FLAMMABILITY OF NOISE ABATEMENT MATERIALS USED IN CABS OF MOBILE MINING EQUIPMENT

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ABSTRACT

Experiments were undertaken to evaluate the flammability of typical noise abatement materials used to line the cab interior of mobile mining equipment. The experiments were conducted using three different experimental configurations:

1. A ventilated tunnel test.
2. A full-size cab test where the interior surfaces were lined with the sample material and then ignited near the floor using a methane-air burner.
3. Standard ASTM E-162 tests using a radiant panel test apparatus.

This paper describes the tests and presents the results obtained for 15 to 20 different materials of various chemical compositions and thickness. With one exception, materials that did not exhibit flame spread in the tunnel test also performed well in the full-scale cab test. All materials that had passed only a small-scale flammability test, such as SAE J369, failed dramatically in all three of the above test configurations. With one exception, all materials that performed well in the full-scale cab test had flame spread indices < 25, based upon the ASTM E-162 results. The lone exception had an ASTM E-162 flame spread index of 68. With regard to samples that failed the full-scale cab test, the carbon monoxide levels within the cab reached lethal concentrations in the range of 1.8% to 3.8% within 2 minutes from ignition of the sample—dramatically illustrating the severe fire environment that can result within the cab space.

INTRODUCTION

Data collected during the period 1990-99, indicate that 339 fires involving mobile mining equipment occurred at U. S. mines, resulting in 159 injuries and 2 fatalities[1]. In some of these instances, fire spread to the cabs of these vehicles, igniting the cab lining materials, producing excessive levels of smoke and toxic gases, and compromising the operator's ability to safely egress the vehicle[2]. With respect to noise abatement, the Mine Safety and Health Administration

(MSHA) has recently issued new regulations requiring the use of engineering controls when necessary to reduce operator exposure to excessive noise levels that can impair hearing[3]. One such engineering control is the use of noise-reducing materials to line the interior surfaces of cabs. Selection of these materials is based primarily upon the material's ability to reduce noise, without the requirement for the selection of these materials based upon their fire resistance. Yet, typical cabs are relatively small in volume and should fires occur within these small spaces, the buildup of smoke and toxic gases occurs rapidly. This consequence seriously reduces the operator's ability to perform emergency maneuvers and safely exit the cab. Some of these materials have undergone no flammability testing, while a significant fraction of these types of materials have been evaluated for their flammability using only small-scale tests, such as the Society of Automotive Engineers test, SAE J369[4]. The SAE J369 test samples measure 0.051 m wide by 0.356 m long and the ignition source is a Bunsen-type burner. A similar test is the Motor Vehicle Safety Code, Standard 302 (MVSS 302)[5]. A smaller percentage of these materials have undergone more extensive flammability tests, most notably the ASTM E-84 Tunnel Test[6], to arrive at flame spread indices for these materials. A series of experiments were undertaken to evaluate the adequacy of these different tests with respect to the full-size cab fire tests and to determine the potential hazard from combustion that can result should these materials ignite and burn within the cab space.

Twenty-one (21) different noise-reducing materials were obtained for testing. These materials encompass the range of materials typically used, not only in terms of their chemical composition, but also in terms of their flammability and fire resistance ratings. There were materials with no flammability rating, to those with only small-scale flammability ratings to those with more extensive, larger-scale flammability ratings.

EXPERIMENTAL

Three different types of tests were used to evaluate the sample materials. The first test used a laboratory-scale tunnel, with a square cross-section of 0.21 m^2, and ventilated at a constant air velocity of 1.0 m/s. Details of this experimental configuration can be found in Reference 7. Samples measuring 0.23 m wide and typical lengths between 1.22 and 1.83 m were placed along the centerline of the tunnel secured to a metal rack with one edge of the sample located approximately 0.12 m from the upstream entrance to the tunnel. A methane burner with 12 nozzles was then positioned so that the methane-air flames impinged on both the top and bottom surfaces of this upstream sample edge. The approximate heat output of the burner was 25 kW. The time allowed for flames to impinge upon the sample varied from 30 s to a maximum of 5 minutes, where the lower times correspond to experiments where ignition and flame spread occurred rapidly while the longer times correspond to experiments where little, if any, flame spread was observed. Each experiment was videotaped and the gases CO, CO_2, and O_2 measured continuously by flowing the gases from a sampling point located in the center of the tunnel exhaust section to three separate gas analyzers. For this test, samples for which flame spread did not advance beyond the vicinity of the ignition area were judged to pass. Samples, where flames spread along the surface beyond the local ignition area, were judged to have failed the test. All of the sample materials were tested in this experimental configuration. A photograph of the tunnel with the gas burner igniter is shown in Figure 1.

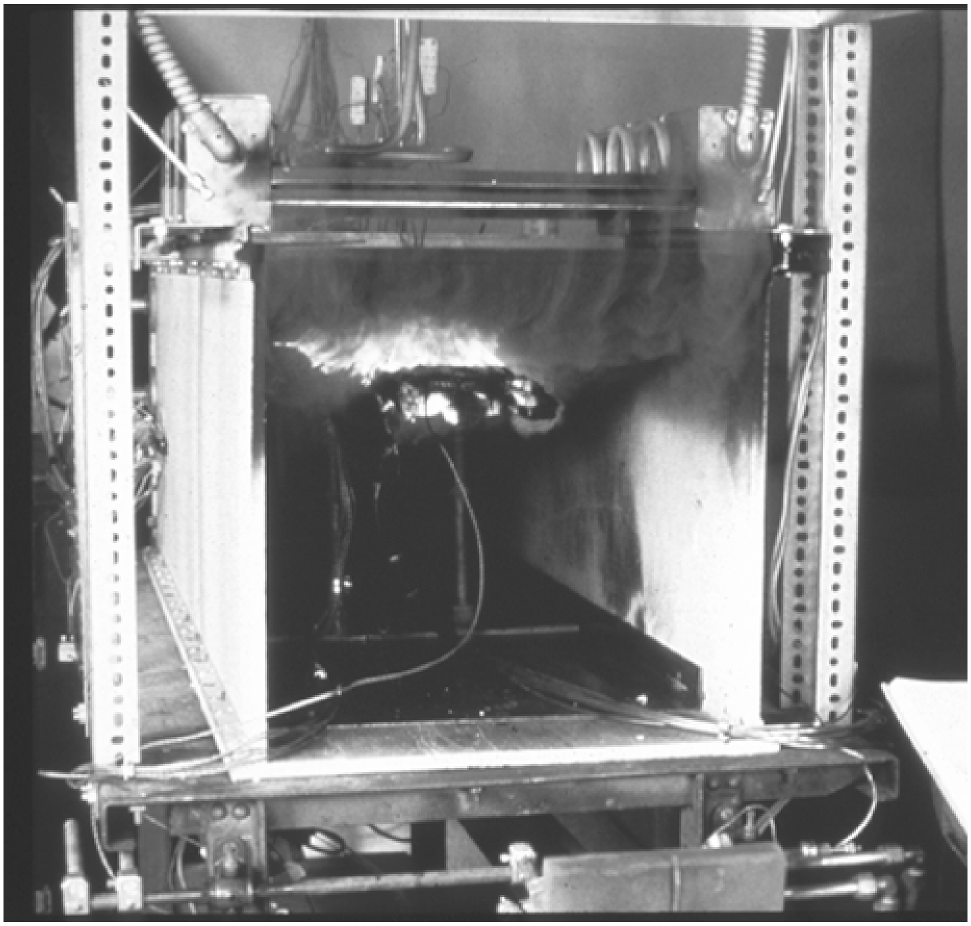

Figure 1. Photograph of the ventilated tunnel with the gas burner igniting a sample material.

Figure 2. Photograph of the full-size cab used in the second type of experiments.

The second type of experiment used a full-size cab, typical of older cabs used on mobile mining equipment (Figure 2). The volume of the cab used in the experiments is approximately 2.5 m^3. In these experiments, sample materials were mounted on the walls and ceiling of the rear of the cab and, in some tests, on the floor of the cab. The samples were ignited at the base of the rear wall using the same gas burner used in the laboratory-scale tunnel tests. Gas temperatures were measured near the ceiling at three different locations along the front-to-rear centerline—0.25 m from front and rear of the cab, and in the cab center--and at three locations along the front-to-rear centerline 0.25 m from the cab ceiling—0.025 m from front and rear of the cab and in the cab center. A gas sampling probe was positioned to continuously flow gas samples from a point in the cab center 0.25 m from the ceiling to gas analyzers for measurement of CO, CO_2, and O_2. All experiments were videotaped using both a standard camera and an infrared thermal imaging camera. In the experiments, a sample material was judged to have passed this full-size cab test if visual examinations of the sample subsequent to the experiment did not indicate any damage (or flame spread) beyond the localized ignition area. Ten of the sample materials were tested in this experimental configuration.

The third type of experiment performed on the samples was the standard ASTM E-162 Test using a radiant heat energy source. This test is described in detail elsewhere[8]. Briefly, the test consists of mounting a standard sample measuring 0.152 m wide 0.457 m long at a 30º angle with respect to a vertically-positioned radiant panel measuring 0.305 m x 0.457 m operating at a blackbody equivalent surface temperature of 670 ºC. The topmost edge of the sample is positioned so that it is approximately 0.0445 m from the surface of the radiant panel. A small pilot flame with a flame length of 0.051 to 0.076 m is positioned so that the flame impinges on the topmost edge of the sample. An exhaust stack containing eight thermocouples is mounted above the sample and the gas velocity at the top of the stack maintained at a value of approximately 1.3 m/s during the test. Once the test has begun, the pilot flame ignites combustible vapors at the topmost edge of the sample and the flame front begins to move downward along the sample surface. The times to reach successive distances of 0.0762 m are recorded until the flame has reached the distance of 0.381 m or, in the event flames do not reach this distance, until 15 minutes have elapsed. The rate of progression of the flame front along the sample and the maximum gas temperature measured in the stack are then used to calculate a number, called the flame spread index. For this experiment at least 3 samples of each material were tested and the average of the three or more separately measured flame spread indices quoted as the flame spread index for that material. In addition, a sample was judged to pass the test if the resultant flame spread index had a value of 25 or less. Sixteen of the sample materials were subjected to this standard test.

THEORETICAL

In general, data from the first and second experimental configurations are most easily analyzed in terms of the heat release rates and total heat outputs calculated from the measured oxygen concentrations. The flame spread index data from the standard ASTM E-162 experiments represent components from both flame spread and heat release rate. Heat release rate, Q_{TOT}, expressed in kilowatts (kW), can be calculated for the tunnel experiments and the full-size cab experiments using the O_2 data from the general expression:

$$Q_{TOT} = Q_{O2} = 13.1\ D_{O2} \quad (1)$$

Where D_{O2} is the rate of depletion of O_2, g/s;

and the factor of 13.1 kJ/g of O_2 consumed in equation (1) an average value for polymeric materials.

For the ventilated tunnel, D_{O2} is calculated from the expression

$$D_{O2} = 1.43 \times 10^{-3}\ V_0 A_0 (\Delta O_2) \quad (2),$$

where the Δ gas concentration is the change in gas concentration, in ppm, from its initial value;
V_0 is the air velocity through the tunnel, 1.0 m/s; and
A_0 is the tunnel cross-sectional area, 0.21 m^2.

For the full-size cab tests, the depletion rate of O_2, may be calculated from the data of gas concentrations vs time to yield the average heat release rates. In addition, for these tests, the maximum O_2 depletion may be used to calculate the energy output from the combustion of the samples using the expression

$$E\ (kJ) = 13.1 \rho_{O2} V_C (\%\Delta O_2/100) \quad (3)$$

where ρ_{O2} is the density of O_2, 1428 g/m^3,
V_C is the cab volume, 2.5 m^3, and
$\%\Delta O_2$ is the average per cent O_2 consumed.

For the standard E-162 test, a flame spread index, I_S, is calculated from the expression

$$I_S = F_S Q \quad (4)$$

where $F_S = 1 + 1/(t_3 - t_0) + 1/(t_6 - t_3) + 1/(t_9 - t_6) + 1/(t_{12} - t_9) + 1/(t_{15} - t_{12})$, and the times t_3 through t_{15} are the arrival times (in minutes) at the respective distances of 0.076, 0.152, 0.228, 0.304, and 0.38 m along the length of the sample. The quantity F_S is a measure of the flame spread rate along the sample surface.
Q is given by $Q = CT/\beta$, with C (a constant) having a value of 5.7, β (a calibration constant for the apparatus) having an average value of 30 ºC/kW, and T being the maximum stack temperature difference (ºC) between the temperature-time curve for the sample and that for a similar curve using an inert sample. Q is, then, a measure of the heat output from the sample.

Previous tests of mine conveyor belting[9] have indicated that the propensity for flame spread scales with the ratio of heat release rate to forced convective air velocity, Q_{TOT}/V_0. For these experiments, a heat parameter, HP, is defined that is the energy output per unit volume, kJ/m^3. For the ventilated tunnel test, HP is obtained by dividing the calculated heat release rate, Q_{TOT}, by the volumetric air-flow rate through the tunnel, V_0A_0. For the cab experiments, HP is the energy output divided by the cab volume. In the results that follow, the heat parameters calculated for the ventilated tunnel and full-size cab experiments are reported for comparison.

RESULTS AND DISCUSSION

In the data that follows, the tunnel and cab heat parameters (HP) are the net values obtained after subtracting the contribution from the methane-air burner used to ignite the samples. For the tunnel tests, the measured HP of the burner was 125 kJ/m^3, while for the cab experiments the measured HP was 650 kJ/m^3, corresponding to a burner duration of five minutes and an oxygen depletion of 3.47%. For the materials tested in the tunnel, the HP ranged from a low value of 115 to a maximum value of 1165. For these tests, materials with HP's less than 225 did not support flame spread. For the full-size cab tests, the HP ranged from a low value of 115 to a maximum value of 2750. For the E-162 tests, values of the flame spread index ranged from a low of 13 to a maximum of 772. It is worth noting that the sample material with the maximum flame spread index had a relatively low HP for the tunnel test (210), but a correspondingly high HP for the cab experiment (2050). Only three materials had flame spread indices less than 25 and one other material had an average flame spread index of 68, based on two series of tests, one yielding an I_S of 95 and the second yielding a value of 40. The data from the experiments are summarized in Table 1.

Sample Designation	**I_S (E-162)**	**Tunnel HP**	**Cab HP**
TFMFR	772	210	2050
TFM	13	115	115
PNR	527	720	2430
PVN	347	675	2610
UPSS1 (1st Set)	95	135	850
UPSS1 (2nd Set)	40	"	"
UPSS2	20	125	230
TFMT	273	675	-----
PPFKA	23	125	650
PMFUF	163	390	1000
PHUF	581	1165	-----
SC4	331	600	-----
SC1	144	330	-----
SC2	124	275	-----
SC3	361	490	-----
AAWM	536	710	2380
AAWMFM	228	640	2750

Table 1. Summary of the flame spread indices, I_S, and the heat parameters for both tunnel and cab experiments. Only those sample materials tested using the E-162 radiant panel test apparatus are shown. The additional five materials were subjected to the tunnel test only, with average HP values in the range of 600 to 1000.

Correlations were obtained between the cab HP and the tunnel HP as shown in Figure 3. Although there is scatter in the data, a least-squares regression of cab HP vs tunnel HP (the solid line of Figure 3) yielded a correlation factor, r^2, of 0.75.

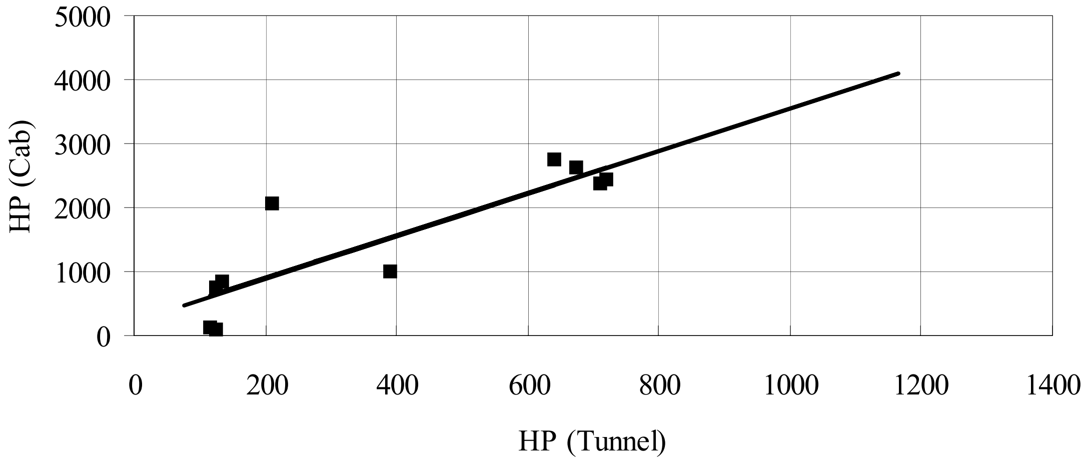

Figure 3. Cab HP vs the tunnel HP for the 10 sample materials tested

Additionally, the measured flame spread indices were plotted as a function of the tunnel HP and are shown in Figure 4. With the exception of one point (sample TFMFR, $I_S = 772$), there is a good correlation between the different experiments as shown by the least-squares regression solid line with an r^2 of 0.84.

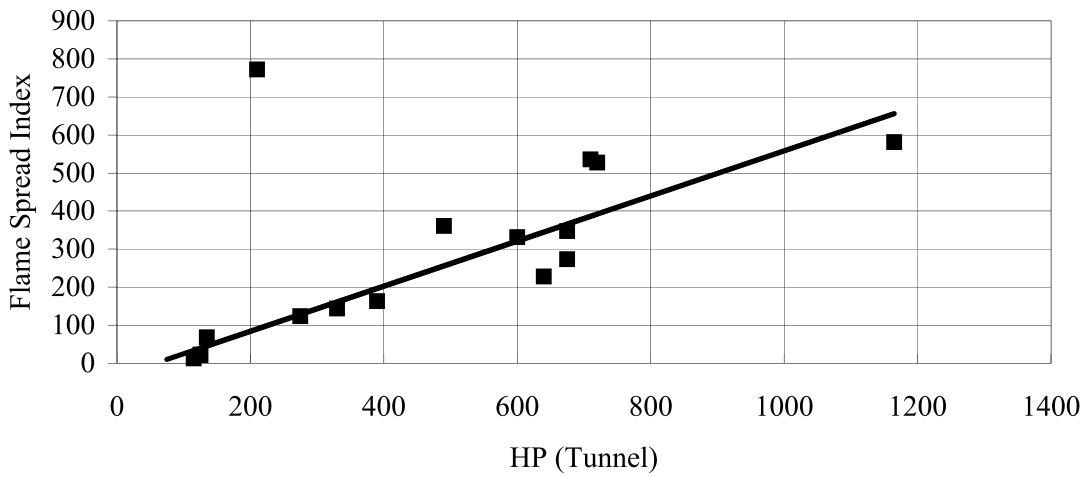

Figure 4. A plot of the measured E-162 flame spread index vs the tunnel HP for the sixteen sample materials tested.

It is worth noting that all of the sample materials with $I_S < 25$ had corresponding tunnel HP's less than 200 and that all sample materials with $25 < I_S < 200$ had corresponding tunnel HP's in the range of 200 to 400, except for the one sample previously noted. With regard to test data obtained by the standard ASTM E-84 tunnel test[6], seven of the sample materials had flame spread indices less than 25. Four of these sample materials were found to be inadequate in either the tunnel or cab experiments, or both, which is an indication that the use of this standard test would not be appropriate for the measure of fire resistance for materials used in the cabs of mining equipment.

The propensity to spread flame, once a material is ignited, is an important consideration in the selection of noise-reducing materials. However, the small volume typical of most cabs increases the potential fire hazard due to the rapid accumulation of lethal gases, such as CO, within this volume, coupled by a corresponding rapid depletion of O_2. The magnitude of this hazard is apparent in Table 2, where the maximum levels of CO and minimum levels of O_2 measured during the full-size cab tests are tabulated. These table values have been corrected for the effects of the gas burner ignition source, and represent levels indicative of the sample material combustion only. Six of the 10 materials produced CO in excess of 1.5%, while five of the 10 materials depleted O_2 levels to well below 15%, resulting in lethal atmospheres inside the cab.

Sample Designation	Cab HP	Maximum CO (%)	Minimum O_2 (%)
TFMFR	2050	1.791	10.00
TFM	115	0.037	20.34
PNR	2430	2.561	7.96
PVN	2610	3.811	7.00
UPSS1	850	0.261	16.41
UPSS2	230	0.004	19.73
PPFKA	650	0.247	17.48
PMFUF	1000	2.211	15.61
AAWM	2380	3.691	8.23
AAWMFM	2750	2.011	6.26

Table 2. The maximum levels of CO and minimum levels of O_2 measured during the full-size cab experiments, corrected for the contribution by the gas burner ignition source.

In addition to the magnitude of these levels, it is also important that the rapidity with which these atmospheres are created also be quantified. This aspect of the problem is demonstrated in Figures 5 and 6, where the best/worse case for CO accumulation and O_2 depletion, respectively, are shown as a function of time.

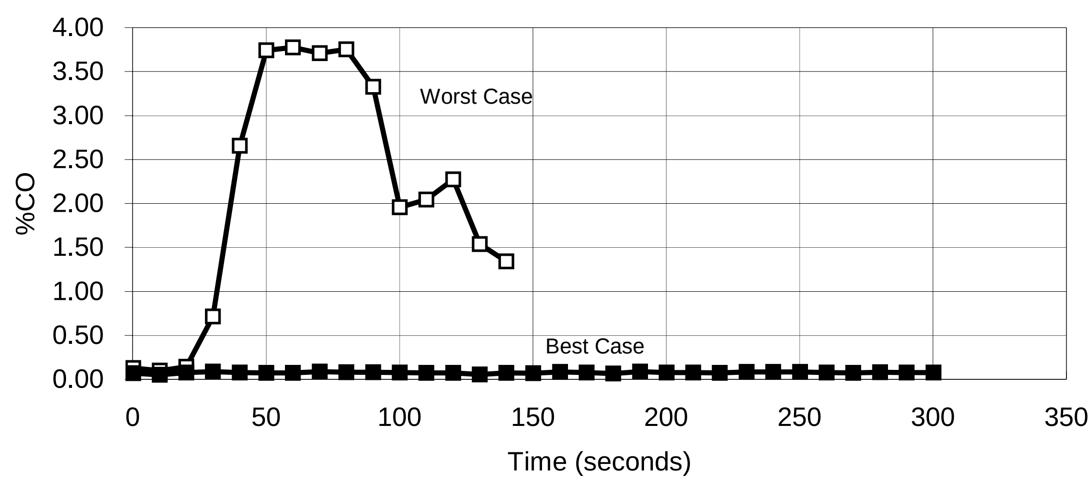

Figure 5. The measured CO concentrations for the best and worst sample materials as a function of time from ignition of the gas burner.

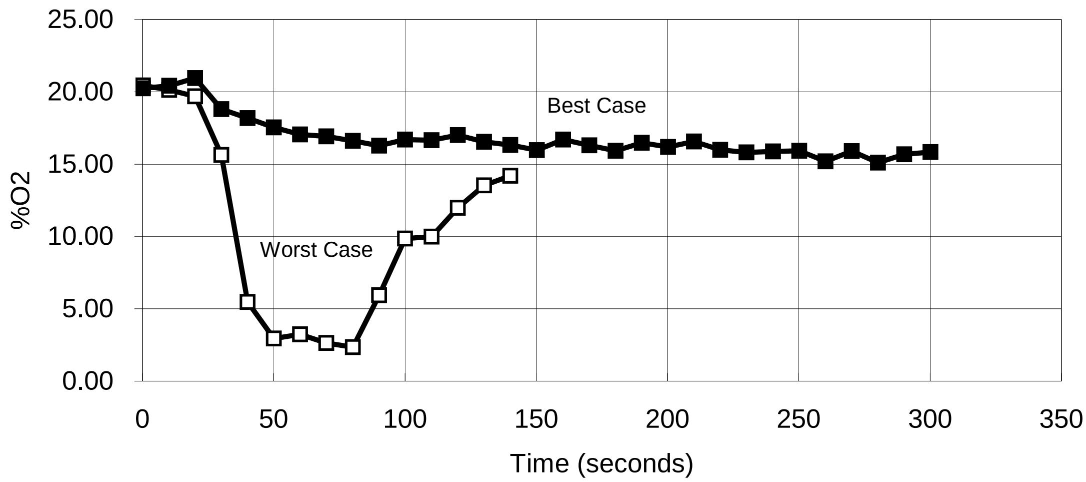

Figure 6. The measured O_2 concentrations for the best and worst sample materials as a function of time from ignition of the gas burner.

Figures 5 and 6 are typical, in terms of the time to produce a life-threatening atmosphere within the cab volume, of those experiments resulting in high levels of CO and low O_2 concentrations. In general, about 20 seconds elapse before the sample material ignites and within less than 10 to 20 seconds from sample ignition, CO levels exceed 1%. This rapid development of CO is due not only to the small cab volume but also to the lack of O_2 to support the combustion so that there is a rapid transition to fuel-rich conditions resulting in significant increases in the production of CO.

CONCLUSIONS

The results of this study indicate that the majority of noise-reducing materials used to line the interior surfaces of cabs of mobile mining equipment are prone to rapid flame spread. Also, the combustion of these materials within the small volume of the cab rapidly results in the formation of life-threatening atmospheres due to the production of CO and depletion of O_2.

For the laboratory-scale tunnel experiments, a heat parameter value of less than 200 appears to be an indicator of good fire resistance. However, one material with a tunnel HP of 210 performed poorly in the full-size cab test and also in the standard E-162 radiant panel test.

Those materials with E-162 flame spread indices of 25 or less performed well in both the tunnel experiments and the full-size cab experiments. One sample material with an average flame spread index of 68 also performed well in both the tunnel and cab experiments.

As mentioned previously, seven of the sample materials had flame spread indices less than 25, based upon the standard ASTM E-84 tunnel test[6]. Four of these sample materials were found to be inadequate in either the tunnel or cab experiments, or both. These results indicate that the use of this standard test would not be appropriate for the measure of fire resistance for materials used in the cabs of mining equipment.

The full-size cab test data show, in general, that good fire resistance of noise abatement materials for use in cabs of mining equipment can be achieved by a flame spread index of 50 or less. As a means of improving fire safety, the Mine Safety and Health Administration (MSHA) presently recommends a flame spread index of 25 or less for noise abatement materials used in cabs or compartments of underground equipment and 50 or less for cabs or compartments in surface equipment. The lower recommended flame spread index as applied to underground equipment is based on the more confined environment for escape.

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