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Research Paper

CFD modelling of livestock odour dispersion over complex terrain, part I: Topographical modelling

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Odour from livestock production is an increasing problem in many countries. To reduce odours and establish the effects of livestock production on their surrounding communities, many studies have been carried out on odour dispersion using diffusion simulations and field experiments. Recently, computational fluid dynamics (CFD) has been effectively used to study odour dispersion. CFD can consider various atmospheric phenomena and topographical conditions to study the occurrence of odours and aerosol dispersions. The ultimate objective of this study was to develop an aerodynamic model to qualitatively and quantitatively predict odour dispersion originating from livestock facilities. This first of two papers, deals with the grid construction method, selection of fundamental design criteria and topographical modelling. A mesh model of complex topography, with a 3.6 km diameter and 2.5 km height, was developed with a fine resolution. Well known, commercially available, computational tools were used for the topographical modelling. An earlier wind tunnel experiment contributed to the selection of the grid size (to ensure grid independence), and the selection of time step and turbulence model for CFD simulation. In the second paper, methodologies for modelling of the dispersion phenomenon are presented. In the future, this model will be used to help ameliorate odour conflicts by predicting odour dispersion according to various meteorological and geographical conditions.

1. Introduction

In many countries, including Korea, the odour from livestock production is an increasing problem for rural communities. A survey of livestock industries in Korea revealed that 32.2% of livestock farmers had encountered complaints in the previous two years, and about 56% of these complaints were regarding pig farms (Hong, Lee, Seo et al., 2008; KSA, 2005). Furthermore, increasing awareness about the need for a healthy and safe residential environment has led to an

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Nomenclature

B_{full}	Dimension of length in prototype
B_{model}	Dimension of length in scaled model
g	Acceleration due to gravity
$\vec{J}$	Diffusion flux of scalar ϕ (kg m^{-2} s^{-1})
k	Turbulent kinetic energy (m^2 s^{-2})
r	Correlation coefficient
S_ϕ	Source term of scalar ϕ (kg m^{-3} s^{-1})
t	Time (s)
T_{full}	Dimension of time in prototype
T_{model}	Dimension of time in scaled model
u_i'	Velocity fluctuation (m s^{-1})
$\vec{v}$	Velocity of fluid (m s^{-1})
v_{full}	Dimension of velocity in prototype
v_{model}	Dimension of velocity in scaled model
X_i	Normalised temperature measured in the wind tunnel test
Y_i	Normalised gas concentration computed by the CFD model
$\overline{Y_i}$	Mean value of normalised gas concentration
ε	Turbulent energy dissipation rate (m^2 s^{-3})
ρ	Density of fluid (kg m^{-3})
ϕ	Arbitrary scalar – e.g., concentration of heat or gas
υ	Dynamic viscosity of fluid (m^2 s^{-1})

increase in odour-related complaints in the rural areas because, according to some scientific researches by Schiffman (1988) and others, health symptoms have arisen from the livestock odours. In the UK, for example, the general public is critical of livestock farming partially due to odour issues associated with these farms (Schauberger, Piringer, & Petz, 2001). To reduce odours and establish positive relationships between livestock industries and their surrounding communities, governments and related organisations have made various efforts. In many countries, standard regulations regarding the separation distance between an odour source and nearby residential areas are being established (Piringer & Schauberger, 1999). At present, many empirical guidelines are being used to estimate separation distance. However, the extent and rate of dispersion can vary significantly, depending on the location of odour release, odour concentration, atmospheric stability, and offensiveness of the odour sensation. Topographical features as well as unpredictable and unstable wind conditions, such as fluctuating wind speeds and changeable wind directions, hinder the analysis of quantitative odour dispersion. It is therefore beneficial to utilise simulations, verified through field experiments, when studying odour dispersion. To date, some field experiments and simulations have been conducted for dispersion predictions (Holmes & Morawska, 2006; Li, Liu, Leung, & Lam, 2006). Field experiments provide the most realistic results while measuring a very limited number of observations, even under various changing meteorological conditions.

Simulations, especially computational fluid dynamics (CFD), can predict detailed air movements and odour dispersion under various environmental conditions, and have become one of the most powerful tools for studying the atmospheric environments. Much research on the use of CFD for the study of atmospheric dispersion has been conducted. Most have focused on modelling the dispersion phenomenon through CFD in flat areas or to nearby areas (Diego, Pelegry, Torno, Toraño, & Menendez, 2009; Li & Guo, 2006; Lin, Barrington, Choinière, & Prasher, 2007; Riddle, Carruthers, Sharpe, McHugh, & Stocker, 2004). However, in South Korea topography is very important because approximately 70% of its land is mountainous. The most troublesome problems occur in the atmosphere close to the ground because this is significantly affected by the shape of the terrain. Therefore, detailed terrain modelling is crucial to simulate atmospheric dispersion. Building and meshing the grids, as a pre-processing procedure for CFD or other scientific applications, are generally achieved by user-developed tools or commercial software. However, several researchers developed their own methods or codes to create meshes over terrains (Chin, Won, & Hur, 2004; Jung & Kwon, 2006; Kakosimos & Assael, 2009; Khan, Odman, & Karimi, 2005; Lee & Kim, 2007). Tools are developed to convert raw geographic information into the desired form; commercial software requires much time and high computational cost to convert the raw information into vertices, edges, faces, and occasionally geometrical volumes (Chin et al., 2004). However, user-developed tools mostly use a structured grid, which can deteriorate the quality of the mesh close to irregular or distorted boundaries and steep features. User-developed tools also need to be modified when applied to other related research. Commercial tools can create a variety of unstructured grids and be used to analyse various cases, despite the inefficiency of the regular routines required by the software. Hussein and El-Shishiny (2009) simulated wind environments around heritage sites. They used GAMBIT (Fluent Inc., NH, USA), a commercial tool, and non-conformal meshes to create unstructured meshes over sites with complex geometry. Hanna, Hansen, Ichard, and Strimaitis (2009) also simulated the dispersion of a pollutant in industrial sites and cities a few kilometres in size. Appropriate grid sizing is an important requirement for a wide range of terrain to satisfy both the accuracy and the economic efficiency of the results. Prospathopoulos and Voutsinas (2006) studied the effects of several grid refinements on a three-dimentional (3-D) wind flow simulation through field measurements when a Reynolds averaged Navier–Stokes (RANS) solver was used. However, the suggested grid conditions had limitations for application to other terrains or research, especially when the large-eddy simulation (LES) model rather than the RANS model was used. Therefore, further research on topographical modelling is required.

The aim of this study was to develop an aerodynamic model for qualitatively and quantitatively predicting odour dispersion originating from livestock facilities. In this paper, the first of two, the methodology for designing a complex topography is suggested, and a 3-D grid model is presented with respect to the study area. The appropriate grid size is determined from a wind tunnel experiment and applied to the topographical modelling. A suitable time step size and the