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Entrainment Analysis Based on the Field Synergy Principle and Air Terminal Device Design

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Abstract

The degree of jet entrainment is affected by the exit conditions and thus affect the air terminal device design. While investigations of jet exit conditions have been carried out by experiments and simulations, it can be considerable advanced by the theoretical analysis. Effect of velocity profile and turbulence intensity at jet exit on jet entrainment are examined based on the field synergy theory by calculating the mass transfer field synergy number, that is the synergy between the velocity vectors and the species concentration gradients for a given jet flow rate. It showed that the entrainment increases with the increase of the mass transfer field synergy number, and vice versa. The mass transfer field synergy number can be changed by the boundary conditions to strengthen or weaken the convective mass transfer of jet entrainment. This work has resulted in a better understanding of the convective mass transfer phenomenon of jet entrainment and give a guide for air terminal device design.

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Keywords: Field Synergy Principle; Convective Mass Transfer; Jet Entrainment; Terminal Device Design

1. Introduction

Jet is very important in building ventilation. Jet is strongly affected by entrainment of the surrounding contaminated air in the jet's mixing region. The degree of entrainment is affected by the design and exit conditions of the jet nozzle. And in fact, the mixing characteristics of jet is a typical convective mass transfer phenomenon.

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During the last several decades, numerical models, experimental investigations have been developed remarkably. Numerous investigations of jet exit conditions[1-3] have been carried out and yielded invaluable insights into the performance of a variety of configurations under a wide range of scenarios, however the design of an effective jet exit terminal device can be considerable advanced by the theoretical analysis.

The field synergy principle about the velocity and the concentration gradient provides a new idea to enhance or weaken the convective mass transfer in the most effective way. The field synergy is first proposed by Guo et al. [4] which is in the interest of revealing the essence from the viewpoint of velocity and temperature fields. Chen et al. [5-6] extended this concept to the convective mass transfer and fluid flow.

The purpose of this work is to study the effect of jet exit conditions on mixing based on the field synergy theory, which can give us a theoretical analysis to understand the mass transfer performance. By the method of numerical simulation, different velocity profiles and turbulence intensities of the air supply exit are investigated.

2. Field Synergy Principle in Convective Mass Transfer on Jet entrainment

Consider a plane free jet of supply air into a large expanse of ambient air. we will find that the jet mixes with the surrounding air. The width of the jet increases as the flow goes downstream. It would be expected that the concentration of supply air decreases with increasing x, while the concentration of ambient air increases with x. Thus means the ambient air has a mass transfer through some boundary, as illustrated in Figure 1.

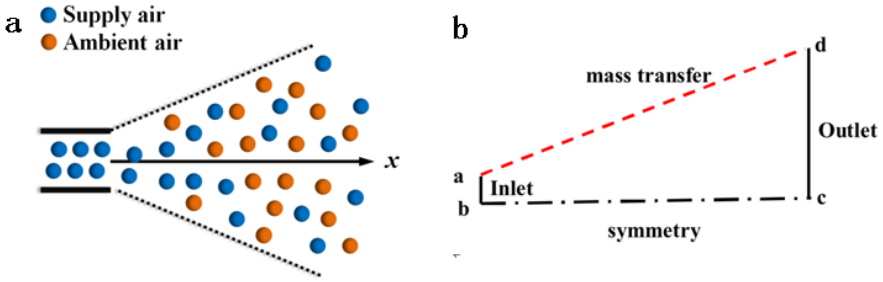

Fig. 1. (a) jet entrainment configuration; (b) convective mass transfer of ambient air into half region.

For convective mass transfer processes of jet, the steady-state two-dimensional species conservation equation without mass sources can be written as:

$$\rho U \cdot \nabla Y = \nabla \cdot (\rho D \nabla Y) \tag{1}$$

where U is the velocity vector, ∇Y is the mass fraction of ambient air, D is the diffusion coefficient.

Integrating this equation over the entire mass transfer domain, Ω

$$\iint_{\Omega=abcda} \rho(U \cdot \nabla Y)\mathrm{d}V = \iint_{\Omega=abcda} \nabla \cdot (\rho D \nabla Y)\mathrm{d}V \tag{2}$$

Transforming the volume integral to the surface integral yield of equation (2) on the left hand, the equation (2) can be written as