Research on Vehicle Exterior Fire Suppression Techniques

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Abstract. This paper studies automatic vehicle exterior fire detection and suppression techniques. The main difficulties include: 1) complex and changeable environment outside the vehicle; 2) low sensitivity of the fire detector; 3) quick dissipation of fire extinguishing agent in the open space outside the vehicle; 4) extinguishing agent nozzle blocking due to dust and sand. This paper selects a special ultra-fine dry powder fire extinguishing agent for automobiles to design the protective nozzle and to study the automatic detection controller with the functions of condition monitoring and fault diagnosis, with an aim to improve fire suppression reliability. Based on the virtual and real vehicle tests, it is verified that the fire extinguishing effect of the designed system meets the design requirements.

1. Introduction

The local fire outside the vehicle tends to spread rapidly to the whole vehicle. If it is not extinguished in time, the personnel and vehicle safety will be in great danger. It might be too late to put out the vehicle exterior fire using the portable fire extinguisher, and sometimes the person may fail to get out of the car due to the fierce fire. Therefore, the research on efficient and reliable automatic vehicle exterior fire suppression techniques is of great significance for personnel and vehicle safety.

The current research on vehicle fire suppression techniques mainly focuses on interior firefighting. Exterior firefighting techniques, however, are relatively difficult to study due to the unfavorable factors including 1) complex and changeable environment outside the vehicle; 2) low sensitivity of the fire detector; 3) quick dissipation of fire extinguishing agent in the open space outside the vehicle; 4) extinguishing agent nozzle blocking due to dust and sand.

The research on vehicle exterior fire suppression techniques mainly covers the selection of fire extinguishing agent, automatic fire detection controller, protective nozzle design, fire extinguishing system layout inside vehicle, and verification tests.

2. Selection of fire extinguishing agent

At present, available fire extinguishing agents include inert gas, fine water mist, halogenated alkanes, aerosols and ultra-fine particles. Their characteristics are analyzed as follows.

- Inert gas
  One of the representative inert gases for fire suppression is IG-541, whose fire extinguishing mechanism is suffocation. Its main disadvantages are 1) low fire suppression efficiency; 2) high concentration requirement for fire extinguishing; therefore, it is demanding in terms of sealing and strength of the container; 3) large size, making it unsuitable for vehicle exterior fire suppression.

- Fine water mist
  The particle size of the water mist is generally between 20 and 120 μm, and its fire extinguishing mechanism is cooling and suffocation. Its fire suppression ability is affected by the size of the water
droplets and the working pressure of the nozzle (higher working pressure of the nozzle, stronger ability to generate droplets). Therefore, the equipment and technology that can turn water into ultra-fine water mist is very important. However, it is not suitable for extinguishing vehicle exterior fire.

- **Haloalkanes**
  Haloalkane fire extinguishing agents mainly include heptafluoropropane, trifluoroiodomethane (code: F23), etc. Heptafluoropropane, featuring non-conductivity, low toxicity, and zero ozone depletion potential (ODP), is efficient and fast in fire suppression. However, its GWP reaches 2900 and it will remain in the atmosphere for up to 37 years, making it unsuitable for long-term use.

  The trifluoroiodomethane concentration for fire extinguishing is 3.9%. When CF3I is thermally decomposed, it will generate I ions, strongly inhibiting the combustion reaction. However, it will generate toxic gases under high temperature and its synthesis is costly, so it is not used widely. Haloalkane fire extinguishing agents are not suitable for extinguishing vehicle exterior fire.

- **Aerosols**
  Aerosols are formed by dispersing ultra-fine solid or liquid particles in a gaseous medium. This type of fire extinguishing agent can form a fire aerosol substance. The fire extinguishing mechanism of the hot aerosol includes chemical suppression, decalescence and cooling, and oxygen concentration reduction; therefore it has high fire extinguishing efficiency. However, it also has some disadvantages: ① the flame is sprayed outward during combustion, which may cause a secondary fire; ② the surface temperature of the equipment is too high; ③ the thermal stability is poor; ④ it is difficult to suppress class A deep-seated fire. Therefore, it has limitations in application and is not suitable for extinguishing vehicle exterior fire.

- **Ultra-fine particles**
  Ultra-fine particles can effectively suppress combustion, with multiple fire extinguishing mechanisms, such as endothermic cooling, gas-phase chemical suppression, solid-phase chemical suppression, and reduction of oxygen concentration. In addition, ultra-fine particles are small in size, usually 3~5 μm, which is larger than the specific surface area. So, they have a high frequency of interaction with the flame and a strong ability to capture free radicals, therefore a high fire extinguishing efficiency.

  The advantages of ultra-fine dry powder fire extinguishing agent include 1) zero ozone depletion potential (ODP); 2) zero GWP; 3) non-toxicity and no harm; 4) non-corrosion to protective materials; 5) non-irritation to human body; 6) high fire extinguishing efficiency.

  Automobile-specific ultra-fine dry powder fire extinguishing agent belongs to the type of ultra-fine particle fire extinguishing agent, and it can adapt to harsh external conditions such as high temperature, low temperature, high humidity, and vibration and long-term vehicle operation. It is suitable to be used not only in the relatively enclosed total submerged fire extinguishing, but also in open local submerged fire extinguishing as well as in the open space fire suppression. Its efficiency is 40 times that of the water-based extinguishing agent, 6 to 10 times that of the ordinary ABC dry power extinguishing agent, 2 to 3 times that of the halon extinguishing agent, and 10 to 12 times that of the heptafluoropropane fire extinguishing agent. It can be used to extinguish A, B, C, E fires on the vehicle as well as fire outside the vehicle.

### 3. Automatic fire detection controller technique

At present, automatic fire detectors used in cars, such as heat-sensitive wires and optical detectors, are susceptible to the outside interference, leading to lower detector sensitivity and the generation of false signals. By researching highly reliable detectors based on state monitoring and fault diagnosis technologies, we can improve the sensitivity and reliability of fire detection. Based on the high temperature characteristics of the flame, the temperature for fusing the special insulation layer between the two metal wires and sending out the signal is generally set as 85~150 °C. This detection method is highly reliable and can not be easily affected by environmental factors.

However, the failure of the detector itself will affect the reliability. Therefore, it is necessary to improve detector reliability by monitoring and diagnosing detector failures, such as damage of the
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insulation layer, disconnection of the detector, damage of the metal protective layer, and grounding of
the metal wire. The control circuit between the automatic controller and the fire extinguisher is also
prone to failure. The control circuit can be used to realize the functions of circuit self-diagnosis and
fault alarm and to determine whether there is short circuit or open circuit, thereby improving the
reliability of the automatic fire suppression system. The working principle of automatic fire control
technique is shown in Figure 1.

![Working principle of automatic fire control technique](image1)

Figure 1. Working principle of automatic fire control technique

4. Protective nozzle
Disk-shaped protective nozzle are used to extinguish fires on circular or roughly circular
planes and rectangular or roughly rectangular planes, and the nozzle is located in the middle
of the plane. The disc-shaped protective nozzle is composed of a nozzle, a protective cover
and a guide rod. The protective cover, located at the upper part of the nozzle, is made of non-
metal or light metal. The guide rod is fixed on the top surface of the nozzle through a screw
connection. When not in use, the protective cover shields the orifices. During fire suppression, the fire extinguishing agent in the pipeline pushes the protective
cover upward, thus exposing the orifices, ensuring the normal and smooth discharge of the
fire extinguishing agent. The advantages of the design include 1) the protective cover can
effectively prevent the orifices from being blocked by mud, dust, gravel, rain and snow, etc.,
and keep the inside of the orifices and the pipeline clean and unblocked, so as to ensure the
reliable operation of orifices; 2) when the orifices are not shielded, the lower flange of the
protective cover can also help to ensure the right spraying direction of the fire extinguishing
agent, thus improving the fire extinguishing efficiency. The disk-shaped protective nozzle is
shown in Figure 2.

![Disc-shaped protective nozzle](image2)

Figure 2. Disc-shaped protective nozzle

5. Layout of fire extinguishing system
The vehicle exterior fire extinguishing system is composed of the fire detector, automatic controller,
fire extinguisher, pipeline and nozzle. When a fire occurs, the detector detects the burning flame and
sends a signal; the automatic controller activates the fire extinguisher; the fire extinguishing agent is
transported along the pipeline to the nozzle and is sprayed out instantly, covering the flame root, and extinguishing the flame at one time. Considering the limited number of fire extinguishers that can be put in the vehicle, the possibility of scattered ignition points and simultaneous ignition of multiple parts as well as the pipeline length and characteristics of pressure distribution, it is necessary to reasonably allocate the limited fire extinguishing bottles on the vehicle.

The vehicle exterior fire extinguishing system can be developed either for newly developed vehicles or for equipped ones. The layout design of the system shall be conduct based on the close negotiation with the vehicle designer or user, and it shall not interfere with other vehicle components. The computer-aided design can help to arrange the fire extinguishing system on the overall design drawing of the vehicle, setting the positions of the nozzle, the fire extinguishing bottle, and the pipeline. The overall layout of the vehicle exterior fire extinguishing system is shown in Figure 3.

6. Conclusion
Tests are needed to verify whether the vehicle exterior fire extinguishing system is reasonable and whether its fire extinguishing effect meets the design requirements. Usually, a combination of virtual test and real vehicle test is adopted, and the real vehicle test is performed only after the virtual test is passed. The advantages of adopting virtual test include 1) save test costs; 2) reduce test risks; 3) shorten the development cycle; 4) increase success rates. The effect of the virtual test is shown in Figure 4, and the effect of the real car test is shown in Figure 5.
Figure 5. Real vehicle test

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