Performance analysis of automatic sprinkler systems in warehouses using fire dynamic simulation

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Abstract. This research is based on studying the capability of automatic sprinkler systems by applying fire dynamics simulation. The selection of scenarios based on NFPA 101. A warehouse containing diving instrument in carton placed on wood pallets, which can cause class A fires. To prevent potential damage to the goods, the conflagration in this specific scenarios is simulated to study the effects of temperature on the roof deterioration, the proficiency of the automatic sprinkler systems to extinguish the fire. Researchers found that the sprinklers located on the ceiling of the warehouse are not able to put out the fire but are able to control further spreading of the fire. Researchers, then, install more fire sprinklers in the racks, following the standard from NFPA 13. Results have shown that the second set of sprinklers is not capable of extinguishing the fire but controlling the spread and significantly reducing the temperature. Furthermore, installing both sets of fire sprinklers can prevent the collapse of the roof.

1. Introduction

Conflagration is one of the most serious disasters, capable of inflicting significant damage to lives and properties. Especially in industries in which manufacture and storage are present, the fire can spread to the nearby rack, allowing the damage to expand easily [1]. Nowadays, warehouses are designed with greater height and size of the racks to maximize the efficiency of its use, causing the goods to be more crowded on the rack [2]. Hence, the extinguishing becomes more difficult. In Thailand, most warehouses are only installed with fire sprinkler on the ceiling. Only few are installed with in-rack sprinklers.

Thus, researchers, seeing that sprinklers on the ceiling alone are not enough to put out the fire in warehouses, design the simulation of installation of both sets of sprinklers to follow the standard from NFPA 13 Standard for the Installation of Sprinkler Systems [3]. This simulation is created to let researchers study the temperature inside the warehouse and analyze the effectiveness of the automatic sprinkler system.

2. Theories

This research is used for studying the proficiency of automatic sprinkler system using Fire Dynamics Simulator and Smoke View

IOP Conf. Series: Materials Science and Engineering 715 (2020) 012005 doi:10.1088/1757-899X/715/1/012005

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2.1. Fire dynamics simulator

The National Institute of Standard and Technology (NIST) has created this software to simulate fire in specific situations. This software is capable of predicting motion of the smoke, movement of the hot air from the fire, affected by wind, ventilation system, and other factors [4].

The software can assist in installing devices to prevent the disaster, using Mesh. Mesh, a certain area used in the simulation, is divided into sub-area, called Grid, to calculate the flow of thermal energy. To process the result, the equation from UT Fire research group [5].

\[ D^* = \left( \frac{\dot{Q}}{\rho \infty c_p T_\infty \sqrt{g}} \right)^{2/5} \]  (1)

when \( Q \) = Heat Release Rate (kW/m²), \( \rho \infty \) = Density (m²), \( c_p \) = Specific Heat (Kw), \( T_\infty \) = Ambient Temperature (K) and \( g \) = Gravity (m/s²). Furthermore, simulation from CAD Models can be imported into Pyroism.

2.2. Automatic sprinkler systems

Automatic sprinkler systems are unanimously the most effective fire extinguisher. The fire can be put out even when the spread has not begun. The systems are being installed worldwide, as the water from the system has no effect on the ecosystem [6].

For the automatic sprinkler systems in warehouses, NFPA13 suggested that the sprinklers are installed both on the ceiling and in the racks, as this was mentioned: “In-Rack Sprinklers. Minimum K-8.0 quick response sprinklers.

Sprinklers shall be installed at each rack upright within the longitudinal flue space and at the face of the rack. The maximum linear spacing between sprinklers shall not exceed 5 ft (1.5 m) at the rack face and 10 ft (3.0 m) within the longitudinal flue space [3].

3. Methods

The simulation of the warehouses has been made by FDS, in which the occupancy is selected as extra hazard as in NFPA 13 [3], and details about the cargo are filled in the software.

3.1. Creating the simulation

This simulation is designed as shown in figure 1, using FDS, as a 252 m² room, chosen from the area of sprinkler operator from the real 3,000 m² construction. Inside the room, diving instrument is stored on 6 m high metal racks. The arrangement of the goods is double row racks. The merchandise is stored inside 2 layers of corrugated carton, with the maximum thickness of 7 mm, placed on wood pallets, which can cause class A fire.

![Figure 1. Model for Simulation.](image)

The material in table 1 derived out of Maximum Heat Release Rates – Warehouse Materials from NFPA 72 National Fire Alarm and Signaling Code 2013 Edition the materials can release heat as calculated from this equation:

\[ Q_m = qA \]  (2)
When $Q_m =$ maximum heat release rate (kW), $q =$ heat release rate density per unit of surface area kW/m$^2$, $A =$ surface area of the fuel (m$^2$), and the merchandise is as packed as possible [7].

**Table 1**: Parts of the building and materials.

| No. | Parts of the building and Materials | Materials in FDS |
|-----|-------------------------------------|------------------|
| 1   | Floor                               | Concrete         |
| 2   | Wall                                | Concrete         |
| 3   | Roof                                | Steel            |
| 4   | Racks                               | Steel            |
| 5   | Pallets                             | Wood             |
| 6   | Boxes                               | Wood             |
| 7   | Diving instrument                   | PVC              |

3.2. Size of the mesh
Evaluation of the fire dynamics could be dramatically affected by the size of the Mesh. Researchers have calculated according to the UT Fire research group. The resolution is 0.15 m [5].

3.3. Location of the sprinklers and thermocouples
The researcher created a model by installing automatic sprinkler systems only at the ceiling. In this simulation, there are 26 upright sprinklers, arranged in branch line with 3 m space between each sprinkler and 3 m space between each branch, with red glass bulb, K-factor 8.0 3/4 in. orifice, which will be activated when the temperature reach 68 °C. The highest flow rate of the sprinkler is 73.323 L/m, calculated from this equation:

$$Q = As \times Ds$$  \hspace{1cm} (3)

when $Q =$ flow (gpm), $As =$ distance between each branch (m)*distance between each sprinkler (m), and $Ds =$ density of storage (m$^2$) [3].

Besides, thermocouples are also installed on the ceiling to determine if the roof can withstand the fire, as ASTM E119 has limited the temperature at 538 °C [8], as shown in figure 2.

![Thermocouple installation point](Image)

**Figure 2.** Thermocouple installation point.

3.4. Setting the scenarios
As referred in NFPA 101 Life Safety Code [9], there are 3 possible scenarios:

1) The fire from cigarette stub lighting the carton and the instrument, heat release rate = 3,405 kW/m$^2$ [7], as shown in figure 3.
2) The fire from diesel, leaked from car crash, ignited by a spark, heat release rate = 2,043 kW/m² [7], as shown in figure 4.

3) The fire from a short circuit creating a spark lighting the carton, heat release rate = 1,248 kW/m² [7], as shown in figure 5.

4. Results
The results from each scenario are as written below:

Scenario 1: after 5 seconds of fire, the sprinklers are activated but the fire cannot be extinguished. The lowest temperature measured on the ceiling level is 120 °C, while the highest is 180 °C, and the average is 165 °C, as shown in figure 6.
Figure 6. Shows temperature from Scenario 1 – Ceiling.

With two sets of sprinklers (ceiling and in-rack), activated after 3 seconds, the fire also cannot be put out, but the lowest temperature is lowered to 90 °C, while the highest stays the same, making the average temperature 137.5 °C, as shown in figure 7.

Figure 7. Shows temperature from Scenario 1 – Ceiling and In rack.

Scenario 2: after 10 seconds, the sprinklers are activated but the fire cannot be extinguished. The lowest temperature measured on the ceiling level is 34 °C, while the highest is 47.5 °C, and the average is 43.75 °C, as shown in figure 8.

Figure 8. Shows temperature from Scenario 2 – Ceiling.

With two sets of sprinklers (ceiling and in-rack), activated after 9 seconds, the fire also cannot be put out. The lowest temperature is lowered to 33 °C, while the highest is 47 °C, making the average temperature 40 °C, as shown in figure 9.

Figure 9. Shows temperature from Scenario 2 – Ceiling and In rack.
Figure 10. Shows temperature from Scenario 3 – Ceiling.

Scenario 3: after 12 seconds, the sprinklers are activated but the fire cannot be extinguished. The lowest temperature measured on the ceiling level is 43 °C, while the highest is 63 °C, and the average is 51.58 °C, as shown in figure 10.

With two sets of sprinklers (ceiling and in-rack), activated after 12 seconds, the fire also cannot be put out. The lowest temperature is lowered to 30 °C, whereas the highest is also lowered to 49 °C, making the average temperature 38.92 °C, as shown in figure 11.

Figure 11. Shows temperature from Scenario 3 – Ceiling and In rack.

Figure 12. Comparison of heat at the ceiling.
As shown in figure 12, it can be seen that the scenarios 1, the ceiling temperature is 165 °C, when the fire sprinkler head is added to the rack can be reduced to 137.5 °C (16.67%). The second scenario, the average ceiling temperature is 43.75 °C. The fire extinguishing water added to the rack can be reduced to 40 °C (8.57%). Scenario 3 The ceiling temperature is an average of 51.58 °C. When the fire sprinkler head is added to the rack can be reduced to 38.92 °C (24.56%), Average temperature drop rate as shown in figure 13.

![Figure 13. Average temperature drop.](image)

When increasing the flow rate of fire water to 20%, 40%, 60%, 80% and 100% will see that can not be extinguished But the average temperature is reduced to 148.75 °C, 139.58 °C, 130.83 °C, 124.58 °C and 118.33 °C, respectively, as shown in figure 14.

![Figure 14. Increasing the flow rate of the automatic sprinkler system.](image)

5. Conclusion
From the simulation and its evaluation of all scenarios, results are, both systems (ceiling-top alone and with in-rack sprinklers) can decrease the temperature from the fire, stopping the further spread. As analyzed from the measured temperature, installation of the in-rack sprinklers, in addition to the first system, is able to considerably reduce the temperature. Additionally, both systems can prevent roof collapse as the temperature did not exceed 538 °C.

In this research, it can be concluded that the automatic sprinkler system in warehouse can control the temperature from the fire and when the flow rate of the fire extinguishing water is increased, the fire spread head is found the fire can control the temperature more effectively.

In addition, this research can be further developed. To find suitable methods for automatic fire extinguishing in the warehouse.

Acknowledgments
The author is grateful to Thunderhead Engineering for FDS Program academic license and Unique Sea Products Co., Ltd for warehouse data.

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