm{div}\,(\rho U \phi) = \mathrm{div}\,(\Gamma_\phi \mathrm{grad}\,\phi) + S_\phi \qquad (3)$$

in which the convective term on the left is balanced by the diffusive and source terms on the right. Although the source term may be nonlinear, it may be linearized so the set of discretized equations can be solved by methods for linear algebraic equations. When the source term, S_ϕ, depends on ϕ, the dependence may be linearized by (Patankar[9]), where S_c and S_p may themselves be functions of ϕ:

$$S_\phi = S_c + S_p \qquad (4)$$

Any desired value of ϕ may be prescribed to be the solution at an internal node point by setting S_c and S_p for that point as, for example, $S_c=10^{30}\phi_p$, desired, and $S_p=-10^{30}$, numbers sufficiently large to make the other terms in the discretized form of the equation negligible. This procedure was used to represent internal obstacles in the calculation domain by, in effect, inserting "internal" boundary conditions.

The governing mean flow equations and the turbulent equations with appropriate boundary conditions were discretized on a staggered grid and a so-called hybrid numerical scheme was used to arrive at the difference equations. The difference equations were solved by the SIMPLE procedure, of which the details may be found in Patankar (1980). The PHOENICS program embodies a methodology which is a deviant of this solution procedure and it was modified to apply to steady, three-dimensional, turbulent recirculating air flow in a rectangular enclosure having air induced through perforated holes in a duct above pen row, and an exhaust fan outlet on the other end of the wall.

EXPERIMENTS AND METHODS

1. Nursery pig compartment

A nursery pig compartment newly constructed was 9 m long, 4.6 m wide and 3.0 m high and housed 90 pigs weighing 5~7 kg each in 10 pens. Five pens were in one row, separated by a center alley of 0.8 m wide. A lamp of 600 W was placed over pig stocks in a pen to locally radiate nursery pigs. An overall view of the nursery pig compartment for experiments was shown in figure 1.

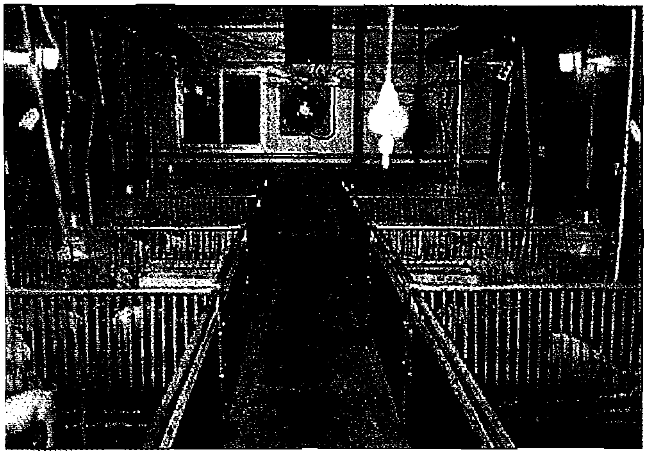

Figure 1. Indoor view of the experimental nursery pig compartment

2. Ventilation system arrangements

Experiments have been performed to investigate the flow and temperature fields with different ventilation system arrangements for six weeks in a nursery pig compartment. The most feasible three ventilation system arrangements were chosen through a preliminary survey and they were constructed in the compartment to investigate their ventilation efficiency so that one of the highest efficiency may become a standard system for nursery pig compartment under Korean climate condition. The detailed arrangements were given in table 1. A typical Dutch system, NA was included in the analysis of ventilation efficiency to evaluate if it works well under Korean climate. Measurements were taken at 27 locations shown in figure 2.

RESULTS AND DISCUSSIONS

1. Air velocity field

Air velocities were measured for three arrangements, NA, NB and NC, by one dimensional hot-wire anemometry with an accuracy of $\pm 10^{-2}$ m/s. Tables 2, 3, and 4 showed air velocity distributions of NA, NB, and NC, correspondingly at the maximum air output rate of exhaust fan of 2.36 m^3/sec (hereafter cms), of which the efficiency in reality was 46% (0.99 cms).

Mean velocity and standard deviation of NC was 1.87 ± 2.99 m/s while the values for NB and NA were 0.11 ± 0.08 m/s and 0.076 ± 0.08 m/s, respectively. In practice, NA and NB with planar inlet of 300 mm wide and 3,700 mm long do not show air current even at the maximum output rate of the exhaust fan. Such poor fan performance might be caused mainly by large-scale perforated polyethylene (PE) film covered ceiling of the compartment which acted as an obstruction. Air velocity drop occurred very rapidly as shown in table 4 for NC, which illustrated a fast expanding jet, which entrained a considerable amount of existing air conglomerates at the edge.

Air velocities over the space of NA (table 2), NB (table 3) were far lower than that of NC (table 4). Even at the height of pigs at maximum ventilation rate, it did not clearly show air movement for NA and NB systems, which can be defined as a stagnant region in the pen. Typical Dutch systems drawing air through perforated ceiling with PE film can create a serious problem in diluting accumulated heat in the compartment, especially in hot summer. In reality, many complaints from people in the field who adopted a Dutch-type ventilation system in a nursery house have been filed for excessive heat and moisture accumulation in hotter and humid summer which can be characterized as typical of Korean summer weather.

2. Air flow patterns

Qualitative study have been further performed for NC as a standard system to compare the observed with the predicted air flow patterns for a nursery compartment, as shown in figure 5(a) and figure 5(b), respectively. The calculation domain assumed symmetrical with respect to the centerline along the alley of the compartment. A primary flow circulated counterclockwise due to the creation of negative pressure regions in the middle. The overall pattern of the predicted and the observed flows were in close accord and the air speed underneath the perforated holes of the duct was about 7.0 m/s which was near the calculated value.

3. Scalar quantities

There are some other environmental parameters which should be controlled in an enclosure other than the air flow patterns and velocities. The pigs were in nursery phase when the experiments were performed in winter, thermal environment in a bay was carefully controlled by using the radiation lamp of two alternating level of 600 W and 300 W to maintain optimum temperature, say about 28℃, at the pig height in the pen. Because the compartment was newly constructed, dust and NH_3 concentrations of the two systems (NB, NC) were observed the order of $10^{-2} \sim 10^{-3}$ mg/m^3 and 3 mg/l, respectively. Although it was clear that the concentration of ammonia and dust over space was getting higher as pigs grew. Clear deviation of scalar quantities, such as temperature, dust and ammonia, was not observed between two systems. The observation reflecting the real situation in a bay should be carried out in the future.

CONCLUSION

The PHOENICS program was modified and applied to the calculation of air velocity and temperature in a full-scale nursery pig compartment which contained internal obstructions and a duct-ventilated air induced ventilation system (NC). Computed results were compared with the experimental data, and the following conclusions were drawn:

1. It is possible to predict, with high accuracy, the overall air flow patterns and air velocity distribution in a nursery pig compartment having several obstacles by modified PHOENICS developed for solving the conservation equations including turbulence model by means of the finite volume method (FVM).
2. Dutch systems (NA, NB) did not demonstrate proper air velocity distribution over space, which leads to excessive heat accumulation in a compartment. NC can be adopted to improve the ventilation efficiency of existing Dutch-type nursery compartments and applied as a standard system for new construction.

Table 1. Arrangements of ventilation systems for experiments

code	ventilation type	air flow path
NA	negative pressure	planar slot inlet in entering wall → perforated ceiling system (∅10 mm×6950 ea/86.4 m^2) with polyethylene (PE) film→ roof chimney fan
NB	negative pressure	planar slot inlet in entering wall → perforated ceiling system (∅10 mm×6950 ea/86.4 m^2) with PE film → exhaust fan in exiting wall
NC	negative pressure	circular duct (∅250 mm) with perforated holes (∅50 mm×9 ea) → exhaust fan in exiting wall

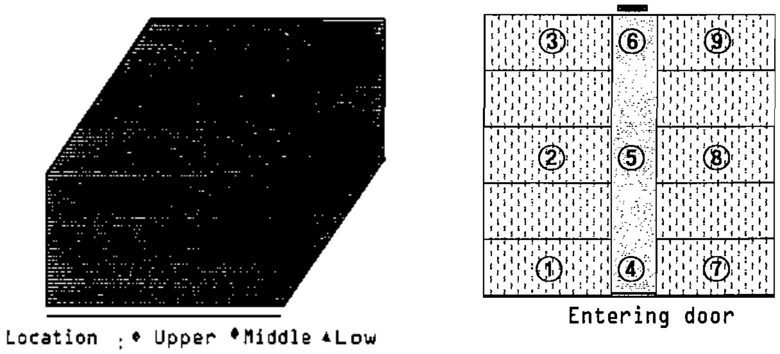

Figure 2. Measurement locations in a nursery pig compartment

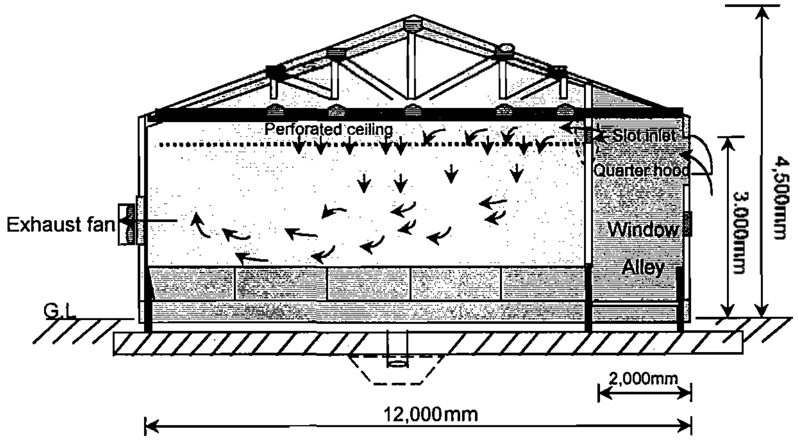

Figure 3. Dimension and anticipated air flow pattern of NB system

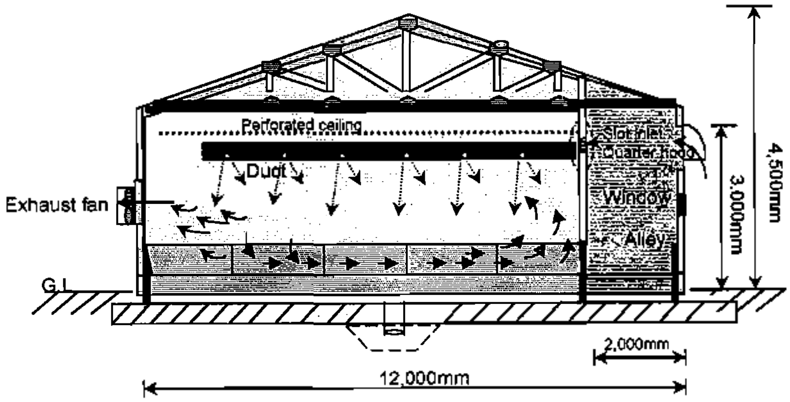

Figure 4. Dimension and anticipated air flow pattern of NC system

Table 2. Velocity distribution of NA in a compartment, m/s

location	front section			middle section			rear section		
	left	alley	right	left	alley	right	left	alley	right
upper	0.11	0.05	0.15	0.13	0.12	0.17	0.08	0.11	0.12
middle	0.03	0.04	0.04	0.05	0.02	0.02	0.07	0.4	0.07
lower	0.03	0.03	0.03	0.02	0.03	0.01	0.02	0.07	0.03

Table 3. Velocity distribution of NB in a compartment, m/s

location	front section			middle section			rear section		
	left	alley	right	left	alley	right	left	alley	right
upper	0.1	0.15	0.13	0.13	0.15	0.14	0.1	0.32	0.08
middle	0.04	0.11	0.15	0.05	0.06	0.15	0.08	0.26	0.11
lower	0.02	0.06	0.03	0.3	0.03	0.03	0.1	0.03	0.03

Table 4. Velocity distribution of NC in a compartment, m/s

location	front section			middle section			rear section		
	left	alley	right	left	alley	right	left	alley	right
upper	7.82	0.12	7.64	7.43	0.20	6.36	7.36	0.32	7.27
middle	0.16	0.18	0.49	0.45	0.03	0.71	0.48	0.10	1.51
lower	0.13	0.07	0.17	0.12	0.04	0.23	0.21	0.25	0.69

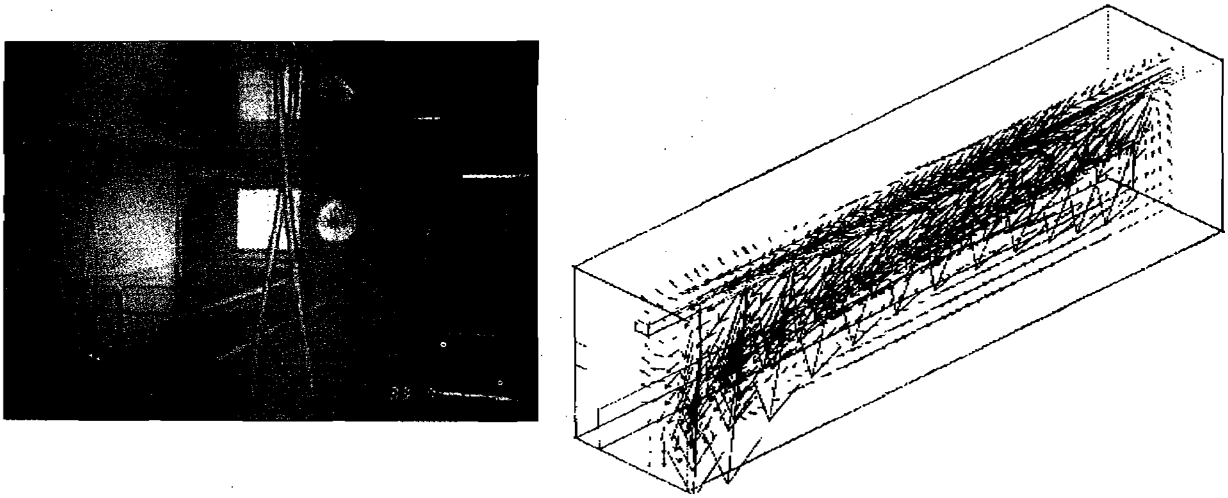

Figure 5. (a) the observed and (b) the calculated air flow patterns for NC

SYMBOLS

c_μ, c_{e1}, c_{e2}, C_D empirical constants
E : constant for logarithmic velocity profile
k : turbulent kinetic energy of motion, $(m/s)^2$
p : pressure, P_a
s : source term
u : fluctuating velocity component, m/s
U : steady velocity component, m/s
E : turbulent diffusion coefficient
ε : kinematic rate of dissipation of turbulent energy, m^3/s^3
κ : constant for logarithmic velocity profile
ν_t : turbulent kinematic viscosity, m^2/s
$\delta_{i,j}$: Kronnecker delta, $\delta_{i,j} = 1$ if $i=j$, $\delta_{i,j} = 0$, if $i \neq j$
ϕ : dependent variable

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