STUDY OF PLUME EQUATION USING SALT WATER MODELING

T.W. Cheung
Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

ABSTRACT

Many equations on fire-induced plume are available in the literature but the accuracy is unknown. Different methods are introduced to verify those plume equations. Salt water modeling is one of those commonly used methods. This modeling method is applied to study the fire-induced flows in a large atrium. In this paper, experiments will be carried out in a 1/40 scale salt water model on assessing the results predicted by the Morton-Taylor-Tuner plume equation for a point heat source. Accuracy of the equation will be checked and theoretical assumption is justified.

1. INTRODUCTION

In the past few decades, fire services system, especially smoke management, is increasingly important in building services engineering, because of the increasing number of atrium buildings. Other large open spaces include the shopping malls, atrium offices, airport, and sports arenas. In order to design an effective smoke control system, the prediction of smoke size and smoke movement is necessary. It is also an important factor in predicting the evacuation time, time of flashover and the amount of radiation heat release.

For atrium fires, the prediction of plume formation is especially essential. Because the height of the atrium is at least 20 m to 30 m, the effectiveness of the sprinkler and heat detector is significantly decreased. As the plume ascends due to the difference in density with the ambient air, entrainment would occur. Mixing between the plume and ambient air will decrease the temperature of the fire plume. Thus, the detection of heat and the operation of the sprinklers will be inaccurate or delayed due to this reason. Also, as the ascending of the plume to the ceiling needs a significant time period, the activation of the smoke detectors will be affected. Therefore, other methods to control or detect the fire are needed in atrium condition, one useful method is smoke control/management.

Smoke behavior has been investigated using different methods. This research project is attempted to study the plume equation using salt water modeling as reported in the literature. Accuracy of the equations and how they can be improved are studied.

In fact, besides salt water modeling, there are some other methods to study the behavior of plume. Full-scale experiments offer the most realistic result, but they are expensive and difficult to instrument and analyze. Drastically reduced-scale fire experiments can reduce the cost, but present the same instrumentation problems in full-scale and introduce scaling questions arising from low Reynolds number phenomena. In principle, mathematical solution of the partial differential equations of fire and flow physics should enable the determination of fire phenomena in enclosures. However, the issues of turbulence modeling are not fully resolved and three-dimensional unsteady flow in complex geometry is still not practical using even the largest available computers. Less fundamental mathematical lumped-parameter or "zone" models [1] reduce the mathematical complexity of the multi-compartment problem by treating the structure as a limited number of connected spatial zones. Their solution is amenable to computers, but with no guarantee to their accuracy or completeness. Indeed, the mixing between zones is only partially addressed, and no explicit attention is given to the time-dependent development of vertical flows in an atrium. For salt water modeling, it gives a clean environment for measurement, and provides good visual results in the experiments; inexpensive equipment and ease of experimental setup also give advantage to this skill. Most importantly, salt water modeling can model most of the features of the formation of fire plume and the plume movement. With these advantages, salt water modeling is adopted. In fact, besides predicting atrium fire, salt water modeling has also been applied to many fire problems including corridor smoke flow, ship board fires and compartment fires [2,3].

2. EQUIPMENT

An acrylic model – rectangular in shape, using 9 mm transparent acrylic sheet, with dimensions of 500 mm × 500 mm × 750 mm (H). An inlet and an outlet fitting are fixed at the top and the side of the model respectively to allow salt water and fresh water to flow in and out of the model. To ensure the fluid flow all pass through the fitting, rubber edges are added at the top opening with screw joint at the cover. This model is used to simulate a 1/40-scale atrium in the experiment (Fig. 1).

A plexiglass water tank – rectangular in shape, using 9 mm plexiglass with opening at the top, the dimensions of the tank are 700 mm × 700 mm × 1200 mm (H). The opening dimensions are 540 mm × 540 mm, so that the acrylic model can be put inside (Fig. 2).

A centrifugal water pump for the pumping of salt water, and a flow meter for measuring the flow rate of salt water into the acrylic model are shown in Fig. 3. The pump characteristics are shown in Table 1.

A digital video is also used for recording the gravity current [4,5] of the experimental results.

3. METHODOLOGY

The salt water modeling [3,6] experiment is conducted by placing an acrylic model into the plexiglass tank where the tank is filled with fresh water from the laboratory tap. Salt water is then pumped in the acrylic through a pipe work. The pipe work runs through a flow meter and some piping fitting. In the experiment, 6 mm tubings are used. The pipe work for the pumping is suggested to be at least 2 m long so as to make sure the salt water is well mixed inside the pipe. The inlet and outlet fitting of the acrylic tank enable the balancing of pressure inside the tank. As this experiment is trying to simulate a fire plume formation in a large atrium fire, no fitting is used to simulate any structure of a building (see Fig. 4).

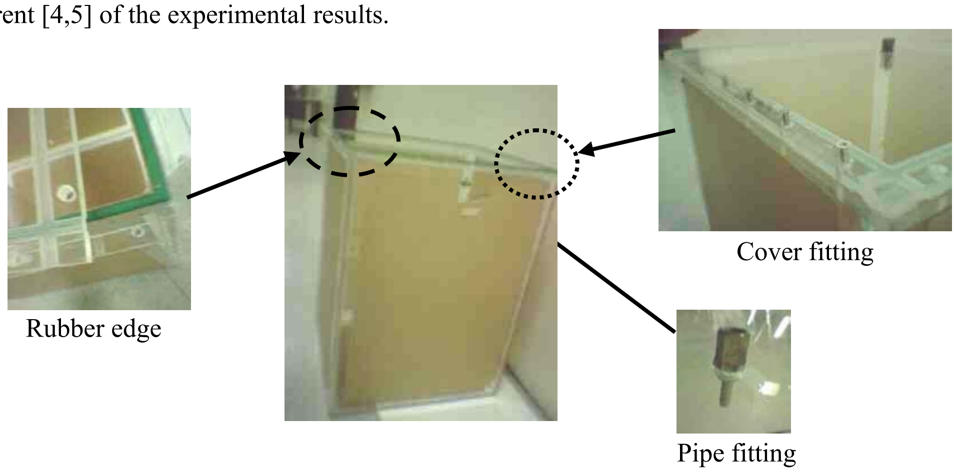

Fig. 1: Details of the acrylic model

Fig. 2: Plexiglass tank

Fig. 3: Pump

Table 1: Pump characteristic

Voltage	Hz	Watt	Ampere	Head available	Gph
220~240	50	6	0, 04	H-m 0, 6 Feet UK 1, 9	l/h 400 Gph UK 88
120	60	6	0, 096	Feet USA 1, 6	Gph USA 90

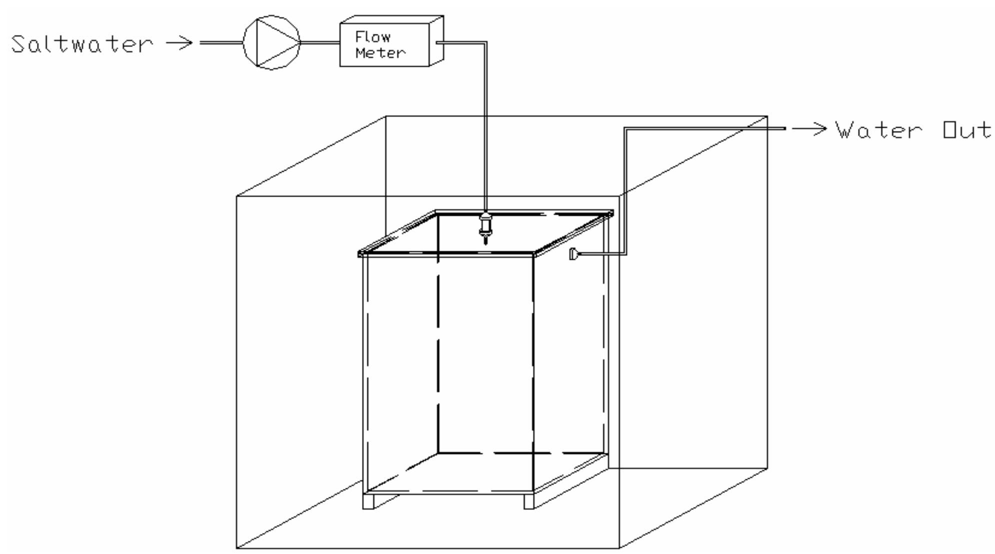

Fig. 4: Experimental setup

The larger tank will contain tap water from the laboratory and will stand for about 10 minutes to ensure the water is at room temperature. This makes sure that there is no heat transfer between the acrylic tank and the surrounding. Although there was no water running through the two tanks, it is still essential to place the acrylic tank inside the glass tank. This setup is to ensure the balance of pressure between the inside and the outside of the tank. If only the acrylic tank stands alone, the material used must be thicker or using glass as high pressure inside the tank, where this will increase the cost of the experiment.

In this research, the density of salt solution used will be ranged from 1003 kgm^{-3} (Fig. 5) to 1101 kgm^{-3} (Fig. 6) [6]. It is because when the solution density is less than 1003 kgm^{-3}, it will be too hard to measure accurately, and with density higher than 1101 kgm^{-3}, the solutions become opaque which make visual observation unreliable. The temperature of salt water will be at room temperature. Preliminary test on salt water characteristics had been carried out. Besides, for visual observation, red dye is added to the salt water.

Fig. 5: 1003 kgm^{-3}

Fig. 6: 1101 kgm^{-3}

For the acrylic model, it will be containing regular tap water from the laboratory at first, with water conditions: pH 6.8, density 1000 kgm^{-3} and at room temperature. When the experiments start, salt water will be pumped into the tank to carry out the simulation.

To obtain a three-dimensional result from the experiment, a mirror can be placed on the top of the acrylic tank at a 45^o angle to show the plan view of the gravity current in the same plane as the elevation view for video recording.

Once the two solutions are prepared, temperature and pH of both solutions must be recorded down. Then the acrylic tank is lowered down into the plexiglass tank, and the pump will be turned on when all the apparatus are ready. Also, the digital video will be turned on to record the gravity current simultaneously.

It should be noted that the salt water modeling does not simulate any heat transfer phenomenon between the fire plume and the surrounding. Also, there was no simulation of heat transfer from the plume to the room surface, heat through the wall and from the room to outside. This experiment is focused on simulating the formation of the plume.

4. PLUME EQUATION

This research is trying to study the accuracy of the plume equation. Among the many equations in predicting the formation of fire plume, the Morton-Taylor-Tuner plume equation was chosen for study.

In Morton-Taylor-Tuner plume equation [7], a point heat source assumption was used. A plume model is shown in Fig. 7. In this plume model, the mass flow rate m into the plume at height Z above the fire source can be presented in terms of the plume half width b, entrainment constant α, density of ambient air ρ_∞, temperature of ambient air T_∞ and local vertical plume velocity component along the plume center axis w_m.

The plume equations are expressed as follows:

$$m = \pi\rho_\infty w_m b^2 \quad (1)$$

The parameters b and w_m are given as follows:

$$b/Z = 6\alpha/5 \quad (2)$$

$$w_m = (C_0/Z)^{1/3} \quad (3)$$

The constant is related to the heat release rate Q of the fire source:

$$C_0 = (25/45\pi)(gQ/\rho_\infty C_p T_\infty \alpha^2) \quad (4)$$

This research is mainly on studying the accuracy of the equation, and also trying to study the feasibility of the theory of point source.

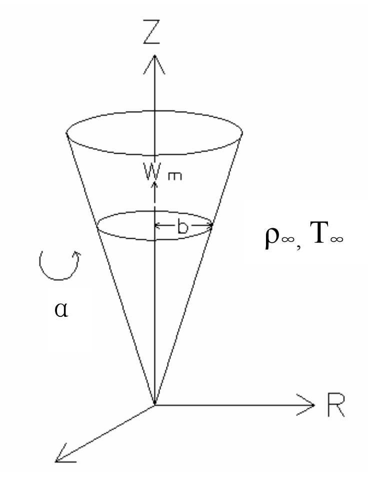

Fig. 7: Plume model

5. CONCLUSION AND FUTURE WORK

Some preliminary tests had been done on the salt water characteristics. In the coming semester, salt water modeling experiments will be carried out. All the results will be studied and analyzed, and compared with the mathematical results obtained using the plume equations. Finally, the accuracy of the plume equations and the possible solution on how to improve the plume equations will be suggested.

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Q & A

No questions.