

## Dust explosion hazard of pulverized fuel carry-over

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### Abstract

This paper reports the results of experiments done to examine the explosibility of the waste products (fly ash and bottom ash) from pulverized fuels (coal and petroleum coke). Tests were conducted for the fly and bottom ashes alone and also for selected fly ashes blended with the fuels. The explosion parameters of interest were explosion pressure and rate of pressure rise. The fly ashes showed no propensity to explode, whereas one of the bottom ashes did show limited explosibility. Both findings can be explained with reference to the volatile matter content of the ashes. Admixture of either coal or petroleum coke with fly ash resulted in explosible mixtures at volatile contents in the range of 7–13%, with the value being dependent on the composition of the mixture components and their particle sizes.  
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### 1. Introduction

In the current global economy, the utility industry is increasingly exploring avenues for less expensive and more environmentally benign fuels. This has led to an increase in fuel substitution (e.g. petroleum coke in place of coal) in pulverized fuel (PF) power plants. While fuel substitution has economic benefits in the form of fuel cost savings, it also changes the explosion hazard of the plant in both the fuel and ash handling systems.

The overall scope of the current research is an examination of the dust explosion hazard of such fuel substitution in fossil fuel fired power plants. This was accomplished by conducting laboratory-scale experiments to determine the relative explosibility of different fuels (Powder River Basin coal, Columbian coal and petroleum coke), fuel blends, fly and bottom ashes, and fuel/fly ash mixtures. The explosion parameters investigated were explosion pressure,  $P_m$ , and rate of pressure rise ( $dP/dt$ )<sub>m</sub>.

The results of the baseline fuel tests and fuel blend tests have been previously reported by Amyotte et al. [1]. From the perspectives of explosion pressure and rate of pressure rise, petroleum coke was found to be an inherently safer fuel than either Powder River Basin coal or Columbian coal. Blending petroleum coke with either or both of these coals also resulted in an inherently safer fuel. In all cases tested, the presence of petroleum coke in the fuel reduced the prevailing dust explosion hazard (primarily because of the low volatile content of the petroleum coke).

The focus in the current paper is on the dust explosion hazard presented by the waste products in a PF plant – i.e. the fly ash and bottom ash. While our previous work [1] has demonstrated the benefits of blending petroleum coke with coal from a fuel explosion hazard perspective, it must be remembered that such a fuel blending procedure also changes the composition of the waste streams from the boiler. The use of petroleum coke as a fuel in PF boilers typically leads to an increase in carbon content of the fly and bottom ashes, thereby raising a concern of an enhanced dust explosion hazard in units such as electrostatic precipitators. (This would be in addition to other implications of the presence of unburned carbon in fly ash, such as the potential impact on the use of

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fly ash as a cement or concrete additive [2].) A companion study to Amyotte et al. [1] was therefore conducted with the results as reported in detail here. A summary of these results, along with minimum ignition energy and minimum ignition temperature data, have been presented by Amyotte et al. [3].

## 2. Experimental

### 2.1. Materials

Samples of fuel and ash were obtained from the Point Tupper Generating Station of Nova Scotia Power Inc. (NSPI). The fuels (as reported here) were Columbian coal (a low-sulphur coal), and petroleum coke (PetCoke – a byproduct of the petroleum industry). Four fly ash samples and two bottom ash samples were received; the fuels burned to produce each type of ash were different. Table 1 summarizes the ash nomenclature.

Each batch of fuel received (Columbian coal and petroleum coke) was surface dried in the laboratory. The surface-dried fuel was sent for particle size analysis and proximate analysis to the Minerals Engineering Centre, Dalhousie University. The proximate analyses of the fuels are shown in Table 2.

The fuels were crushed to a nominal particle size of 70% minus 200 mesh. This size requirement was specified by NSPI as the solid fuel particle size fired at the Point Tupper Generating Station. Particle size analyses of the fuels were performed using a Malvern Instruments 2600 Series Analyzer. The results are summarized in Table 3. The particle size distributions of the fuels were kept as close to each other as possible. This reduces the influence of particle size on the hazard comparison of different fuel blends. The mass mean diameter ( $D_w$ ) of the dust particles is also given in Table 3.

Each ash sample was also sent to the Minerals Engineering Centre for particle size distribution analysis and proximate analysis. The results of the proximate analyses are summarized in Tables 4 and 5 and the particle size distributions are given in Table 6. As seen from Table 4, the as-received bottom ash samples had high moisture contents, making them

Table 1  
Ash fuel source

Ash name	Ash type	Fuel composition
Fly Ash A	Fly Ash	20% PetCoke, 70% Columbian coal, 10% PRB coal
Fly Ash B	Fly Ash	20% PetCoke, 70% Columbian coal, 10% Nova coal
Fly Ash C	Fly Ash	20% PetCoke, 70% Venezuelan coal, 10% Nova coal
Fly Ash D	Fly Ash	90% Venezuelan coal, 10% Nova coal
Btm Ash A	Bottom Ash	20% PetCoke, 70% Columbian coal, 10% PRB coal
Btm Ash B	Bottom Ash	20% PetCoke, 70% Columbian coal, 10% Nova coal

unsuitable in this form for dust dispersion. Thus, the bottom ashes were dried overnight to 0% moisture at the Minerals Engineering Centre. The analyses of the ashes, on a moisture-free basis, are summarized in Table 5. The bottom ashes were also sieved to under 0.5 mm to make them suitable for dispersion. The particle size distributions of the sieved bottom ashes, and the fly ashes, were measured with the Malvern Instruments 2600 Series Analyzer.

### 2.2. Apparatus and procedures

The explosibility experiments for  $P_m$  and  $(dP/dt)_m$  were performed in a 20-L Siwek chamber (Fig. 1). This apparatus consists of a spherical vessel into which the sample dust is dispersed and subsequently ignited by a centrally mounted chemical ignitor. Further details on the equipment and method of operation can be found in Kuhner [4] and in a number of previous publications from our research group (e.g. Amyotte et al. [1] and Dastidar and Amyotte [5]). In the present work the ignition delay time and ignition energy were fixed at 60 ms and 5 kJ, respectively. This choice of ignition energy, although suitable for the relative ranking of explosion hazards, means that the explosion data presented here should not be used for assessment of explosion protection requirements such as venting.

Experiments for the ash samples were conducted as outlined in Table 7. The purpose of these tests was to determine the explosion hazard of these ashes and to determine if the

Table 2  
Proximate analyses of Columbian coal and petroleum coke

Fuel	Moisture (wt.%)	Ash (wt.%)	Volatile matter (wt.%)	Fixed carbon (wt.%)	Heating value (kJ/kg)
Columbian coal	0.4	7.7	36.4	55.5	26847
Petroleum coke	0.4	3.9	17.0	78.7	32006

Table 3  
Particle size analyses of Columbian coal and petroleum coke

Fuel	<500 $\mu\text{m}$ (wt.%)	<125 $\mu\text{m}$ (wt.%)	<75 $\mu\text{m}$ (wt.%)	<45 $\mu\text{m}$ (wt.%)	<20 $\mu\text{m}$ (wt.%)	$D_w$ ( $\mu\text{m}$ )	Specific surface area ( $\text{m}^2/\text{cm}^3$ )
Columbian coal	99.9	83.0	72.6	53.1	29.3	72.0	0.02
Petroleum coke	99.9	82.6	75.2	62.1	38.3	69.3	0.02

Table 4  
As-received ash composition

Ash	Moisture (wt.%)	Ash (wt.%)	Volatile matter (wt.%)	Fixed carbon (wt.%)
Fly Ash A	0.1	84.4	2.1	13.5
Fly Ash B	0.0	71.7	2.2	26.1
Fly Ash C	0.0	64.1	2.3	33.6
Fly Ash D	0.2	68.0	3.0	28.8
Btm Ash A	27.5	50.6	4.9	17.0
Btm Ash B	26.0	21.6	8.8	43.6

Table 5  
Ash composition on moisture-free basis

Ash	Ash (wt.%)	Volatile matter (wt.%)	Fixed carbon (wt.%)
Fly Ash A	84.4	2.1	13.5
Fly Ash B	71.7	2.2	26.1
Fly Ash C	64.1	2.3	33.6
Fly Ash D	68.2	3.0	28.8
Btm Ash A	69.8	6.7	23.5
Btm Ash B	29.2	11.9	58.9

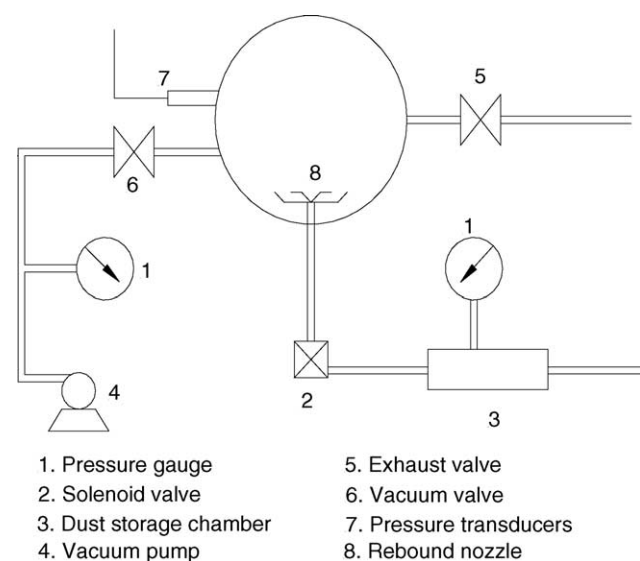


Fig. 1. Schematic diagram of 20-L Siwek chamber.

parent fuel composition had an effect on the ash explosibility. Btm Ash B was tested twice, by varying the ignitor configuration. The first set of tests was conducted using one 5-kJ ignitor (centrally mounted, pointing downward); these

Table 6  
Summary of particle size analyses of ashes

Ash	<500 $\mu\text{m}$ (wt.%)	<125 $\mu\text{m}$ (wt.%)	<75 $\mu\text{m}$ (wt.%)	<45 $\mu\text{m}$ (wt.%)	<20 $\mu\text{m}$ (wt.%)	$D_w$ ( $\mu\text{m}$ )
Fly Ash A	99.9	85.1	76.4	60.3	41.2	62
Fly Ash B	100.0	71.9	56.7	44.4	29.1	92
Fly Ash C	99.4	49.1	38.3	28.9	15.7	155
Fly Ash D	100.0	58.1	43.6	32.6	21.8	116
Btm Ash A	99.5	36.4	18.0	8.9	3.6	181
Btm Ash B	99.3	20.8	6.5	3.5	1.5	220

Table 7  
Explosibility testing for fly and bottom ashes

Ash	Dust concentration ( $\text{g}/\text{m}^3$ )	Ignition energy (kJ)
Fly Ash A	250, 500, 1000, 1500, 2500	5
Fly Ash B	250, 500, 1000, 1500, 2500	5
Fly Ash C	250, 500, 1000, 1500, 2500	5
Fly Ash D	250, 500, 1000, 1500, 2500	5
Btm Ash A	250, 500, 1000, 1500, 2500	5
Btm Ash B	250, 500, 1000, 1500, 2500	5
Btm Ash B	500, 1000, 1500, 2500	$2 \times 2.5$

tests were then repeated using two 2.5-kJ ignitors (centrally mounted, pointing outward in opposite directions). This was done to investigate the effect of ignition source geometry on the explosibility of the bottom ash.

Explosibility experiments were also conducted for ash blended with fuel dust. The ashes used were Fly Ash C and Fly Ash D, with each fly ash being mixed with each of the two fuels (Columbian coal and petroleum coke). Test conditions were as shown in Table 8, with the extension to high additive percentages being undertaken because of the potential for these conditions during a process upset. The purpose of these tests, which formed the bulk of the experimentation, was to observe the explosion characteristics of ash of different parent fuels contaminated with different fuels (in other words, to investigate the explosibility hazard of fuel carry-over into the ash).

### 3. Results and discussion

#### 3.1. Fly and bottom ash explosibility tests

The ash explosibility tests (Table 7) resulted in no explosions being recorded for any of the fly ashes. This result was expected and is supported by previous work done by Dastidar and Amyotte [5]; they found that for the fly ash/coal dust mixtures they tested, a volatile content of 7–12% was required before the mixture would explode. (A range of volatile percentages arose because a range of fly ash particle sizes was used in their study.) Tables 4 and 5 indicate that the volatile matter contents of the fly ashes used in the present study were  $\leq 3\%$  (on either a wet or dry basis). Thus, there is insufficient volatile matter present in the fly ashes for an explosion to occur.

With respect to the bottom ashes (A and B), neither exploded with a single 5-kJ ignitor. This result is not surprising

Table 8  
Explosibility testing for blends of fly ash and pulverized fuel

Ash	Additive fuel	Additive percentage (%)	Dust concentration ( $\text{g}/\text{m}^3$ )	Ignition energy (kJ)
Fly Ash C	Columbian coal	10, 30, 50, 70, 90	250, 500, 1500, 2500	5
Fly Ash C	Petroleum coke	10, 30, 50, 70, 90	250, 500, 1500, 2500	5
Fly Ash D	Columbian coal	10, 30, 50, 70, 90	250, 500, 1500, 2500	5
Fly Ash D	Petroleum coke	10, 30, 50, 70, 90	250, 500, 1500, 2500	5

for Btm Ash A with its volatile content of 6.7%. For Btm Ash B with its volatile content of 11.9% (and recalling the findings of Dastidar and Amyotte [5]), the non-explosibility of the sample must mean that the relatively large particle size (mass mean diameter of  $220 \mu\text{m}$ ) has a dominant effect over the volatile percentage. In other words, although the volatile content could lead to marginal explosibility, the particles are too large to permit significant release of volatiles in the time available.

It was determined, however, that this particle size influence could be partially countered by altering the ignition source configuration from one 5-kJ ignitor to two 2.5-kJ ignitors. This is illustrated by the upper plot in Fig. 2 for those tests in which the explosion pressure satisfies the generally accepted explosion criterion of a 1-bar overpressure – i.e.  $P_m = 1 \text{ bar}$  (g). (In all data plots in the current paper,  $P_m$  is the explo-

sion pressure corrected for the ignition source contribution and cooling from the vessel wall, and  $(dP/dt)_m$  is the maximum rate of pressure rise for a particular test.) With two multi-point ignition sources releasing a shower of pyrotechnic sparks, Btm Ash B demonstrated an explosible nature at the higher concentrations tested ( $1000\text{--}2500 \text{ g}/\text{m}^3$ ). Even with this obviously more effective ignitor configuration, the results from Btm Ash B are still marginal; replicate tests at  $1000$  and  $2500 \text{ g}/\text{m}^3$  resulted in both explosions and non-explosions.

Finally, it should be remembered that these results for the bottom ashes are for moisture-free samples. As received, the bottom ashes had moisture contents approaching 30% (see Table 4). Not only would the samples in this state be non-explosible, it would not be possible to disperse them in the explosion chamber.

### 3.2. Fuel carry-over tests

Unburned fuel carry-over into ash silos is a concern to operators of power plants. This concern is increased when there is a change in fuel leading to different ash properties, which when blended with the new fuel may pose an unforeseen explosion hazard. The test protocol shown in Table 8 was designed to investigate these issues.

Figs. 3–6 show the effects of both dust concentration and volatile content on the explosion pressures and rates of pressure rise of fly ash blended with Columbian coal and with petroleum coke. There are several features of Figs. 3–6 that are in accordance with dust combustion theory. For example, as dust concentration is increased for a fixed volatile matter content (for combustible mixtures), the values of  $P_m$  and  $(dP/dt)_m$  attain maximum values and then decrease. At low volatile content (e.g. 30% coal or 12.55% volatile matter in Fig. 3), these maxima are shifted to higher dust concentrations than those for the pure fuel. Figs. 3–6 also demonstrate that there are volatile content boundaries below, which the fuel/ash mixtures will not explode. This point is discussed further at the end of the current section.

The data in Figs. 3–6 reveal an interesting issue concerning the fuel carry-over problem. The discussion that follows is restricted to the  $P_m$  (upper) plots, although similar considerations apply for  $(dP/dt)_m$ . It can be seen in the most extensively tested region of Figs. 3 and 5 (i.e. dust concentrations of  $500 \text{ g}/\text{m}^3$  and less) that some Columbian coal/fly ash mixtures containing 70% or more coal dust had higher  $P_m$  values than 100% (i.e. pure) coal dust. This occurrence is even more pronounced with the petroleum coke/fly ash mix-

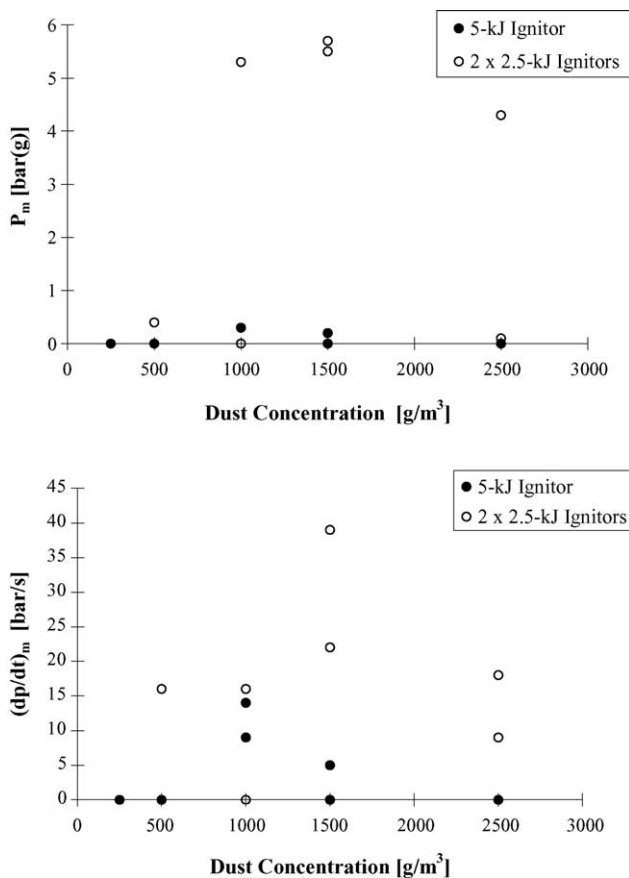


Fig. 2. Influence of dust concentration and ignitor configuration on (a) explosion pressure (upper plot) and (b) rate of pressure rise (lower plot) of Btm Ash B.

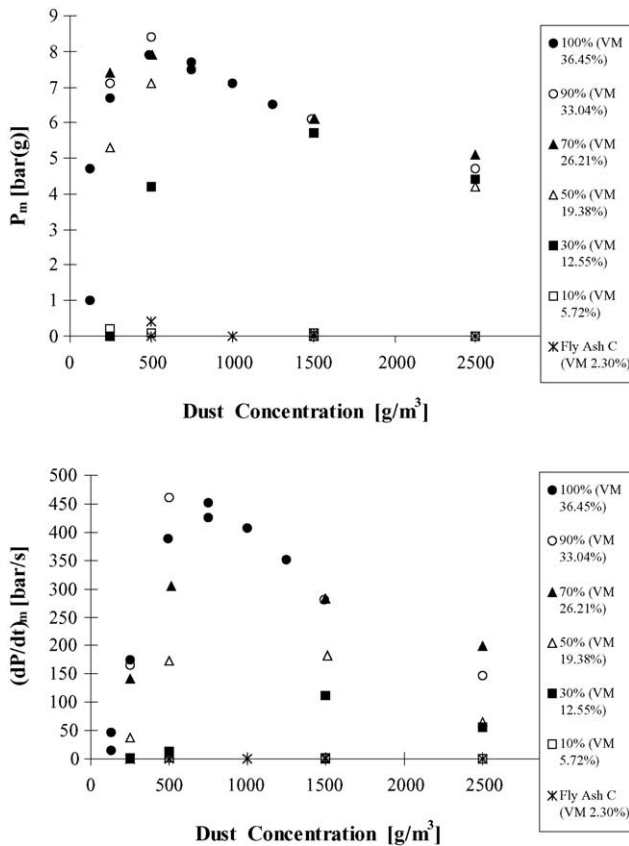


Fig. 3. Influence of dust concentration and fuel contaminant percentage on (a) explosion pressure (upper plot) and (b) rate of pressure rise (lower plot) of Fly Ash C blended with Columbian coal.

tures. Figs. 4 and 6 (again, dust concentrations of 500 g/m<sup>3</sup> and less) show that some petroleum coke/fly ash mixtures containing 50% or more petroleum coke dust had higher  $P_m$  values than 100% (i.e. pure) petroleum coke dust. The net result is a shift of the maxima in  $P_m$  in Figs. 4 and 6 to leaner dust concentrations than that determined for the petroleum coke alone (750 g/m<sup>3</sup> as reported by Amyotte et al. [1]). The same conclusion applies to the maximum values of  $(dP/dt)_m$  shown in the lower plots of Figs. 4 and 6.

The phenomena described in the preceding paragraph can be explained by looking at the issue being studied as one of explosion inerting. While the emphasis to this point has been on determining how much fuel dust is required to create an explosible mixture with fly ash, it is helpful to turn the problem around and look at it from the perspective of how much fly ash is required to create a non-explosible mixture with fuel dust. The addition of insufficient amounts of fly ash is seen to make the situation worse by leading to higher overpressures and rates of pressure rise than for the fuel dust alone. This is a clear manifestation of SEEP – Suppressant Enhanced Explosion Parameter – as identified by other researchers in 20-L laboratory-scale and 1-m<sup>3</sup> intermediate-scale [6] and industrial-scale applications [7].

The SEEP phenomenon was observed by Dastidar et al. [6] when insufficient amounts of inertant (or suppressant) ma-

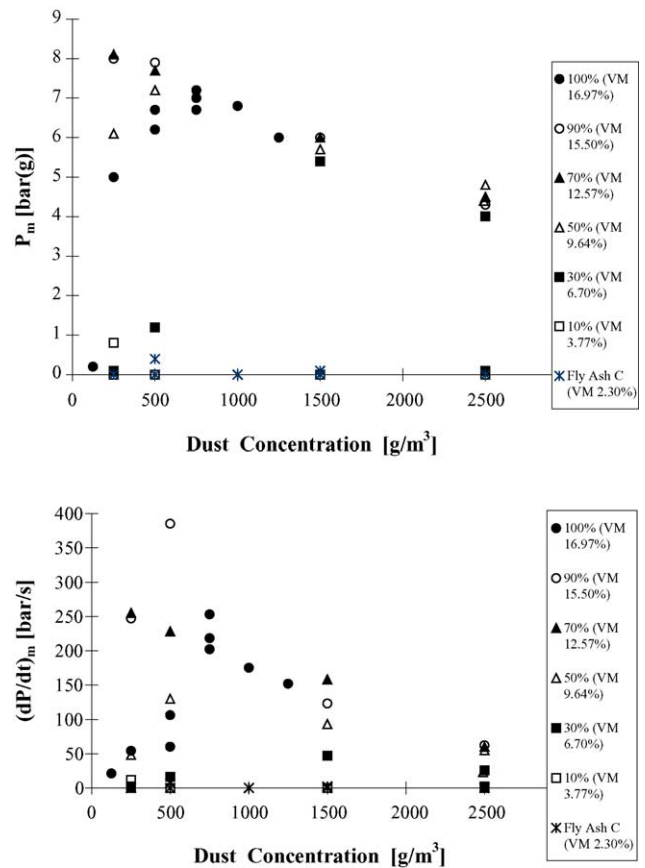


Fig. 4. Influence of dust concentration and fuel contaminant percentage on (a) explosion pressure (upper plot) and (b) rate of pressure rise (lower plot) of Fly Ash C blended with petroleum coke.

terial (sodium bicarbonate and monoammonium phosphate) were added to aluminum fuel dust. The resulting explosion overpressures were enhanced to levels greater than that for the pure aluminum dust. Dastidar et al. [6] attributed this to decomposition of the inertant by heat from the combustion of the aluminum. In the case of sodium bicarbonate, carbon dioxide would be produced and for monoammonium phosphate, ammonia and hydrogen (both flammable gases) would be evolved.

In the current work, the reason for the occurrence of SEEP may be based in either the physics or the chemistry of the situation (or both). It is possible that the addition of the fly ash has a physical effect by enhancing dust dispersion in a manner similar to fluidization enhancement additives. This may further lead to chemical effects such as an enhanced rate of devolatilization from the fuel dust. It is also possible that more effective dispersion could promote a higher heating rate of the dust particles, leading to a greater overall volatiles yield than would normally be expected. The fact that the lower-volatile petroleum coke is affected to a greater extent by SEEP than the higher-volatile Columbian coal would tend to support this line of reasoning. An additional chemical effect which may be speculated is that the fly ash acts as a catalyst to promote at least partial burning of the fixed carbon present in both the

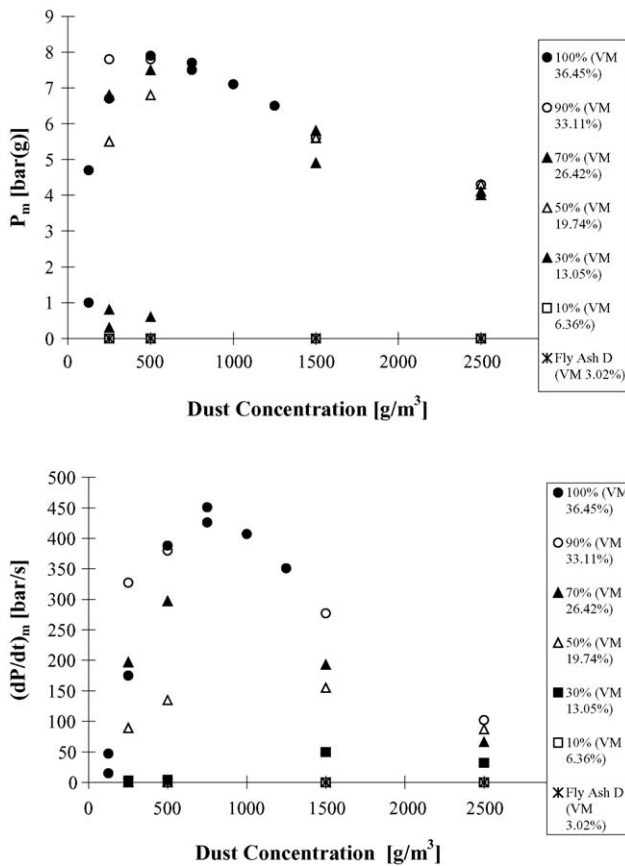


Fig. 5. Influence of dust concentration and fuel contaminant percentage on (a) explosion pressure (upper plot) and (b) rate of pressure rise (lower plot) of Fly Ash D blended with Columbian coal.

fuel dust and the fly ash itself. It seems reasonable to conclude that if combustion of fixed carbon were to occur, it would have to be because of an accelerated rate of heterogeneous combustion (given that the available time for combustion would not likely change). As discussed in the previous section, the low-volatile containing fly ashes are themselves chemically inert.

Further insight into the key role of mixture volatile content can be gained by replotting the data in Figs. 3–6 with the same ordinate values, but with the abscissa values being expressed as volatile matter concentration rather than dust concentration (where the volatile matter concentration is the mass of volatile matter – fuel dust and fly ash at a particular dust mixture concentration – per unit volume). A representative plot of this type is given by Fig. 7 (which corresponds to the data in Figs. 5 and 6). One of the limitations in presenting the data in this manner is that the explicit role of dust concentration is lost; for example, Fig. 7 seems to show that it is possible for the same volatile content to result in either a non-explosion (i.e.  $P_m$  less than 1 bar (g)) or an explosion with a relatively high overpressure. It must be noted, however, that these non-explosions are for pure fly ash, and fuel/fly ash mixtures with a high percentage of fly ash, at correspondingly high overall dust concentrations. In spite of the higher volatile concentra-

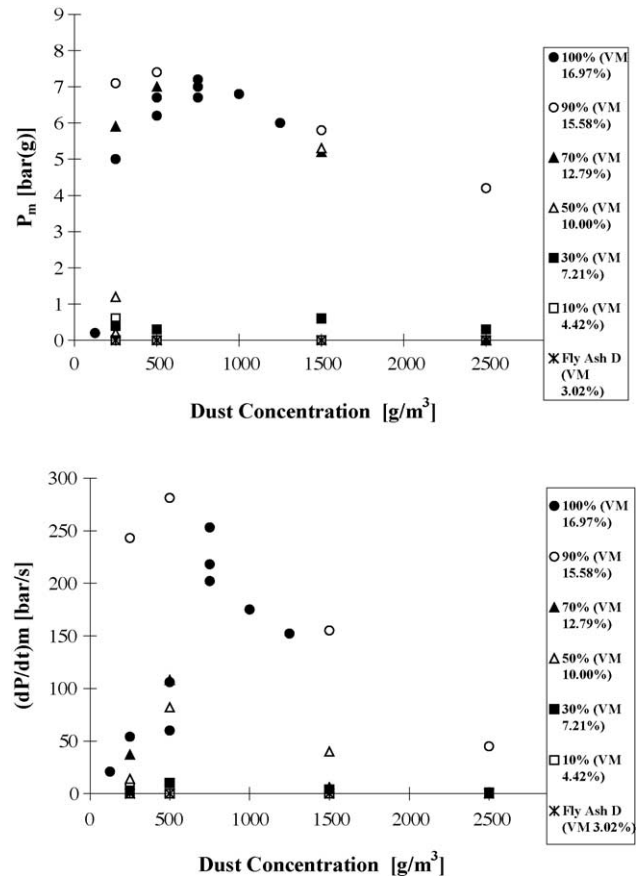


Fig. 6. Influence of dust concentration and fuel contaminant percentage on (a) explosion pressure (upper plot) and (b) rate of pressure rise (lower plot) of Fly Ash D blended with petroleum coke.

tions under these conditions, there is also a very high inert matter concentration.

The usefulness of Fig. 7, and a similar plot that would correspond to Figs. 3 and 4, is illustrated by the following observations:

- Even with the admixture of Fly Ash C and Fly Ash D, and the attendant occurrence of SEEP, the relative ranking of Columbian coal having higher maximum overpressures and rates of pressure rise than petroleum coke, is maintained.
- There is a general decrease in both  $P_m$  and  $(dP/dt)_m$  as volatile matter concentration increases beyond about 200 g/m<sup>3</sup> for Columbian coal/fly ash mixtures, and about 100 g/m<sup>3</sup> for petroleum coke/fly ash mixtures. In other words, peak overpressures and rates of pressure rise occur below these respective boundaries.
- There is a general trend of Fly Ash C leading to slightly higher values of  $P_m$  and  $(dP/dt)_m$  than Fly Ash D when mixed with Columbian coal and with petroleum coke. Table 1 indicates that the parent fuels for these two fly ashes were the same except for the presence of 20% petroleum coke in the fuel burned to produce Fly Ash C. (This accounts for the fact, as shown in Table 4, that Fly Ash C

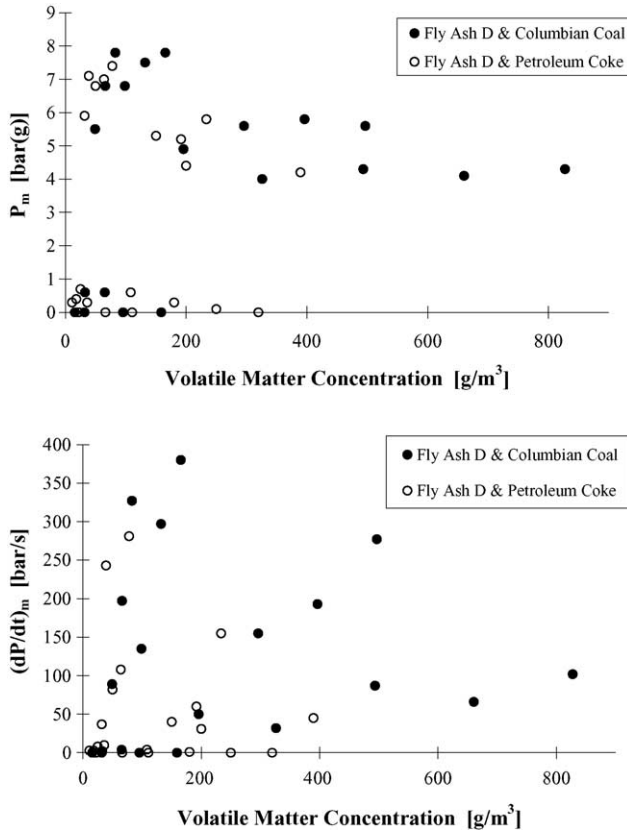


Fig. 7. Effect of volatile matter concentration on (a) explosion pressure (upper plot) and (b) rate of pressure rise (lower plot) of Fly Ash D blended with Columbian coal and with petroleum coke.

has a somewhat higher fixed carbon percentage than Fly Ash D.) While it is possible that these compositional differences account for the explosion behaviour of the fuel/fly ash mixtures, a more plausible explanation lies in the larger particle size of Fly Ash C, which has a mass mean diameter of 155  $\mu m$  (Table 6) compared with a value of 116  $\mu m$  for Fly Ash D. It is well-established that coarse materials are less effective at inhibiting dust explosions than finer sized inertants.

To conclude the discussion on fuel carry-over, attention is shifted from high carry-over amounts to lower quantities. The data in Figs. 3–6 (upper plots) were reinterpreted in terms of the lowest fuel percentage (i.e. lowest volatile content in the dust mixture) that would support combustion. The results are shown in Fig. 8, and are discussed in light of the data plotted in Fig. 9 from Dastidar and Amyotte [5]. Dastidar and Amyotte [5] determined the explosibility of mixtures of Pittsburgh pulverized coal (volatile content of 36.0% and mass mean diameter of 60  $\mu m$ ) with Ontario Power Generation (OPG) fly ash (fine, as-received, and coarse samples having mass mean diameters of 14, 39 and 101  $\mu m$ , respectively). They tested only at low fuel dust percentages and in increments of 5% fuel dust. In the current work, tests were conducted over the entire range of fuel dust percentages and in increments of either 10 or 20% fuel dust. The work of Dastidar and Amyotte [5]

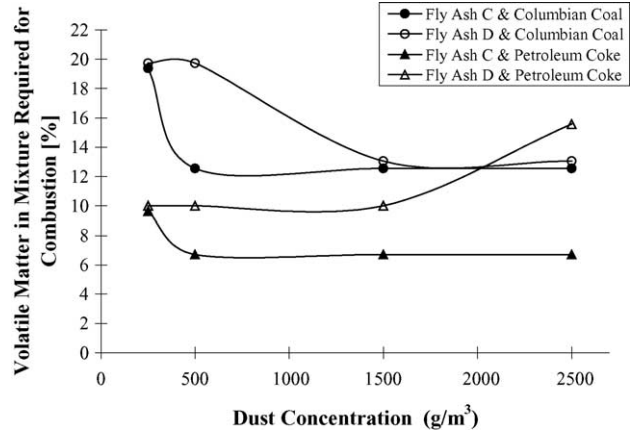


Fig. 8. Percent volatile matter required to create an explosible fly ash mixture (current work).

therefore yielded relatively precise explosibility boundaries (Fig. 9), whereas the boundaries in Fig. 8 are more appropriately viewed as approximate.

In spite of these differences in experimental focus and approach, there are consistent data trends shown in Figs. 8 and 9. The influence of fly ash particle size clearly shown in Fig. 9 is also evident for a given fuel dust in Fig. 8 (recalling that Fly Ash C has a larger mass mean diameter than Fly Ash D). It was previously mentioned that for the fly ash/coal dust mixtures studied by Dastidar and Amyotte [5], a volatile matter content of 7–12% was required before the mixture would explode. These are the data shown in Fig. 9, and are consistent with the minimum range of 7–13% volatile matter for the four fly ash/fuel combinations shown in Fig. 8.

In terms of actual fuel carry-over amounts, these minimum values of volatile content correspond to 30% fuel in the mixture for all cases except the Fly Ash D/petroleum coke blends, which required 50% fuel for an explosible mixture. Again, it must be stressed that these are approximate explosibility boundaries. The focus in this work was on the entire fuel percentage range and thus fuel contents of 0, 10, 30, 50,

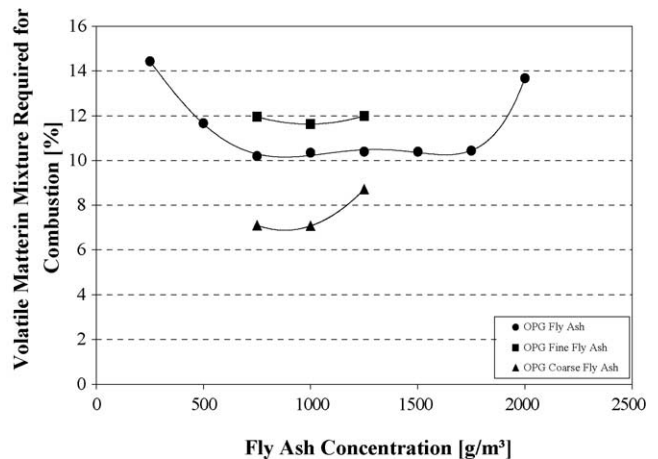


Fig. 9. Percent volatile matter required to create an explosible fly ash mixture (Dastidar and Amyotte [5]).

70, 90 and 100%, but not 20 and 40%, were tested. Even so, it does appear from Fig. 8 that carry-over of low percentages of petroleum coke is potentially more problematic than carry-over of similar amounts of Columbian coal (although coal dust carry-over is most definitely a hazard in its own right). This is essentially a low-percentage counterpart to the SEEP effect of higher percentages of petroleum coke (and Columbian coal, although to a lesser extent).

#### 4. Conclusion

All fly ashes tested in the current work were found to be non-explosible, meaning that the fuel burned to produce the ash had no impact on ash explosibility. The determining factor in rendering each of the fly ashes non-explosible was the low volatile matter content of each. However, when mixed with fuel dust, the fly ash explosion hazard increased significantly – in terms of both the basic explosibility of the resulting mixture and the overpressures and rates of pressure rise of the mixture in relation to the pure fuel.

The amount of fuel carry-over required to form an explosible fuel/fly ash mixture was found to be such that the volatile content of the resulting mixtures was in the approximate range of 7–13% (depending on the particular fuel and the particular fly ash). The current work has demonstrated that precautionary measures must be taken to prevent petroleum coke carry-over, if the inherent safety benefits of substitution of petroleum coke as a fuel are to be fully realized.

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