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Some relevant parameters for assessing fire hazards of combustible mine materials using laboratory scale experiments

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ABSTRACT

When combustible materials ignite and burn, the potential for fire growth and flame spread represents an obvious hazard, but during these processes of ignition and flaming, other life hazards present themselves and should be included to ensure an effective overall analysis of the relevant fire hazards. In particular, the gases and smoke produced both during the smoldering stages of fires leading to ignition and during the advanced flaming stages of a developing fire serve to contaminate the surrounding atmosphere, potentially producing elevated levels of toxicity and high levels of smoke obscuration that render the environment untenable. In underground mines, these hazards may be exacerbated by the existing forced ventilation that can carry the gases and smoke to locations far-removed from the fire location. Clearly, materials that require high temperatures (above 1400 K) and that exhibit low mass loss during thermal decomposition, or that require high heat fluxes or heat transfer rates to ignite represent less of a hazard than materials that decompose at low temperatures or ignite at low levels of heat flux. In order to define and quantify some possible parameters that can be used to assess these hazards, small-scale laboratory experiments were conducted in a number of configurations to measure: 1) the toxic gases and smoke produced both during non-flaming and flaming combustion; 2) mass loss rates as a function of temperature to determine ease of thermal decomposition; and 3) mass loss rates and times to ignition as a function of incident heat flux. This paper describes the experiments that were conducted, their results, and the development of a set of parameters that could possibly be used to assess the overall fire hazard of combustible materials using small scale laboratory experiments.

1. Introduction

Fires represent one of the most significant hazards that can occur in underground mines, with significant potential for injury and loss of life. Materials that smolder and burn can expel large quantities of toxic gases and smoke into the mine's ventilation airflow where these products are transported to distances often far-removed from the seat of the fire. When smoldering fires are left unattended, their eventual transition to flaming and subsequent fire growth and flame spread render the underground atmosphere untenable and cause disastrous consequences for both life and property. Mining involves the use of many types of combustible materials that are brought underground to facilitate the mining process. Such materials include brattice curtains, conveyor belts, mine foams and sealants, electrical insulating materials, and so on, with many different chemical formulations possible for each. However, along with providing their necessary functions to the mining activities, many, if not most, of these combustible materials may represent significant fire hazards if not selected with criteria that are intended to minimize any potential dangers.

Some of these materials are required by regulations to pass stringent tests for flame spread, such as conveyor belts, while others may have to be certified as fire-resistant based upon the results of other standard laboratory tests [1]. While fire resistance and flame spread are important parameters to limit the potential hazards that fires involving these materials may present, there exist other properties relevant to the material and also to the resultant effects of their combustion that are quite important. For instance, the relative ease or difficulty of materials to thermally decompose or their response to various levels of heat flux and/or elevated temperatures that result in their ignition are important parameters. As materials thermally decompose during their smoldering stages, smoke and potentially toxic gases may be produced that can render the mine air untenable and result in severe adverse health effects. Subsequent to ignition, flaming materials tend to generate smoke with higher carbon content (i.e., black carbon) and additional toxic

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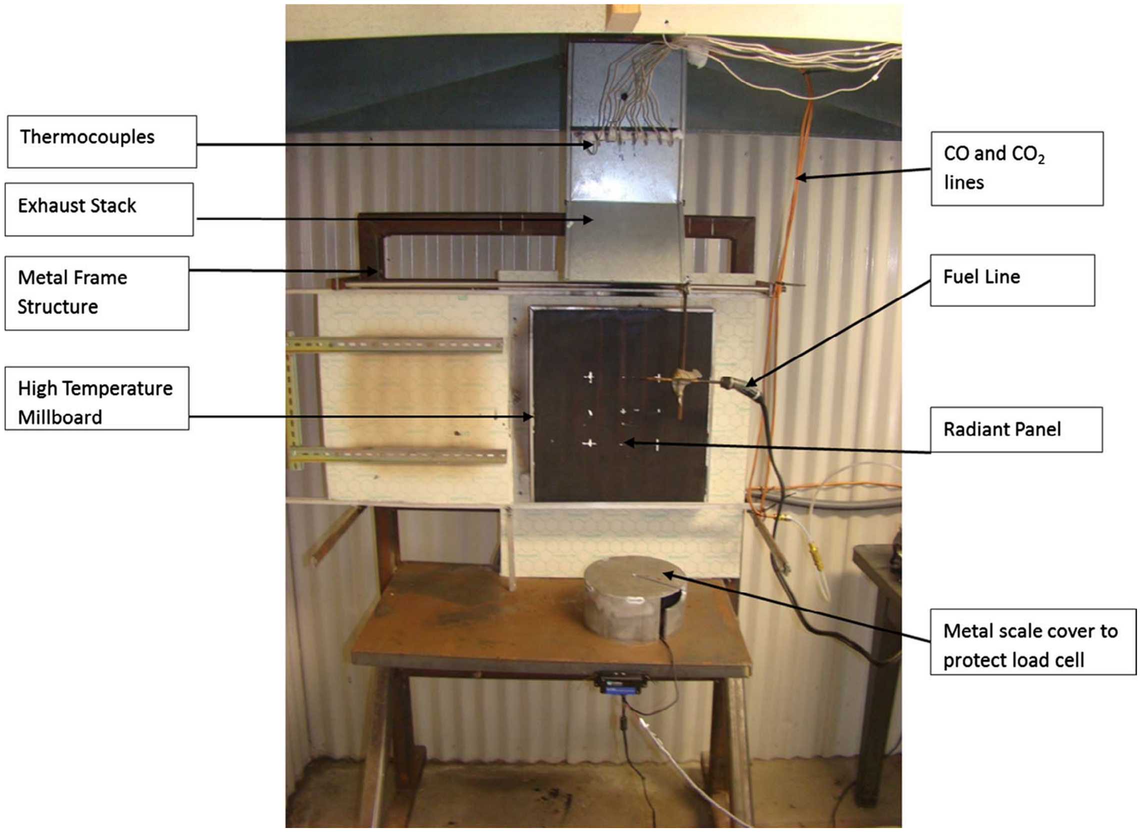

Fig. 1. Radiant panel apparatus.

gases, and as the fire intensity increases, the production of smoke and toxic gases also increases.

Prior research efforts have generated data on the thermal decomposition and ignition properties of a wide range of combustible materials, and much of this research has also addressed the generation of smoke and toxic gases, primarily subsequent to ignition and as a function of the fuel-to-air ratio [2–5]. Litton et al. studied the ignition and flame spread properties of a variety of noise abatement materials in both medium- and large-scale experiments and developed the concept of a heat parameter to assess the relative risk of flame spread [6]. Paciorek et al. [7] catalogued the yields of over 500 toxic gas compounds during the thermal decomposition of numerous combustible mine materials [8,9]. This previous research spans the period from the mid-1970s to the mid-1990s, and while much of this work remains relevant, very little research has been conducted more recently to measure and quantify the hazards from the many new combustibles used in today's underground mines. In addition, the testing and evaluation of some materials, in particular, conveyor belts, has most recently been accomplished only through large-scale testing that is difficult and expensive, while smaller, laboratory-scale studies have been sorely lacking.

The research described in this report seeks to fill that void through the development of a suite of smaller-scale laboratory experiments that quantify the various hazards mentioned above via parameters that are relevant to a diverse range of combustible mine materials. Such parameters will include a smoke hazard parameter (SHP) that defines both the relative smoke obscuration level and the particle surface area that can be related to adverse health effects; toxicity indices (TI) that define weighted sums of the toxic gases produced both during flaming and non-flaming combustion; and thermal parameters (TP1 and TP4, which explained in Theory section) that define a combustible material's ease of ignition and subsequent fire intensity. All of these parameters can be used to rank the materials in terms of the hazards they present, from low hazard to high hazard. The paper concludes with a discussion of the potential utility of these parameters for an overall hazard evaluation that may be used to assess potential risk, and describes how this evaluation may lead to the selection of those materials that pose the lowest overall risk.

2. Experimental

In order to address the various hazards that fires and developing fires may present, it was necessary to conduct experiments using two distinct experimental arrangements:

1. A radiant panel to quantify the material's ease of ignition and heat of gasification as a function of known heat flux at the material surface; and
2. A smoke chamber for quantifying the yields of toxic gases and smoke, along with the relevant smoke properties, for both flaming and non-flaming combustion.

The experimental configurations and methodologies used for the radiant panel experiments and the smoke chamber experiments, along with detailed results, are presented by Harteis et al. and Litton et al., respectively [6,9]. These experiments and the parameters derived from the radiant panel and smoke chamber experiments will be discussed and summarized in the following sections and then used to assess the overall fire hazard.

2.1. Radiant panel experiments and theory

2.1.1. Experiments

A radiant panel apparatus was constructed to determine the various combustion properties of the mine materials during the thermal decomposition and ignition stages of combustion. A metal structure was