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Fire behavior of mining vehicles in underground hard rock mines

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ABSTRACT

The results from a number of investigations and fire experiments are presented and analyzed in order to characterize the fire behavior of mining vehicles in underground hard rock mines. The analysis also includes fire safety and fire protection measures with respect to the mining vehicle fire behavior. Earlier studies on fires in underground hard rock mines have shown that vehicles or mobile equipment are the dominant sources of fire. A better knowledge about the fire behavior of vehicles in underground hard rock mines is therefore needed. During the analysis the direction and flow rate of the ventilation in a drift was found to have a significant impact on the fire behavior, causing for example flame tilt with rapid fire spread. The shielded sections of a vehicle will be less affected by the ventilation flow resulting in for example a decreased flame spread. It was also found that spray fires may result in considerable heat release rate but are generally of shorter duration and will not make any significant contributions to the overall heat release rate of the fully developed vehicle fire. The fire duration of a loader tire from a full-scale fire experiment was found to be at least 200 min and will largely determine the total fire duration of the vehicle. A different scenario with different conditions with for example a slower flame spread resulted in an even longer fire duration. The radiative and convective fraction will be a key factor when determining the heat transfer mechanisms involved in a fire and will vary from material to material. Calculations show that the radiative fraction of the tire fires on two mining vehicles is significantly lower than found in earlier experiments. The design and construction of the mining vehicle will have an important impact on the fire behavior and could possibly mitigate the consequences of a fire and allow fire personnel to extinguish a fire that otherwise would have had a too high heat release rate.

1. Introduction

Describing and quantifying the fire behavior of a certain object involves providing information about relevant risks, and the kind of environment of the mining personnel and fire personnel will encounter, etc. One of the key factors when quantifying fire behavior is the heat release rate of the object in question. Determining the heat release rate is essential when calculating the temperature distribution, smoke production, fire duration, heat fluxes, etc. These factors in turn will give clues to questions such as follows. Will an adjacent object ignite and prolong the fire duration? Will fire suppression be possible and at what stage? How should the egress safety be designed in the mine?

A number of papers have been published on the heat release rate of mining vehicles [1,2]. This paper focuses on the clues given from the heat release rate and temperature measurements as well as fire phenomena and fire behavior occurring in the absolute vicinity of the mining vehicle fire.

Earlier studies on fires in underground hard rock mines showed that vehicles or mobile equipment are the dominant sources of fire [3,4]. A major concern was the lack of documented full-scale fire experiments in vehicles or mobile equipment and the lack of heat release rate curves. Thus a better knowledge about fire behavior for vehicles in underground hard rock mines is needed. An investigation was performed in order to look into the fire cause and fire behavior of vehicle fires in underground mines in Sweden [5]. The investigation was based upon incident reports from fires in underground mines during the years 1988–2010 and comprised a total of 410 vehicle fires. The investigated fires ranged from fires involving only the initial object to fires involving the entire vehicle.

Fires involving only the initial object amounted to 94.6% of the total number of fires, thus a clear majority of the fires. The dominating fire cause in these cases was electrical fault caused by short circuit. Fires caused by electrical faults were usually characterized by a slow and limited fire spread, a very low-intensive fire behavior (limited amount of smoke being emitted and no flames being visible in some cases) and a fire that is easily extinguished, often self-extinguished when the power is cut off or extinguished using a

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combination of a fire extinguisher and turning off the power supply. Fires limited to the initial object and an adjacent object amounted to 2.2% of the total number of fires. Same as for the cases only involving the initial object, electrical faults dominated as the fire cause, and the fires displayed low-intensive fire behavior and were easily extinguished. The electrical cables in these cases often provide the bridge to adjacent objects.

Fires involving the entire vehicle amounted to 3.2% of the total number of fires. These types of fires were typically caused by diesel being sprayed on hot engine parts or headlights, often due to a pipe or a hose coming loose and resulting in a rapid fire spread and an extensive fire where the fire spread to adjacent combustible objects. Fires involving flammable liquid sprayed upon a hot surface were usually characterized by a rapid fire spread, suddenly engulfing parts of the vehicle. In many cases, the driver or operator had to flee the site almost at once and had no chance initiating any extinguishing attempts. The spray fires occurred in the engine compartment, an enclosure where a continuous release of a flammable liquid will lead to a rapid increase in temperature. Fires caused by electrical fault generally involve flammable liquid in order to achieve a rapid fire growth to larger amounts of nearby combustibles. Fires involving the entire vehicle most commonly happened to service vehicles and loaders; see Fig. 1.

The investigation shows that fire seldom spreads further than the initial object, but if it does, it will likely involve the entire vehicle rather than simply another, adjacent item. It also suggests that as the fire has spread to an adjacent object, it is difficult to stop or extinguish it with the equipment at hand during the initial phase. At this stage, the fire development generally requires professional fire personnel.

2. Mining vehicles: general fire behavior, fuel load and surroundings

Operating an underground mine will normally require a large number of various types of vehicles. The vehicles will generally be found throughout a mine and not restricted to a limited number of places due to the system of ramps and drifts. The mine presents a unique and tough environment on the mining vehicles; wear and tear on tires, hoses, electronics, etc., are exceptional due to the tough and harsh environment. Due to such environment, the design of mining vehicles is often distinguished by a compact design and rugged construction.

Fire hazards and the amount of combustible components will vary from vehicle to vehicle depending on the type of vehicle and its dimensions. Combustible components commonly found are: diesel, hydraulic oil, motor oil, cables, hoses, interior details and tires. The large quantity of diesel, hydraulic oil and hoses as well as tires with large dimensions, a fully developed fire involving the entire mining vehicle can in many cases be expected to have a rapid fire development, extensive smoke production and a fire with long duration. The maximum heat release rate of larger vehicles can be several tens of megawatts and causing great problems to the personnel in the mine and to the fire and rescue personnel.

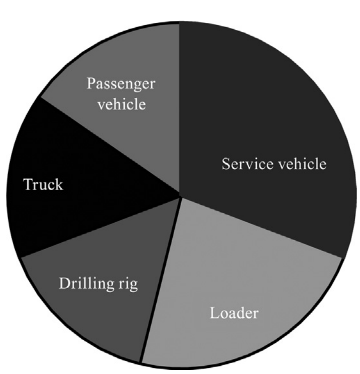

Fig. 1. Distribution of types of vehicles-fires involving the entire vehicle [5].

Drifts, levels and ramps in an underground hard rock mine are characterized by their general openness, lack of barriers, sporadic pockets of combustible materials and large distance barren drifts, where the rock will cool off the fire gases from the fire. Following upon the latter two factors, the likelihood of the fire spreading from the first item ignited is generally small in a hard rock mine. The surrounding rock in the direct vicinity of the fire will after the initial heating process increase the re-radiation mechanism back to the fire, influencing the combustion process. The rock further downstream of the fire will have more of a cooling effect on the fire gases. The cooling effect of the surrounding rock will therefore depend on the distance from the fire.

During a fire, the major portion of the hot fire gases will be found in the upper region of the mine drift and any fuel components found in the lower region. Thus, an adjacent mining vehicle will not necessarily be engulfed in hot fire gases, limiting the effect of the convective spread mechanism. Also, if the mine drift height is considerable, the roof impingement of flames will not be as common as in the case of road tunnel fires. On the other hand, with lower height, earlier ignition of adjacent fuel components will take place as the average fire gas temperature will increase, flames may be deflected at the drift roof and thereby increasing the view factor to adjacent fuel components. The width of the mine drift will also affect the fire behavior. A decrease in width will result in earlier ignition due to an increase in the average fire gas temperature and also an increase in the re-radiation to fuel surfaces. The inclination of the mine drift also affects the ignition of fuel components. If the inclination increases, earlier ignition of adjacent fuel components will follow due to an increasing flame tilt and an increasing risk of flame impingement.

Flames and fire plume in a mine drift are affected by the ventilation flow from the mechanical ventilation system. The effect on the fire behavior can be seen in the tilting of flames which leads to faster flame spread and ignition of adjacent fuel items. The ventilation flow will lead to a more effective supply of air to the fire site, increasing the mixing of oxygen and fuel and thus the combustion efficiency. The large air volumes available in the mine drifts and the influence of the mechanical ventilation makes ventilation-controlled fires less likely than fuel-controlled fires (i.e. excess access to oxygen). Obstacles in a mine drift may block the ventilation flow and reduce the influence on the fire plume and the possible tilt of flames further downstream. The same phenomenon could occur where the construction of the vehicles would block the longitudinal ventilation flow and prevent any significant flame tilt from occurring inside the vehicle or along the outside of the vehicle [6].

The fuel load and composition of combustible materials will vary depending on the type of vehicle. A loader can be distinguished by the large tires and large supply of hydraulic oil, while a drilling rig by the large number of hydraulic hoses and large supply of hydraulic oil. The electrical cables and hydraulic hoses on vehicles will generally form a bridge between the combustible items, allowing for a continuous fire spread along the vehicle. The fuel load of a burning vehicle will be one of the factors that dictate the duration of the fire if the fire is fuel-controlled. If instead the fire has limited access to oxygen, the mass flow of air will have a major impact on the duration of the fire.

The following types of major combustible components or combustible sections can generally be found on mining vehicles: tires, diesel, hydraulic oil and motor oil, hydraulic hoses, electrical cables, and cab. The different components or sections will have different