A Study of Temperature Field with Fire Sources in a Tall Building

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1 INTRODUCTION

Tall building is constructed to accommodate large machinery of nuclear power plant for normal operation and maintenance works. Part of this tall building is vertically segmented with gratings to allow the access to tall equipments. Once fire incepted in the building, the natural convection transfers the generated heat and combustion products to these segmented spaces and the environmental condition and visibility in the building deteriorate by the heat and combustion products accumulation. The transient natural convection arising from an incipient fire in a residential room has been studied extensively and most residential room has this typical height to control the damage of fire. It is well known that the induced convective flow depends upon the size and location of the fire, the room geometry, and a host of other variables [1,2]. The height of tall building of nuclear power plant is ten times higher than that of typical residential room. The role of the buoyancy force on the natural convection in this tall building becomes much larger than that in a typical residential room. A series of experiments in a toll building has been carried out with crib and flammable liquid fire sources by measuring vertical temperature distributions to investigate the vertical heat transfer mechanisms.

2 EXPERIMENTAL SETUP

Experiments have been carried out in an experimental chamber of 25 m (length) x 25 m (width) x 22m (height) with a 6.5 m (width) x 2 m (height) opening. The experimental chamber was vacuumed with a ventilation system at a rate of 90000 m^3/h. Two kinds of fire source were used in this experiment. One is an oil pan of 0.9 m x 0.9 m filled with 5 l of heptane, another is a crib of 0.73 m x 0.73 m cross section. A crib is constructed with Japanese #2 crib of 0.73 m x 0.73 m x 0.7 m. Two or three #2 cribs were stacked to increase heat release rate. An oil pan of 0.73 m x 0.73 m filled with 1.5 l of heptane was used to ignite crib. The duration of this oil pan fire was approximately 80 seconds. The duration of the crib fire was 180 seconds. After the free burning, the crib was extinguished with water. The oil pan fire of 0.9 m x 0.9 m was also carried out to see the effect of cooling of water on the vertical temperature distribution. The duration of the free burning was approximately 240 seconds. A 20 m long thermocouple tree was used to measure the vertical temperature distribution at 3 m, 6 m, and 12 m from the fire source. Thermocouple junctions were located at every one meter. The experimental conditions are shown in Table 1. Experiments 14N301, 14N302, and 14N303 were carried out to investigate the effect of heat release rate on the vertical temperature distribution.

Experiments 15N301, 15N303, and 15N304 were carried out to investigate the spread of the fire plume in the space. Experiment 15N302 was carried out to investigate the vertical temperature distribution without water application.

3 EXPERIMENTAL RESULTS AND DISCUSSION

The vertical temperature distribution was plotted with the time after ignition. The vertical temperature distribution of experiment 14N301 is shown in figure 1. Temperature is shown in Celsius degree. Clear temperature rise was seen after t = 25 s near the ceiling of the experimental chamber from H = 14 m to 20 m. Temperatures from H = 12 m to 18 m increase from t = 70 s to 180 s. Temperatures from H = 12 m to 18 m decrease after water application at t = 180 s. Lines of 33 and 34 degree drop sharply at t = 180 s. The vertical temperature distribution of experiment 15N304 is also shown in figure 1. Temperatures between H = 8 m to 20 m form t = 40 s to 180 s are with many curved isothermal lines, which indicates the flow field is non-steady.

Table 1: Experimental Conditions

EXPERIMENT	FIRE SOURCE	THERMOCOUPLE TREE LOCATION
14N301	CRIB 26 kg	L = 6 m
14N302	CRIB 53 kg	L = 6 m
14N303	CRIB 78 kg	L = 6 m
15N301	CRIB 57 kg	L = 6 m
15N302	HEPTANE 5 l	L = 6 m
15N303	CRIB 56 kg	L = 12 m
15N304	CRIB 55 kg	L = 3 m

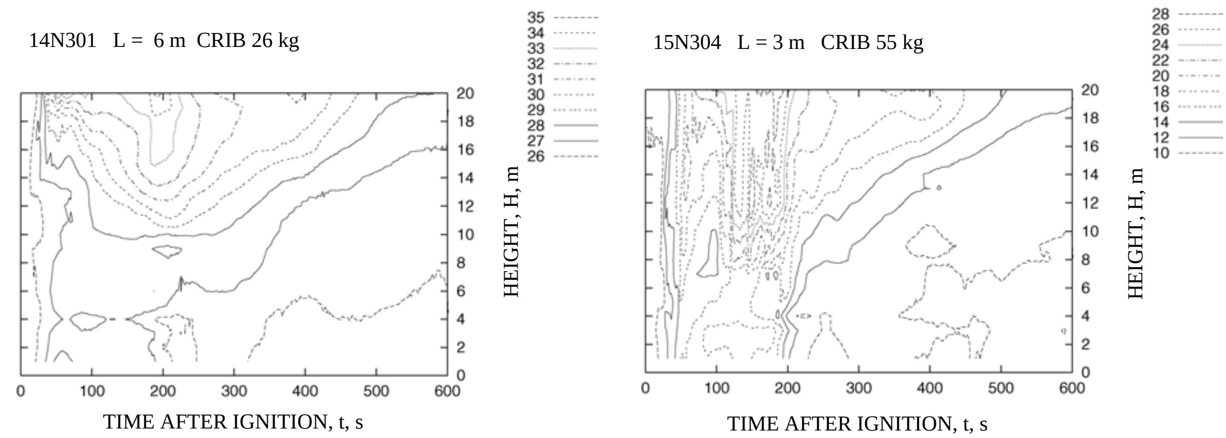

Figure 1. Vertical temperature Distribution in experimental chamber with time.

As seen in figure 1, a temperature field is formed in the experimental chamber. In this density field induced by the temperature distribution, internal waves may be excited by non-steady flow of experiment 15N304 as seen in figure 1. The angular frequency of the Brunt-Vaisala frequency, N is [3]

$$N = [- (g / \rho) (d \rho / dz)]^{1/2} \qquad (1)$$

Assuming the gas is perfect gas, the density ρ is obtained from temperature record. The square of the Burnt-Visala frequency in the experimental chamber is shown in figure 2. The negative value of the square of the Burnt-Visala frequency indicates that no internal wave is propagating in that area. The positive value of the square of the Burnt-Visala frequency indicates that internal wave which angular frequency is smaller than the Brunt-Visala frequency is allowed to propagate in the area. A crescent shaped positive area of N^2 = 0.02 is seen at the middle of the experimental chamber in both cases. The lower boundary of the area of N^2 = 0.02 lowered after t = 120 s for the case of 14N301 and t = 50 s for experiment 15N304. Small crescent shape negative value area of N^2 appears near H = 20 m after t = 200 s for experiments 14N301 and 15N304. A band of negative value area of N^2 is seen around H = 4 m in experiment 15N304. Scattered negative value area of N^2 are seen from t = 0 s to t = 200 s in figure 2. By converting the measured temperature field into the Brunt-Vaisala frequency plot, a normalized plot of density field in the experimental chamber is obtained. The frequency of the allowed internal wave is from 0 Hz to 2.25 x 10^{-2} Hz for N^2 =0.02.

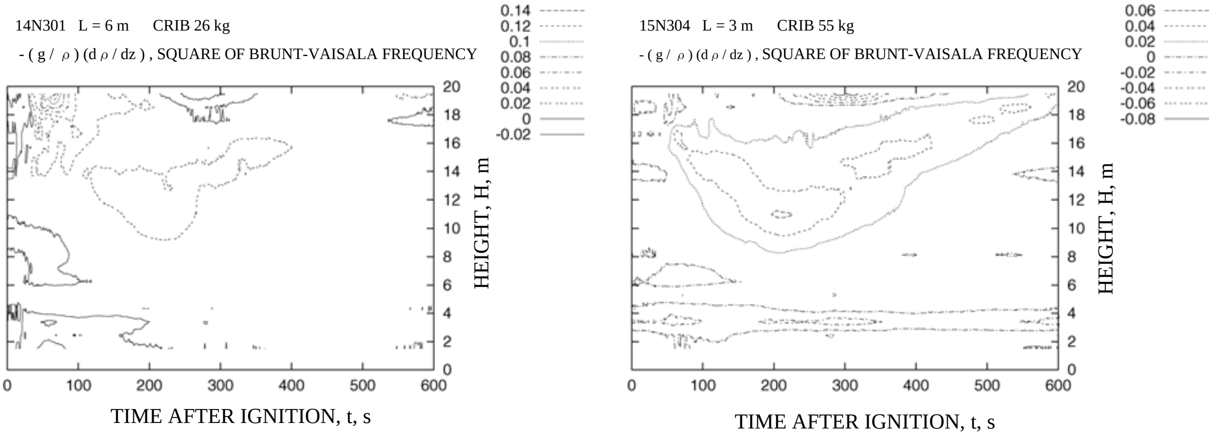

Figure 2. Brunt-Vaisala frequency distribution in experimental chamber with time.

Due to the mixing by the convection in the experimental chamber, the density of the fluid changes with time. The normalized density change velocity depends on the convection induced by fire source or water-cooling and the stability of the density layer. To investigate the effect of the stability of the density layer on the mixing of the density layer, the normalized density change velocity, B is defined as

$$B = (1/ \rho) \, d \rho / dt \qquad (2)$$

The normalized density change velocity, B of experiments 14N301 ~ 15N304 are plotted with the square of the Brunt-Vaisala frequency, N^2 in figure 3.

The negative value of B indicates the heating period and the positive value of B indicates the cooling period. The plots of experiments 14N302 and 14N303 differs from that of experiment 14N301 that fire source is smallest among three cases. Large velocities are seen N^2 > -0.03 in experiment 14N301. During the heating period of small value of the Brunt-Vaisala frequency N^2 < -0.03, the normalized density change velocity, B is seen near 0. Plots of experiments 15N301, 15N302, and 15N303 show similar distribution in figure 3. Plot of experiment 15N302 which fire source is an oil pan appears around B = 0 line. The natural convection induced by the fire source seems to be dominating the heat transfer in the experimental chamber during the heating period of N^2 < -0.05 excluding experiment 15N304. Larger scatter is seen for the plot of experiment 15N304 during the period of N^2 > -0.05, which horizontal separation from the fire source to the thermocouple tree is smaller than that of experiment 15N301 or 15N303.

The density gradient and the horizontal flow velocity affect the stability of the density gradient. The normalized density change velocity seems to be affected with the flow turbulence that depends on the strength of fire source and the distance between the fire source and the thermocouple tree.

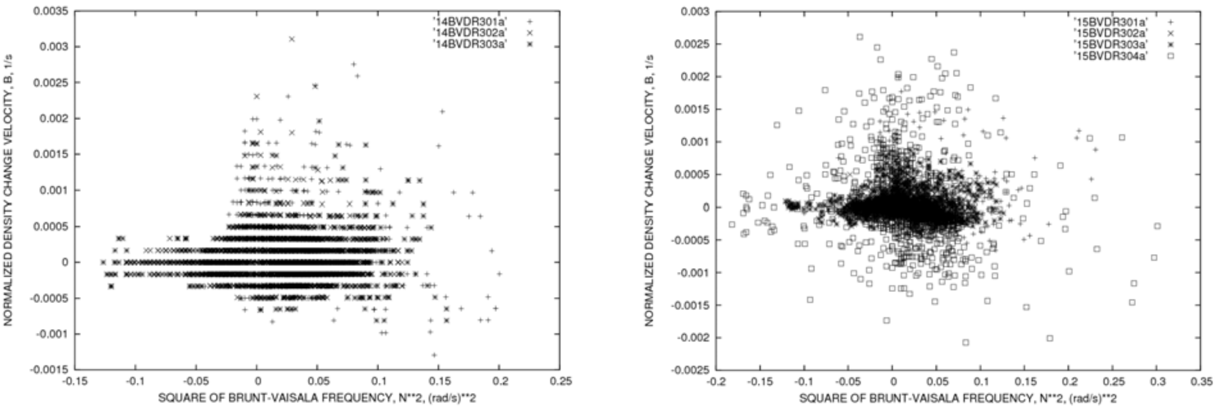

Figure 3. Normalized density change velocity with square of Brunt-Vaisala frequency

4 Conclusions

Experimental temperature distribution in a tall building was examined using the Brunt-Vaisala frequency plots. Excluding the initial heating period and the cooling period, the square of the Brunt-Vaisala frequency is positive, which indicates the formed density gradient is stable and the natural convection is suppressed. A crescent shape area of internal wave allowed area was found in the plot. The mixing rate of density layer was estimated from the normalized density change velocity plotted with the square of the Brunt-Vaisala frequency to see the effect of density layer stability. The convection dominating heat transfer is seen during the heating period.

5 Acknowledgments

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