M6-016 Sprinkler Effects on Smoke Filling in Small Compartment

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ABSTRACT

Smoke and fire gases formed in most unwanted fires, are dangerous products of combustion that have critical influences on life safety, property protection, and fire suppression practices in building. The automatic sprinkler system is perhaps the most reliable method available for controlling fire and smoke. This paper examines sprinkler effects on smoke filling in small compartment. The fire simulation was carried out using the NIST Fire Dynamic Simulators (FDS) model. The inputs for the model were taken similarly to those of Chung, K-C and Tung, H-S experimental work (2005). The results of this work show that smoke obscuration level tends to decrease in sprinkler turned-on condition than no sprinkler used in the small compartment. Smoke filling time of the sprinkler fire scenario may have a 10-20% faster compared to the un-sprinkler one. Room temperature, burning rate and heat release rate decrease after sprinkler activation.

Keywords: smoke filling, obscuration, sprinkler effect, burning rate, heat release rate, temperature

1. Introduction

Smoke is the collection of airborne solid and liquid particulates and gases emitted when a material undergoes combustion or pyrolysis, together with the quantity of air that is entrained or otherwise mixed into the mass. The effect of exposure to smoke is a very complex function of the magnitude of the smoke signature, for example, concentration of gas species, visibility reduction, temperature, radiant flux, and the duration of the exposure [1-4]. Smoke may adversely affect the building occupants, the fire brigade members, the properties, and the mission continuity in a building fire. Smoke inhalation is also a danger of smoke that can cause serious injury and death. Therefore, to understand the phenomenon of smoke spread and fill in a compartment is an important factor for life safety design. Especially, the smoke filling processes in a compartment must be quantified for the evaluation of the critical obscuration rate and the time for the occupant evacuation assessment [4-5]. Recently, many computational methods for determining smoke filling time and obscuration rate in a confined space or small compartment have been reported for fire safety design purposes [5-6]. Most buildings are required to install sprinkler systems under the local fire regulations in many countries. The automatic sprinkler system is perhaps the most reliable method available for controlling fire and smoke [7]. It is widely accepted as the most efficient form of automatic fire detection and extinguishment. For a small compartment, the sprinkler system can play a very important role for the suppression of fire. This paper examines sprinkler effects on smoke filling in small compartment by a modified pool fire simulation model using FDS (Fire Dynamic Simulator) [6].

2. Fire Modelling

The geometry of room for fire modeling were taken similarly to those of Chung, K-C and Tung, H-S experimental work (2005) [5]. The room model sizes are 13 m * 7 m sides and 3 m height. The room has one door, one window (vent) and one exhaust vent.

The sprinkler was placed in the middle of the room. The burning materials are made of paper having a heat release rate of 500 kW/m^2. The source of fire is placed next to the paper. With the dimension mentioned above, than the grid with size of 120 x 70 x 30 cm was selected. The grid size is considered to be sufficient for the current simulation. In addition, it could also reduce the iteration time needed. In this simulation, the door, window and exhaust vent were opened. The size of the door is 2 m height and 1 m width. Meanwhile, the window and the exhaust vent sizes are 0.6 m width and 1.2 m height.

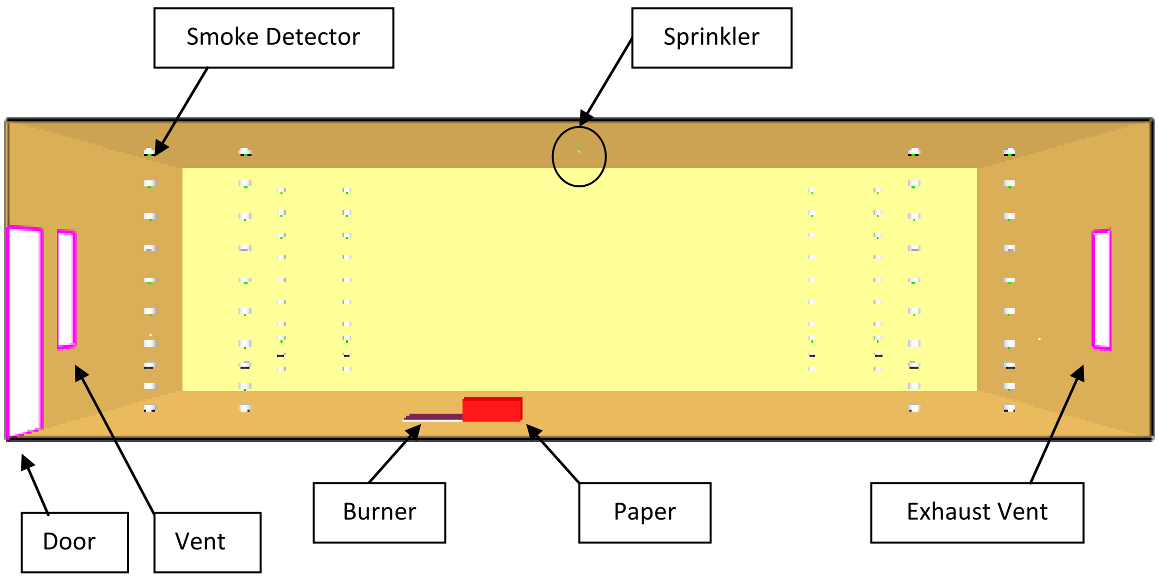

Figure 1. Room Front view

Tabel 1. Parameter and Conditions Used in Simulation

Parameter	**Value**
Test size	12 x 7 x $3m^3$
Grid point	120 x 70 x 30
Calculated Time	220 s
Initial temperature	30°C
Fire Source	

Heat release rate (kW/m^2)	Q= 500
Sprinkler RTI $(ms)^{1/2}$ C-factor $(m/s)^{1/2}$ Activated temperature (^oC) Flow Rate (l/min) Location (m)	 105 0.647 68 120 (6,3.5,2.85)
Paper Conductivity (W/m.K) Specific heat (kJ/kg/K) Reference Temperature (^oC) Heat of Reaction (kJ/kg) Heat of Combustion (kJ/kg) Density (kg/m^3)	 0.18 1.34 150 2700 17000 930

The size of fire (burning rate) or HRRPUA (Heat Release Rate Per Unit Area) is 500 kW/m^2, with a fire size of 0.7 m x 0.7 m [5]. Fire will burn the paper before it spreads to other material. In the model, the smoke generated will be recorded locally by using a number of smoke detector on designated locations.

3. Simulation Results

Simulation results on the evolution of smoke, fire and temperature developments are presented in the following parts.

- **Smoke Development**

From the Figures 2 to 5, it can be seen that the spread of smoke in sprinkler condition is wider than the un-sprinkler condition. This is because the mass of water from a sprinkler is heavier than the smoke's, so that the amount of smoke at the upper level of the room is reduced. Consequently, smoke is pushed down to the lower area of the room which then filled with smoke. With terms of distance from the human perspective, the condition of the use of sprinkler far better perspective because people can rarely be far away. This can also increase the opportunity for people to find a way out and save himself when the fire occurred.

Substances from combustion which can be categorized as a drug, such as: carbon monoxide, hydrogen cyanide, carbon dioxide, and a reduction in the amount of oxygen. The following is the amount of substances concentration of drug that can cause loss of consciousness if being inhaled for 30 minutes, i.e.CO not exceed 1400 ppm, HCN not exceed 80 ppm, O_2 not exceed 12%, and CO_2 not exceed 5%

- **Smoke Development**

Sprinkler **Non Sprinkler**

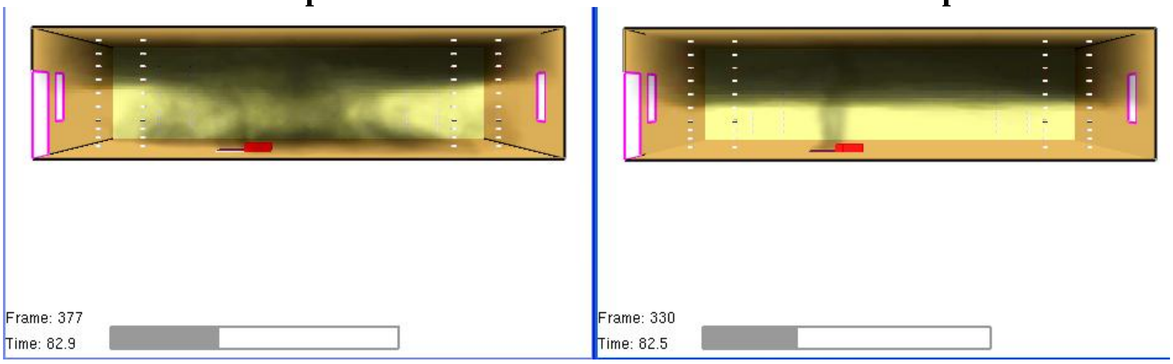

Figure 2. Smoke development at t = 82 s

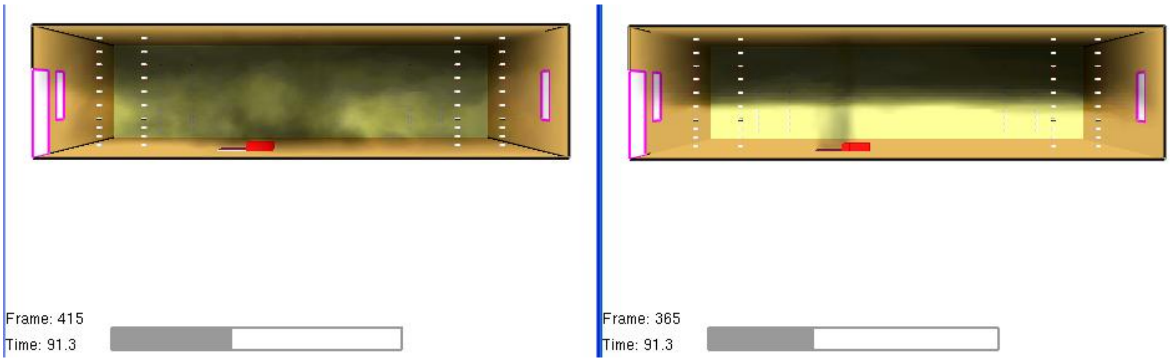

Figure 3. Smoke development at t=91 s

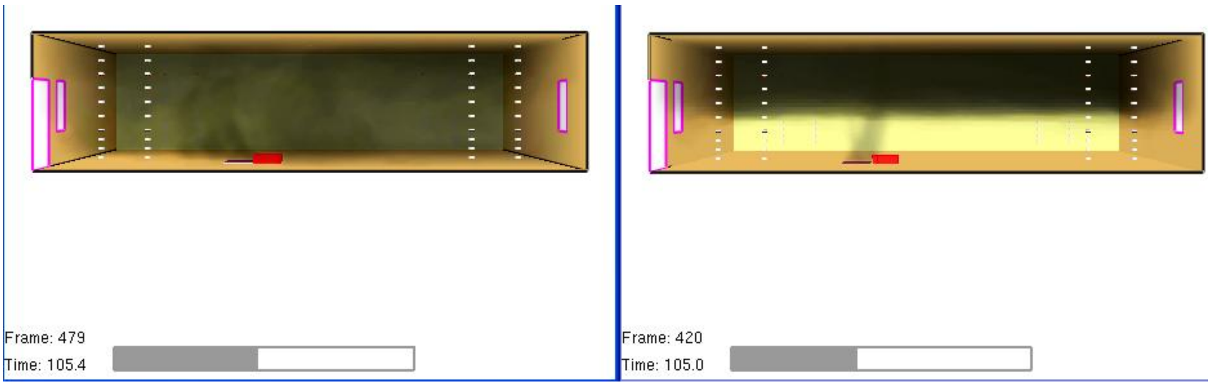

Figure 4. Smoke development at t=105 s

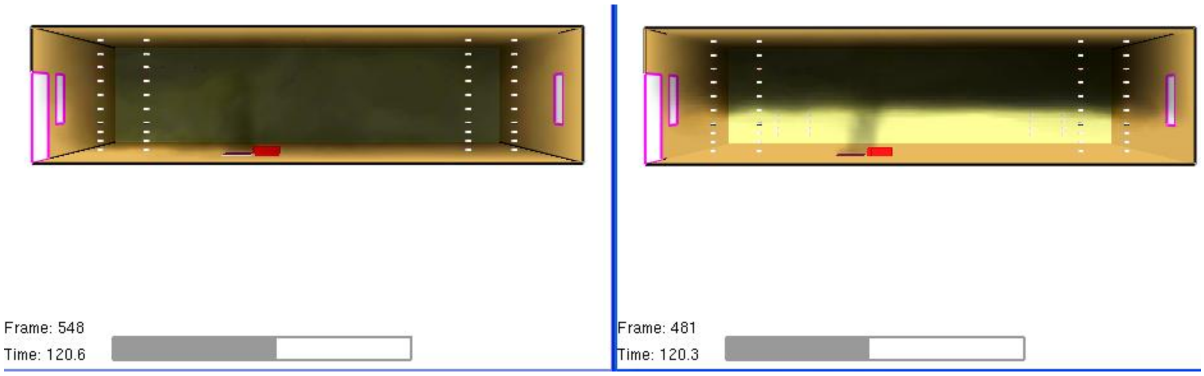

Figure 5. Smoke development at t=120 detik

- **Fire Development**

Sprinkler **Non Sprinkler**

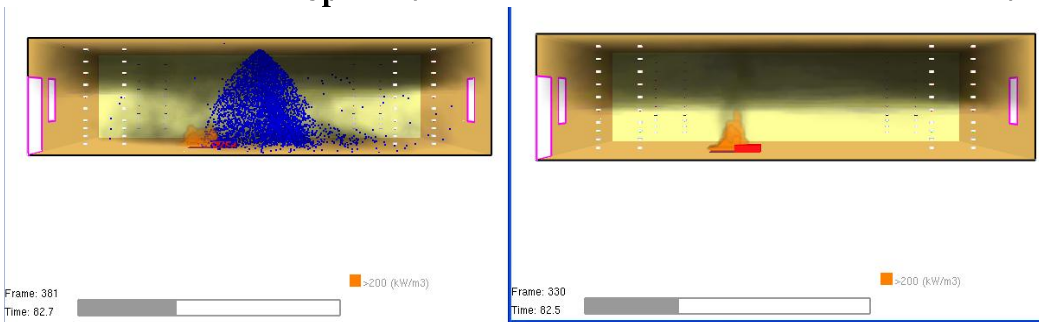

Figure 6. Fire development at t=82 s

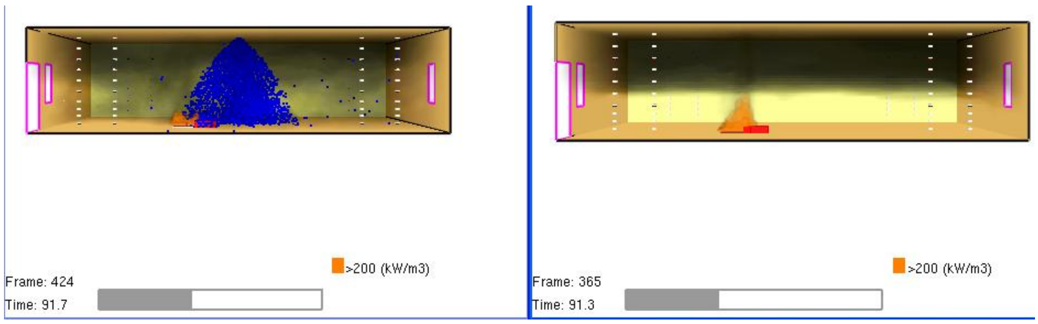

Figure 7. Fire development at t=91 s

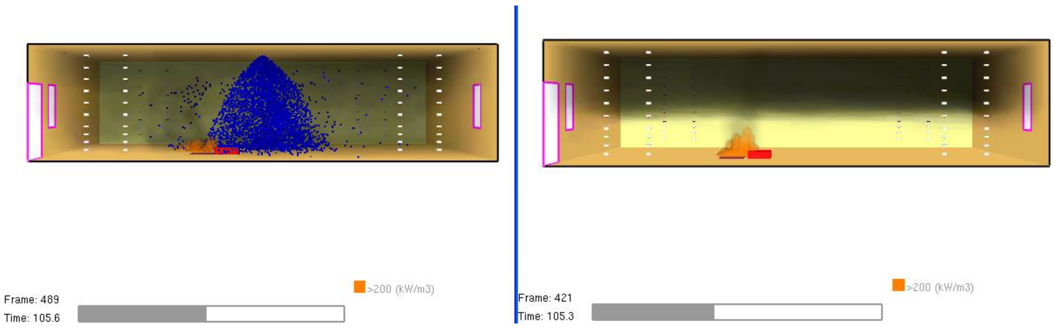

Figure 8. Fire development at t=105 s

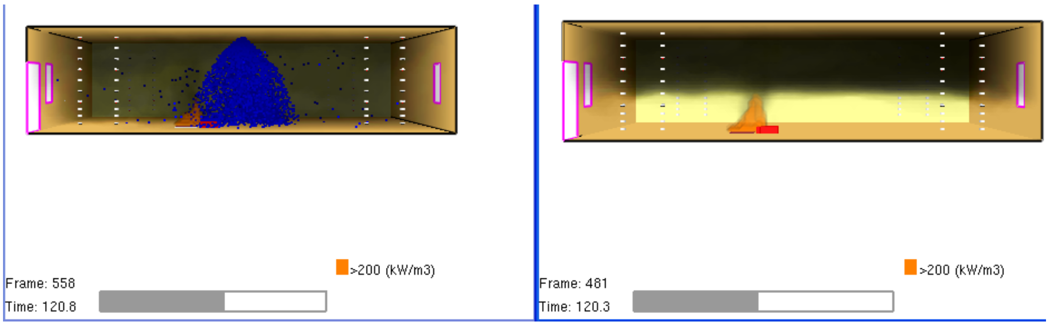

Figure 9. Fire development at t=120 detik

Figures 6-9 show that the sprinkler take important role in preventing the spread of fire to other materials in the vicinity of the fire source (ignition source). Sprinkler can produce water curtains that prevent the occurrence of a convective fluids to the nearest material. Resilience of the material nearest the fire will also increase due to the wet nature of the water resulted [5].

- **Temperature Distribution**

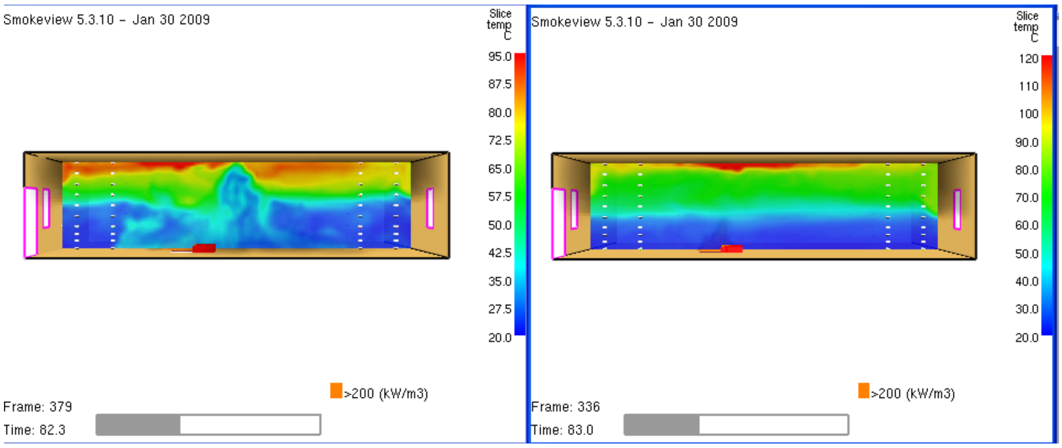

Figure 10. Temperature distribution at t=82 s

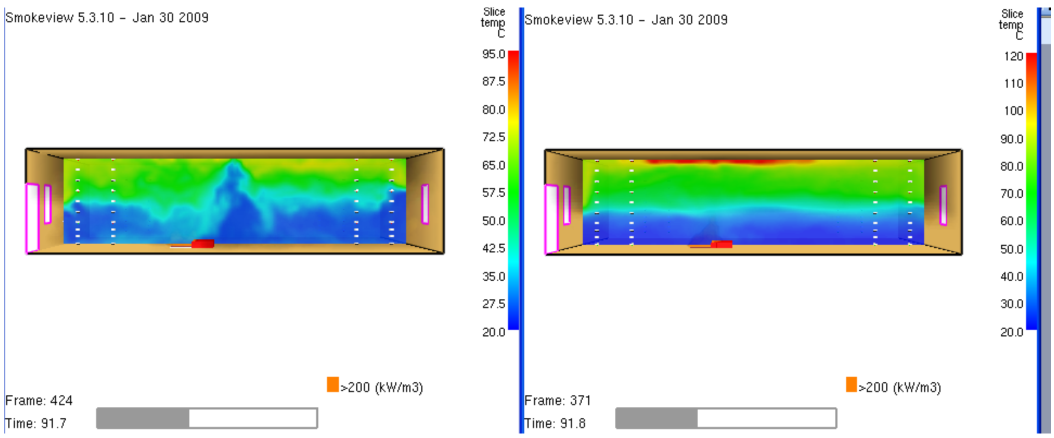

Figure 11. Temperature distribution at t=91 s

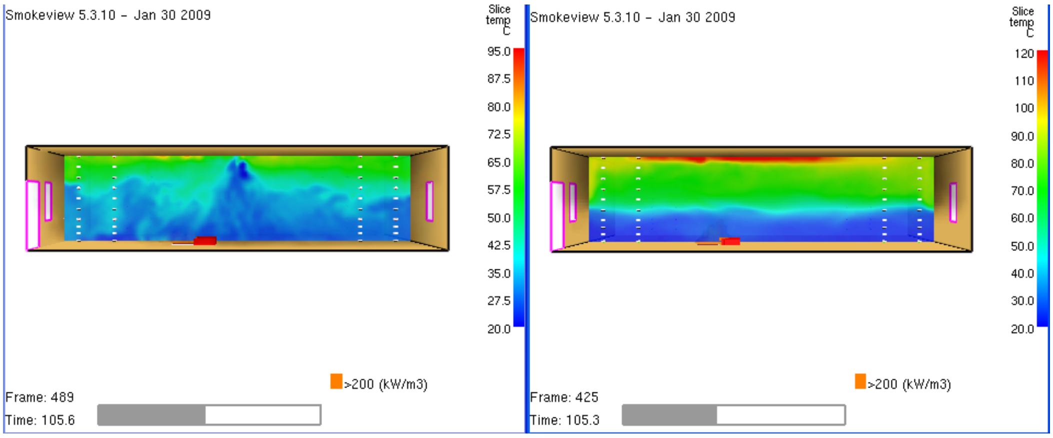

Figure 12. Temperature distribution at t=105 s

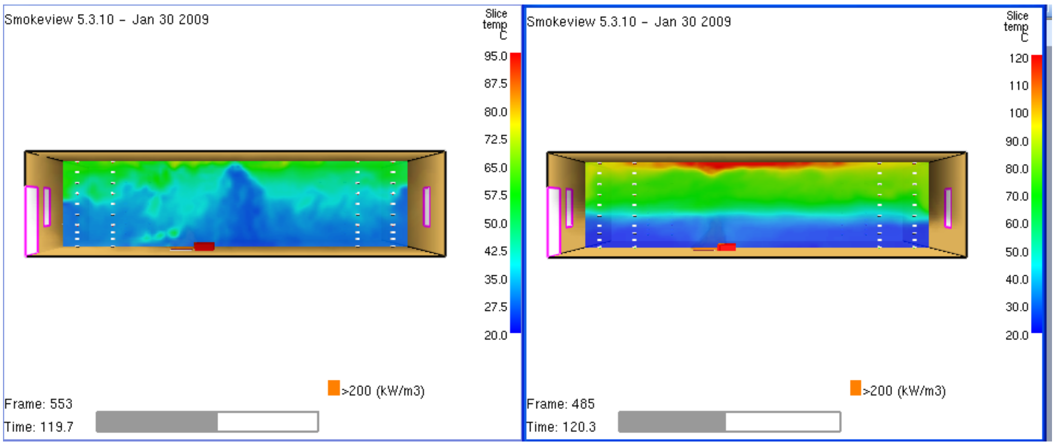

Figure 13. Temperature distribution at t=120 s

From above figures (Figures 10-13), shortly after the sprinkler was turned on the room temperature moderated to lower values than the conditions without sprinkler. In the conditions with the sprinkler, at the 82s, the room temperature around roof (ceiling) was around 85^{o}C while otherwise in a condition without a sprinkler, roof temperature around 110^{o}C. At 45 seconds after the sprinkler was turned on, the roof temperature is 57.5^{o}C and temperature at the middle of the room has been reduced to 35^{o}C. Otherwise in a condition without a sprinkler, i.e. 120s, the roof temperature 120^{o}C and temperature at the center of the room become 70^o

4. Graphical Analysis

In this work it is also possible to analyze the time to time development of temperature, heat release rate, and smoke in the designated room. These parameters is important to note, especially for analyzing time to escape which allows people to evacuate from the room and reduce the impact that possibly generated by these unwanted fire.

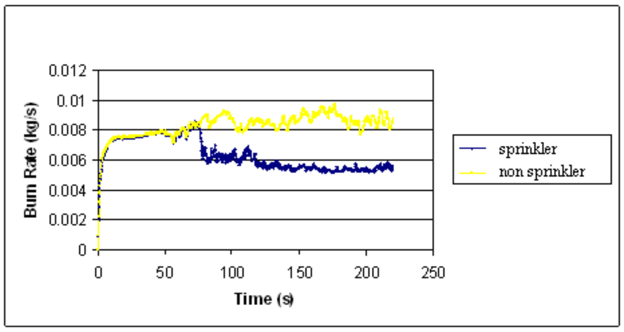

Figure 14. Burn Rate versus Time

From Figure 14, it can be seen that the burn rate tends to decrease significant after sprinkler activation. This indicates that the sprinkler works effectively in lower burn rate. In the condition without a sprinkler, after the 100s, burn rate propagation occurs less stable. This is due to other substances (in this case material paper) starting to burnt. With a few times temperature increasing in the graph, it can estimated that the unstable fire propagation process has occurred and controlled by ventilation. The first increase called flashover after air mixture is rich. This stage is using fuel derived from paper that is located next to the fire.

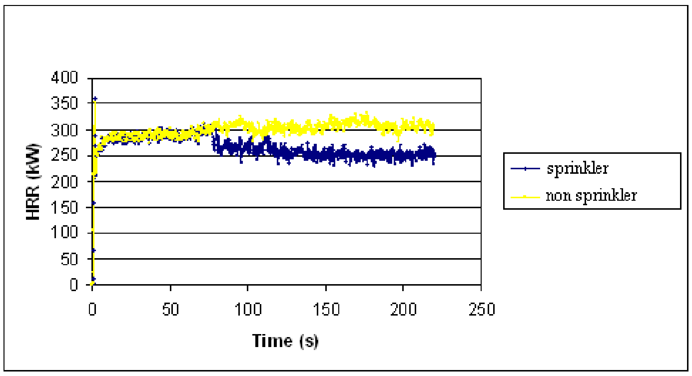

Figure 15. Graphic HRR versus Time

From figure 15, one can note that the heat release rate by fire tends to increase until the first 75s. After sprinkler activation the HRR value decreased quite significantly at about 20%.

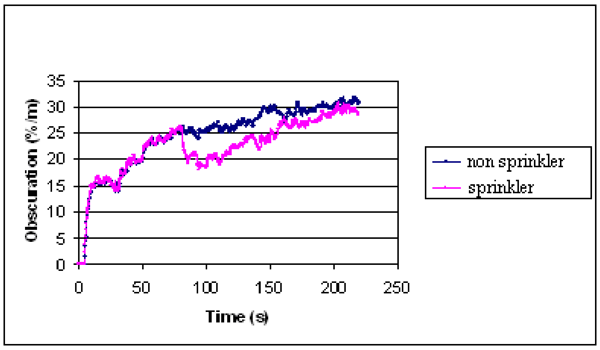

Figure 16. Graphic Obscuration versus Time

Obscuration is a measure of smoke in the room that determine human level of vision. The higher the percentage of obscuration, the shorter distance we could see and conversely [2]. Thus, obscuration is a very determining factor in fire safety. One should keep the obscuration value in a small value. One of the methods to minimize obscuration level is to use tools such as fire sprinkler. From Figure 16, it can be seen that the percentage of the level of smoke (obscuration) in the use of sprinkler can be smaller than without the use of sprinkler. After the sprinkler activation at the 75s, the percentage of obscuration decrease dramatically.

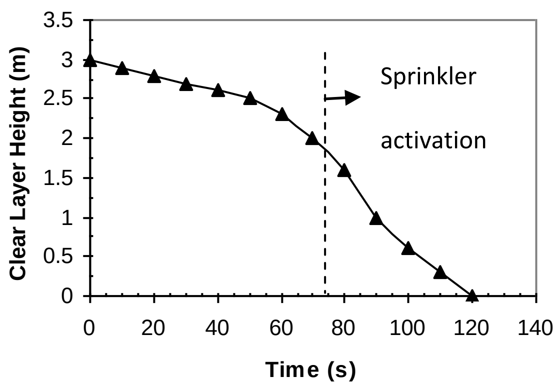

Figure 17. Graphic Clear layer height Vs Time (using sprinkler)

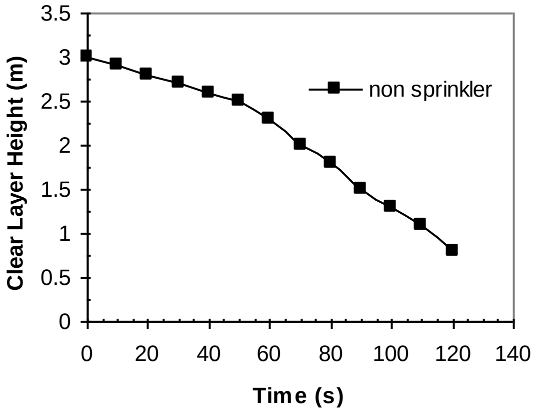

Figure 18. Graphic Clear layer height Vs Time (without sprinkler)

Figures 17 and 18 show that smoke filling time of the sprinkler fire scenario is faster than un-sprinkler one.

When compared between condition of sprinkler and un-sprinkler, smoke filling time in the sprinkler condition 10-20% faster than the conditions without sprinkler in a small compartment.

In general the outcomes of the modeling and simulation works are in good agreement with the experimental works reported by Chung, K-C and Tung, H-S [5].

5. Conclusion

- Smoke obscuration level tends to decrease in sprinkler turned on condition than no sprinkler used in the small compartment.
- Smoke filling time of the sprinkler fire scenario may have a 10-20% faster smoke filling time than the un-sprinkler one
- Room temperature decreased after sprinkler activation.
- Burning rate and HRR decrease after sprinkler activation in the small compartment.
- Smoke obscuration rate decrease in using sprinkler condition which can reach up to 10% if compared with un-sprinkler condition in the small compartment.

Acknowledgements

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6. References

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