SCALE MODELLING OF SMOKE MOVEMENT IN LINEAR ATRIUM

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ABSTRACT

Atrium is a popular architectural feature in the Far East including Hong Kong in the past two decades. There are many technical issues in building services systems for the atrium, especially on fire safety. In case of fire, a plume will be formed which buoyancy as its driving force, and smoke layer will be formed by ceiling jet after the impingement of the plume to the ceiling. The hot smoke layer on the compartment shall have a clear zone for evacuation. However, it is found that in a linear atrium, a clear zone cannot be seen. It is because the smoke will travel a long distance as a ceiling jet allows more air entrainment. The smoke layer temperature is reduced and lost buoyancy for maintaining smoke layer at high level. Thus, smoke control system is important in a linear atrium, and this paper will apply the scale modelling method to study the smoke movement in linear atrium in order to design an appropriate smoke control system.

Keywords: linear atrium, scale modelling, smoke movement

1. INTRODUCTION

Atrium [1] has become a popular architectural feature in building construction of Hong Kong in the past twenty years. Many building services systems technical issues have arisen from the buildings with atrium design [2], particularly with fire safety aspect as an atrium fire is very different from that occurring in a traditional building. The complex internal layout in large modern atria would limit the application of traditional fire engineering designs. Smoke is identified to be a more critical issue than the thermal aspects in an atrium. Smoke control system must be designed carefully and guidelines for atrium smoke control have been worked out. There are three types of atrium that can be classified [2]:

- Cubic Atrium: the transverse dimensions are similar to its height.
- Vertical Atrium: the height is comparatively longer than the transverse dimensions.
- Linear Atrium: the transverse dimensions are longer than the height.

From the survey [3] of the geometrical shapes in 138 atria in 79 shopping malls in Hong Kong, 50 atria (36.2%) can be classified as linear. It is an important and challenging problem to establish appropriate design guides for local atrium design.

2. SMOKE MOVEMENT IN A LINEAR ATRIUM

In case of fire, people would die most likely by suffocating of smoke rather than burning by fire. Therefore, smoke control system in atrium is vitally important. Consider a typical room fire, plume will be formed and smoke will rise to the ceiling, once the plume impinges the ceiling, the plume travels along the ceiling by ceiling jet with constant velocity and depth until it impinges on the end wall. After that [4] , a group of waves are reflected back toward the jump near the fire room, traveling on the interface. Mixing occurs during the wall impingement process, but no significant entrainment occurs during the travel of the nonbreaking reflected wave. When these waves reach the jump near the fire room door, the jump is submerged in the warm gas layer, eliminating the entrainment of ambient lower layer air at this position. After several wave reflections, the ceiling layer which is more uniform in depth will be produced.

When fire occurs in a linear atrium, as the special architectural layout that the transverse dimensions in comparison with their height, so the smoke needs to travel for a long distance in order to impinge the wall, thus, it is believed that the smoke will lose buoyancy force due to the long traveling distance, and there will not be clear zone for evacuation. Therefore, studying the smoke filling process in linear atrium is important for designing the appropriate fire installation as well as the smoke control system.

3. SCALE TEST

Scale model can be used to study the smoke filling process in atrium. Because of space limitation in Hong Kong, full scale model is not feasible and the application of computational fluid dynamics (CFD) would be very time-consuming. Application of the scale model would be more economic and flexible. Experimental studies in scaled models require the preservation of many parameters. Scaling laws can be applied to the study of pre-flashover fires [2,5,6]. With the assumptions that smoke in atrium is a homogeneous gas at uniform temperature, constant outside ambient temperature, negligible viscosity and species transfer, and the gas is incompressible, by the conservation law and dimensional analysis [2,5], the scaling law for the velocity and length of the scale model and real size atrium is:

$$\left(\frac{L_M^*}{L_M^*}\right)^{\frac{1}{2}} = \frac{v_M^*}{v_R^*} \quad (1)$$

The scaling law for the time and length of the scale and real size atrium is:

$$\frac{t_M^*}{t_R^*} = \left(\frac{L_M^*}{L_R^*}\right)^{\frac{1}{2}} \quad (2)$$

The scaling law for the heat release rate and length of the scale model and real size atrium is:

$$\frac{Q_M}{Q_R} = \left(\frac{L_M^*}{L_R^*}\right)^{\frac{5}{2}} \quad (3)$$

Equations (1), (2) and (3) are scaling laws with preservation of the Froude number used in this study.

4. RESULT AND DISCUSSION

A clear plastic (acrylic) model of size 0.4 m × 1.2 m × 0.4 m was constructed to study the smoke filling process in a linear atrium, see Fig. 1. Quality images from X and Y were recorded from the experiments. The typical photographs for the heat source which placed in center of the model were shown in Fig. 2.

The flow that was formed traveling along the ceiling (Figs. 2a to 2b) with ceiling jet layer until it impinged on the end wall (Figs. 2b to 2c). In room condition, the smoke after impinging the wall should be reflected back toward and traveled on the interface to form a two-zone model. However, in linear atrium, the smoke layer traveled relatively long distance so that much air was entrained to the plume, it lost buoyancy force to reflect back the layer to form interface, the smoke moved downward (Figs. 2c to 2d) to form accumulation near the wall, then further accumulated toward central of the atrium; thus a clear zone layer could not be observed.

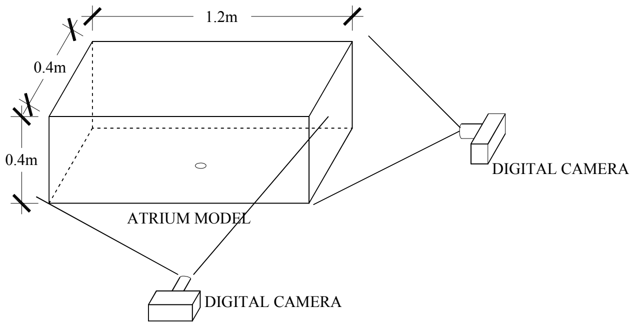

Fig. 1: Experiment setup of smoke filling process in atrium model

5. CONCLUSION

From the scale modelling experiment, it was observed that there was no clear zone in the atrium. A clear zone enables people to find an evacuation route in case of fire. Smoke extraction system is necessary to ensure keeping safety evacuation route in atrium. Before answering what is the appropriate design, such as the location of the installation (smoke detector, sprinkler and extraction vent), power of extraction fan, etc., a full-scale burning test will be carried out to study the real smoke filling up process in a real atrium, to compare the data with the atrium model, with different fire load as well as heat release rate. After that, optimal strategies of smoke control in linear atrium can be proposed by using scale model.

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NOMENCLATURE

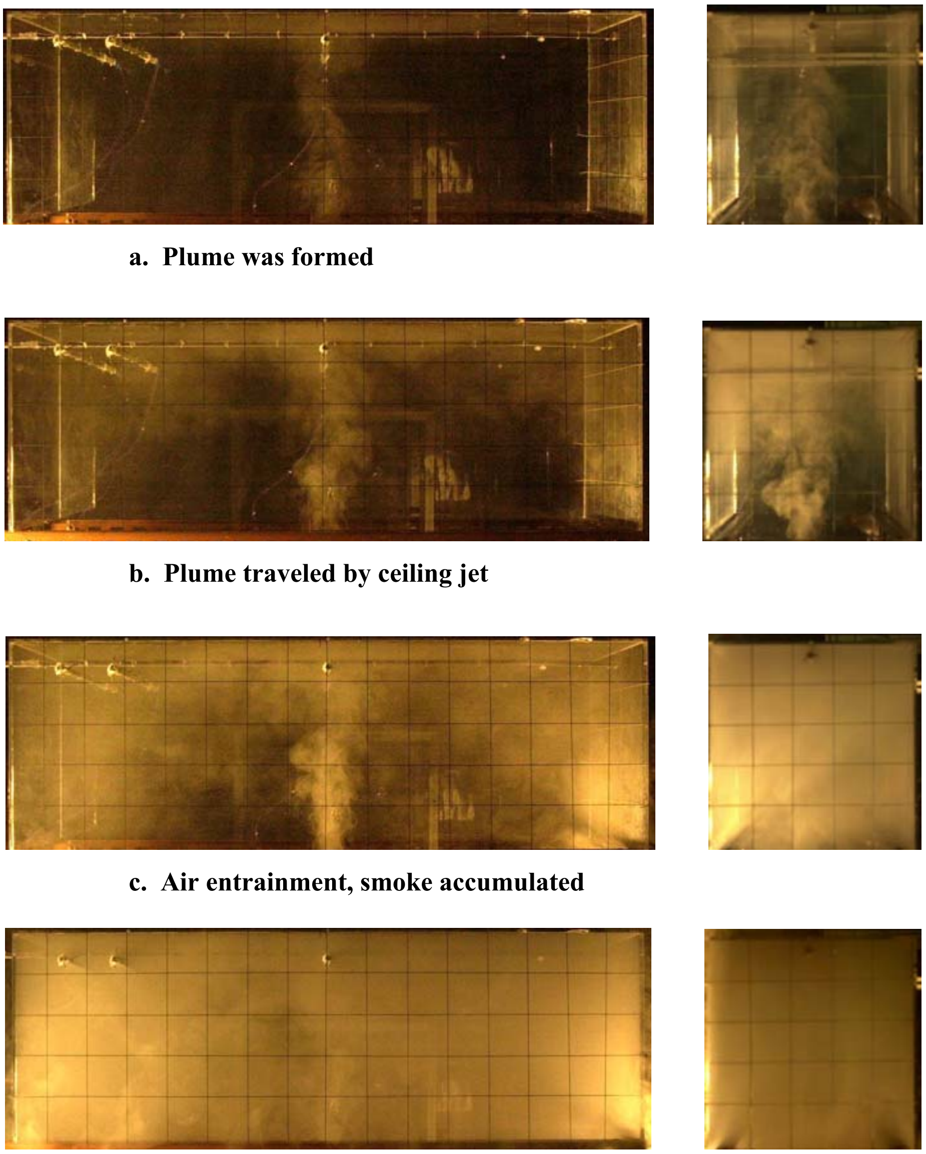
L	length, m
Q	chemical energy production rate, kW
T	temperature, K
v	velocity, ms^{-1}

Subscripts

M	of scale model
R	of full size

Superscripts

*	characteristic quantity



Front View **End View**

a. Plume was formed

b. Plume traveled by ceiling jet

c. Air entrainment, smoke accumulated

d. Smoke filled up the atrium

Fig. 2: Typical smoke filling for the heat source placed of model center

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