Boussinesq Approximation of Hydrogen Dispersion in a Ventilation Model Using Finite Element Analysis

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Key Words: *Hydrogen, Dispersion, Boussinesq approximation, Stabilized finite element method.*

ABSTRACT

Hydrogen is expected as new fuel instead of fossil fuel. It will be used as fuel of a fuel cell for which development is performed actively. But it is difficult to experiment the hydrogen dispersion in case of hydrogen leaks. Therefore clarifying the hydrogen dispersion with numerical analysis becomes important. Furthermore, hydrogen dispersion under various conditions can be clarified with numerical analysis, which is useful to use hydrogen safely. This paper deals with computer simulation of the hydrogen dispersion by a finite element method. The mathematical model of hydrogen dispersion is governed by the momentum equations, the continuity equation and the hydrogen mass conservation equation. The model presented here is a three-dimensional, incompressible, non-stationary model. This paper describes a finite element method with the stabilization technique for solving Navier-Stokes equations and the advection-diffusion equation for hydrogen concentration like the Boussinesq approximation of thermal convection problems. We use Bercovier-Pironneau elements for the velocity and the pressure, and P1 elements for the concentration of hydrogen as the velocity. A suitable implicit time difference is also used. Numerical results are shown for a sample model [1].

Basic Equations:

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}\cdot\nabla)\mathbf{u} - 2\nu\nabla\cdot D(\mathbf{u}) + \nabla p = -\beta C\mathbf{g} \qquad \text{in } \Omega,$$

$$\nabla\cdot\mathbf{u} = 0 \qquad \text{in } \Omega,$$

$$\frac{\partial C}{\partial t} + \mathbf{u}\cdot\nabla C - a\Delta C = S \qquad \text{in } \Omega,$$

where $\mathbf{u} = (u_1, u_2, u_3)^T$: velocity vector [m/s], t: time [s], ν: kinematic viscosity coefficient [m^2/s], p : normalized gauge pressure [m^2/s^2], $\mathbf{g}$: gravity [m/s^2], β :coefficient [-], C : the mass concentration of hydrogen [mass%], a: the hydrogen diffusion coefficient in air [m^2/s], S: source term [1/s], D_{ij}: the rate of strain tensor [1/s] and

$$D_{ij}(\mathbf{u}) = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right).$$

Results: Figure 1 shows the hydrogen concentration at four sensors. We compare these results with the data of the reference [1]. Figure 2 shows the reference data. Both our results and the data are similar. We can say that we have more accurate verification of computational results than that in the previous paper [2].

Conclusions: The dispersion phenomena of hydrogen are modeled using the analogy of thermal convection problems with the Boussinesq approximation. The flow of hydrogen is grasped by using a stabilized finite element method.

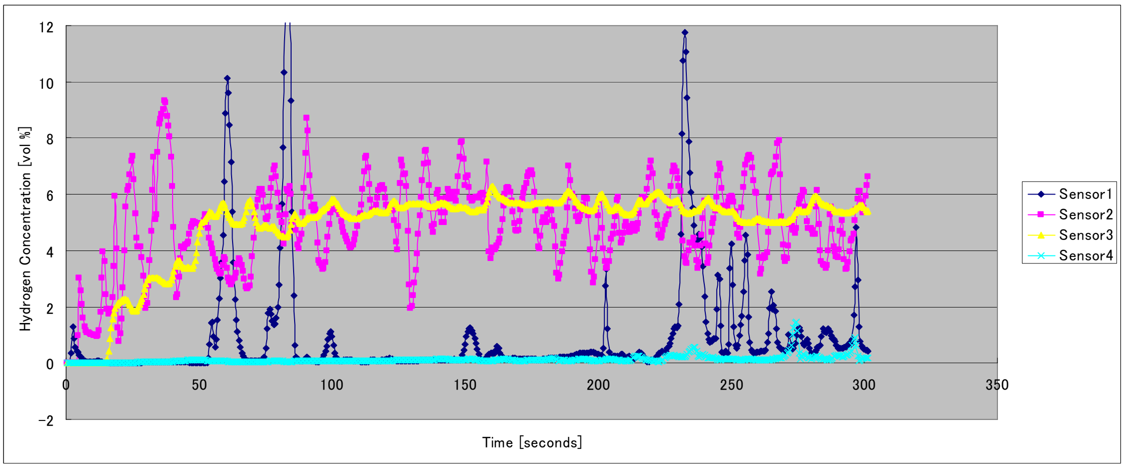

Fig.1 The hydrogen concentration at four sensors

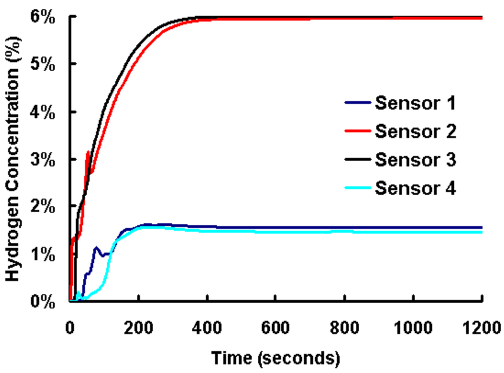

Fig.2 Stuart Energy's Data [1]

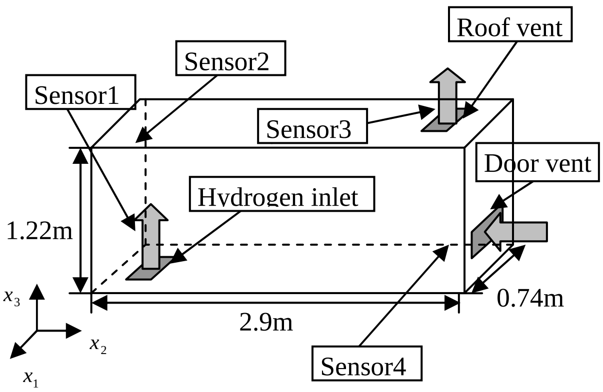

Fig.3 The Ventilation Model [1]

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