Fire Simulation Research on a Bus Based on Pyrosim

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Abstract. Aiming at the problem of automobile fire simulation, a common model bus is taken as the research object, and the Pyrosim software is used as a tool to realize the fire simulation. In this study, Auto CAD was used to establish a three-dimensional bus model, and then it was imported into Pyrosim software, and Pyrosim software was used to simulate the fire of the bus model. Through research, it is found that the fire of a bus has its own characteristics, which can be divided into four stages: initiation, flashback, deflagration, and stability. According to the simulation results, the flue gas simulation analysis and thermal power analysis were done, and the simulation results were analyzed and discussed in depth. During the research, it was found that although the application of Pyrosim software has certain limitations in the simulation of automobile fire simulation, the research results can still provide a reference for automobile fire simulation and automobile fire prevention and control.

1. Introduction

According to statistics from the global fire department, vehicle fires accounted for 21% of the total number of global fires, while car fires accounted for 18%[1]. The bus is the main tool for urban public transportation. Since the bus is a highly crowded area, the threat of fire to personal safety will inevitably increase greatly. It is of great significance to study the fire characteristics such as the mechanism and spread of bus fires[2]. Scholars and experts from various countries have conducted a lot of research on the spread trend of automobile fires, thermal efficiency release, smoke spread characteristics, and thermal properties of materials. K Okamoto et al. [3] have studied the fire spread of automobiles, and discussed the different ways of spreading of different ignition points. Weisenpacher P et al. [4] used a computer to simulate a car fire.

Since 2010, Chinese scholars such as Bi Kun, Tang Xiaorong and Li Na have studied the automobile fire by using FDS(Fire Dynamics Simulator) technology[5-6]. It is proved that the software is effective and scientific for automobile fire simulation, but the relevant research in China is still relatively few, which provides limited technical support for automobile fire prevention, especially bus fire.

Based on the situation mentioned above, Pyrosim software is used to simulate the fire of a certain bus, and the characteristics of bus fire are further explored. It analyzes the process of bus fires, and obtains the bus fire spread process and corresponding characteristics, which provides reference for bus fire safety and fire protection design.
2. FDS theory and Pyrosim software

Fire is the sum of complex chemical changes and physical changes, but it still complying with many nature conservation laws of nature, which is the basis that FDS simulate fire.

Generally speaking, FDS theory has mass conservation equation, momentum conservation equation, energy conservation equation and component conservation equation. In some specific cases, the ideal gas equation can be added to control it. The mass conservation equation, momentum conservation equation and energy conservation equation are the most basic conservation equations, which exists in almost all reactions.

FDS can simulate the spread process of fire, and the foundation of FDS is the establishment of combustion model. The role of combustion model is to determine the chemical and physical changes of various substances in complex chemical and fluid dynamics. Combustion simulation is generally divided into mixed control combustion models and finite combustion control models.

Pyrosim software is used in the simulation and analysis of fire. It is a mixed-control combustion model, based on FDS and smoke simulation program Smokeview, which is an easy-to-operate user program developed.

3. The establishment of a fire model

3.1. Ways to build models

Because Pyrosim software has some limitations in modeling, and it is mainly used in architecture, AutoCAD is chosen to model and import into Pyrosim. It is necessary to optimize the simulation, slice and cell [7-8]. The flow Figure of the model is shown in Figure 1.

3.2. Model parameters

3.2.1. Model size and location.

The model is established by a common bus. Its size is 12m*2.5m*3m. The model location parameter as shown in Table 1.

| Table 1. Model location parameter |
|---|---|---|
| X  | Y  | Z  |
| Min(M) | 16.53 | -5.1 | -10.47 |
| Max(M) | 27.21 | 0   | 3.1   |
3.2.2. Setting and numerical value of combustible materials.
Combustibles on the bus are mainly made up of seats, surface covering materials, fuel oil and passengers’ outer materials. Due to the limited material selection in the Pyrosim library, the materials such as plastics, rubber and so on are chosen for simulation. The parameters of combustible materials are shown in Table 2.

| Name            | Material Science                  | Size(m)                           |
|-----------------|-----------------------------------|-----------------------------------|
| Chair           | Plastic (Flexible PY)             | Cushion:0.6×0.5×0.05;Leyback:1.0×0.5×0.05 |
| Body periphery  | Soft plastic (Rigid PU), textiles | Slightly                          |
| Fuel            | Octane                            | 0.1×0.1×0.2                       |
| Tyre            | Rubber                            | R0.85 × 0.45                     |

3.2.3. Thermal properties of materials.
The thermal properties of bus materials are shown in Table 3.

| Name   | Specific heat (kJ/kg·K) | Ignition temperature (℃) | Combustion heat (kJ/kg) |
|--------|-------------------------|--------------------------|-------------------------|
| Fabric | 1                       | 350                      | 15000                   |
| Plastic| 1                       | 350                      | 30000                   |
| Soft plastic | 1.7                  | 350                      | 30000                   |
| Rubber | 1.88                    | 350                      | 32000                   |
| Fuel   | 2.45                    | 400                      | 43700                   |

3.3. Data reconstruction and model establishment
The model of the bus can be reconstructed by the above value, and the bus model diagram is shown in Figure 2. After referring to bus fire characteristics, the fire source is set up in the compartment, which is located in the front part of the compartment. The size of the fire is 0.8m*0.5m*0.3m and the material is set as fuel. The most common reason in the bus fire is flammable and explosive dangerous goods, usually located in the compartment. The fire location is shown in Figure 3.

Figure 2. Model diagram  Figure 3. Fire source diagram

Taking into account the accuracy and reasonableness of the calculation, the grid is 10cm*10cm*10cm, the number of sub grids is 270,000, and the simulation time is set to 600 seconds. For usual bus fire, fire spread time is about 10 minutes. Generally, after ten minutes, the fire spreads to the whole body, and no longer changes the fire, until the fire is extinguished due to the burnout of the fuel.

4. Simulation process and analysis
4.1. Fire simulation analysis
4.1.1. Initial stage.
In the simulation, the initial phase is 0 to 100 seconds, during which the fire starts to spread in the compartment, but the fire is not big and the spreading speed is slow. Initial-phase schematic diagram is
shown in Figure 4. When the fire source starts to ignite, the thermal efficiency is released slowly. At this time, the fire is still concentrated in a small area and there is no large-scale diffusion.

Fire-simulation schematic diagram at 100 seconds is shown in Figure 5. At the end of the initial stage, the fire spread to the middle part of the car to form a certain scale.

Figure 4. Schematic diagram of the initial stage

Figure 5. Schematic diagram at 100 seconds

4.1.2. Reignition stage.
At this stage, the fire will decrease and basically disappear. It is a transitional stage between the initial stage and the deflagration stage. Backdraft-stage simulation diagram is shown in Figure 6.

Figure 6. Simulation diagram of backdraft stage

4.1.3. Deflagration stage.
The time of deflagration is from 100 seconds to 240 seconds. This stage ignites bus accessories, such as seats, carpets and billboards, and spreads to the entire compartment. The schematic diagram at 180 seconds is shown in Figure 7.

At the end of the deflagration stage, the fire has spread to the whole compartment and is burning fiercely. After 30 seconds, the fire will reduce, but it will also maintain a strong level and start to enter the stable stage. The schematic diagram at 240 seconds is shown in Figure 8.

Figure 7. Schematic diagram at 180 seconds

Figure 8. Schematic diagram at 240 seconds

4.1.4. Stabilization stage.
The last stable phase starts from 240 seconds to the end of 600 seconds. This is the last stage. The fire will remain stable, and the combustion will be maintained until the fire is over. The fuel consumption is exhausted. The schematic diagram at 450 seconds is shown in Figure 9.
4.2. Flue gas simulation analysis

In fire, about 70% of the casualties are caused by excessive toxic smoke inhalation. Therefore, the analysis of flue gas simulation is very important.

In the whole process, the initial concentration of smoke is not high, because the spread of the fire does not ignite bus accessories. This stage is also the best stage for passengers to escape. In the later stage, due to the increase of fire, the surrounding accessories, such as blankets, billboards, and so on, began to produce a large number of toxic fumes, which would also cause harm to passengers.

In the backdraft stage, although the fire reduce, the toxic smoke is still full of the entire compartment, meanwhile visibility decreases, and toxic gas concentration reaches peak.

During the deflagration stage, a large amount of smoke was produced. However, due to the large air circulation, smoke concentration decrease, but it remained at a higher stage. This state would continue until the combustion process ended.

4.3. Thermal power analysis

In the Pyrosim software, the simulation software automatically generates the thermal efficiency release value of the whole simulation process, and this value is of great significance for the fire spread process study. Thermal power release in the whole process is shown in Figure 10.

![Figure 10. Whole process thermal power release diagram](image)

At the initial stage, the thermal power rises, which is due to fire spread in the compartment. However, due to initial spread rate is slow, although the thermal power rises, the speed is very slow, reaching 4000kW in the next stage.

During the backdraft stage, the thermal power release begins to decrease and disappear.

In the deflagration stage, the fire spread rapidly, and the thermal power began to release to a maximum, about 13000kw.

During the stable phase, the thermal power release starts smoothly and continues until the fire is over, and it will decrease with combustibles consumption until zero.
4.4. Analysis and discussion of simulation results

4.4.1. Analysis of simulation results.

(1) The whole simulation process lasts for 600 seconds, the initial stage is the beginning stage, the heat power release smoothly, the fire spreading speed is uniform, and the flue gas starts to release. During this stage, thermal power and smoke originating from the combustible materials around the fire source are ignited, which is consistent with initial stage characteristics.

(2) Deflagration is outbreak stage, and heat power release starts to rise rapidly, and the fire spread rapidly and smoke is produced. At this stage, air influx causes the thermal power to rise rapidly and the fire spread to the entire compartment. The model maximum efficiency is approximately 13000 kW, which is basically consistent with the experimental results of vehicle fires in document [2]. It is proved that the simulation results are correct.

(3) The stable stage is the main stage. When the fire spread to the whole space, the heat power and flue gas are released and the rate is stable. At this stage, because the whole space structure of the fire is stable, the fire spread is intense but stable.

4.4.2. Discussion of the backdraft stage

The backdraft stage is a special stage. Because of the combustion process at the beginning and the high temperature environment after the combustion, the combustibles in the space still undergo pyrolysis reaction, and gradually accumulate a large amount of combustible gas. Once the ventilation condition is improved, the air will be added to the combustible gas with the gravity flow form. When the mixture is ignited by ash, a large intensity and rapid propagation flame will be formed. At the same time, a huge fireball will be formed at the ventilation, causing both indoor and outdoor hazards. This phenomenon of resurgence is called backdraft. Backdraft reason can be concluded as follows: the bus model is set as a closed model. At the initial stage, the fire starts to spread, and the combustion consumes air. When the air is exhausted, the fire begins to alleviate. At this moment, due to factors such as personnel escape and high temperature cracking, fresh air influx makes the fire intense, which is also the reason for the deflagration phase.

5. Conclusion

This study simulated the bus fire by using Pyrosim software. According to the simulation results, the fire spread, smoke spread and thermal power release were analyzed in three aspects. The results show that the bus fire spread presents obvious stage differentiation, which is divided into initial, backdraft, deflagration and stabilization stages. The backdraft stage is a special stage, and its formation reason may be that the flame breaks the window glass or the passengers open the door to escape to make fresh air inflow. In the future, the follow-up studies can be carried out on the basis of this research: (1) Testing and verifying the cause of the backdraft stage; (2) Propose a bus design optimization plan based on fire prevention.

Acknowledgments

This program was supported by the 2020 Innovation and Entrepreneurship Training Program of Panzhihua University, China (Grant: 2020cxxy080).

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