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- Subconsultant to EFI Global
- Provide a review of computational (CFD) blast modeling
- Share relevant coal dust explosion research
- Structural blast damage indicators
- EFI Global provided blast load estimates to SciRisq

Modeling efforts focus

- Expand our understanding of the event
- Provide technical explanations of critical elements of the event
- Generate feedback that may aid the facility in future design and operational decision making
- Help delineate plausible scenarios
North Coal Reclaim Tunnel Configuration

North Reclaim Tunnel Plan

hinge/vibrator No.
CFD Model Overview

Main Tunnel Body (north end)
- northern half view – looking ESE
- southern half view – looking ENE

Escape Tunnel
- Escape Tunnel Doors with failure elements

Closed Shaker/Hoppers (blue)

Open Shaker/Hoppers (purple)

Main Tunnel Body (south end)
- Coal Dust
  - ASTM sample tests showed $K_{st} = 126\text{ bar m/s}$ & $P_{max} = 7.8\text{ bar}$; performed in 20L vessel
  - Assessments have shown this is produced if dust/air volume is burned at a rate of $\approx 3.5\text{ m/s (M}_f=0.01)$; same rate seen in 1D environment with no obstacles; similar to laminar burning velocity of a gas/air mixture
  - Past studies have shown that dust explosions in 1D environments with obstacles increases flame speed on the order of 10 times
- Propane
  - Confinement of propane/air clouds are well known to accelerate burn rate
  - Flame speeds in 1D with obstacles can approach $M_f=1$ or higher for stochiometric mixtures; will be less if cloud is lean or rich
- Methane
  - Confinement of methane/air clouds are also well known to accelerate burn rate
  - Flame speeds in 1D with obstacles can approach $M_f=0.5$ or higher for stochiometric mixtures; will be less if cloud is lean or rich
Review of Mixed Dust and Gas Clouds

- Bulk coal can contain entrained methane
- Methane can be released naturally
- Methane release can be increased during the agitation (i.e., friction, grinding, breaking) of transfer systems
- Methane release in 1D environments such as a transfer tunnel with limited ventilation could develop pockets of detectible methane clouds

**Mixed Dust-Gas-Air Combustion**

- Introduction of gas (i.e., methane, propane) within a combustible dust cloud is know to “boost” flame speeds that result in higher energy release explosions
- **NFPA 68**
  - Presence of ignitable gas within combustible dust-air mixtures reduces both LFL and the amount of energy required to ignite cloud and results in both increased maximum pressures and rate of pressure rise

![Graph](image)

Fig. 5. Burning velocity of coal dust/methane gas mixtures in air with different initial gas equivalence ratios using the MP1 reaction mechanism.
• Qualitative information collected from video that captures dynamics of event at tunnel openings
  • South portal opening, escape tunnel egress, and at uncovered hoppers (13, 14, 15 and 21)
• Relevant background
  • Pressure front will lead the combustion reaction front for dust and gas cloud explosions that occur with a burn rate of $M_f=1$, which represents deflagration events
  • Pressure front induces velocity resulting in fuel-air cloud ahead of moving combustion reaction front which would result in unburned cloud being discharged from the tunnel openings listed above
  • If a fuel-air cloud discharges to an ambient environment there is the potential of combustion external to the tunnel which is dependent on mixture with the introduction of a new oxidizer (air) and potential ignition sources
  • The long tunnel’s aspect ratio (i.e., 1-dimensional) and limited venting will result in generation of quasi-static pressure within the tunnel due to heating the air in the tunnel
Approximate Blast Estimates from Structural Damage Indicators

- Based on nonlinear dynamic single-degree-of-freedom analysis
- Using simplified pressure waveforms

Incident Pressure and Durations – Approximate from field observations

- P > 10 psi
- P < 10 psi, long $t_d$
- P > 10 psi
- P = 18 psi, $t_d$ = 100-400 ms
- P = 5 psi, long $t_d$
Coal Dust Explosion Simulation with Ignition near Shaker 10

- Coal dust cloud uniformly distributed along most of tunnel length
- 3m/s burn velocity

Simulation observations
- Pressure wave (P) ahead of combustion reaction front (rx)
- Unburnt coal (rx) driven out of south portal opening
- Unburnt coal (rx) dispersed from south portal opening has large fireball potential

- The south portal plume effect will be similar in other simulations since the effect is geometry driven

- Other ignition locations along tunnel
- Other explosive sources/mixtures
  - Coal dust, methane, propane
Coal Dust Explosion Simulation with Ignition near Shaker 10

- Dynamics similar to gun blast/flash event
- Pressure front from internal deflagration forces coal-air mixture out the south end of the long tunnel
- Coal-air cloud further mixes with ambient air affecting flammability limits
- Due to under expanded release, flow accelerates and pressure drops just before exiting portal
- A compression front forms with a high-pressure “bubble” further downstream of the portal that can represent an ignition source
- This can happen long before any product from the internal explosion reaches the exit and is most likely the source of the observed fire ball
- Expected south fireball could extend 50-75ft out of the end of the south portal
• Additional simulation observations
• Ramp up of quasi-static pressure within tunnel
• Due to small openings in system compared to total tunnel volume
  - Analogous to putting your thumb over the top of a shaken soda bottle and leaving a small opening with your thumb
• Results in long duration pressure loading
  - High impulse
• Drive unburnt coal (rx) out of the open loading holes at grade
  - Dust geysers
• **Geyser observations**
  • Pressure front from internal deflagration forces coal-air mixture out the open loading holes at grade
  • No external high-pressure “bubbles” forming above openings external to tunnel
    - Therefore, external ignition of coal-air cloud not likely
  • Product of combustion from internal deflagration eventually vents from loading openings but would not be expected to accompanied with a fire ball
  • Discharge plumes could extend 75ft or more vertically
Coal Dust Explosion Simulation with Ignition near Shaker 10

- Simulation observations at escape tunnel
- Ramp up of quasi-static pressure within escape tunnel
- Due to small openings in system compared to total tunnel volume
  - Analogous to putting your thumb over the top of a shaken soda bottle and leaving a small opening with your thumb
- Results in long duration pressure loading
  - Bottle cart in escape tunnel launched due to long duration loading
- Unburnt coal (rx) driven towards north end of tunnel
  - Unburnt coal is diluted as it makes a 100deg turn to move down the escape tunnel
  - Unburnt coal observed on north half of escape tunnel walls
• **Escape tunnel observations**
  • Pressure front from internal deflagration forces coal-air mixture down and out of escape tunnel
  • Coal-air mixture thins out (diluted non-flammable condition) at escape tunnel exit that reduces probability of ignition
  • No external high-pressure “bubble” forms external to escape tunnel opening
    - Therefore, external ignition of coal-air cloud not likely
  • Combustion front becomes unstable
  • Unlikely to experience a fire ball at escape tunnel exit
• Damage indicators show that blast loading near Shaker 4 was more significant than at adjacent shakers and dead zone.
• Blast pressure loads most plausible from an ignition not at Shaker 4 but further south down the tunnel.
• This scenario results in a pressure wave moving north and interacting with the north end wall and creating a reflected blast load that approximately doubles the incident pressure blast load.
A number of simulations were run with various ignition locations:

- **Coal-only**: both full-height and half-height tunnel clouds with normal and “boosted” flame speeds
- **Gas-only**: 40lb cloud at north end near Shaker 4 and 10lb cloud near Shaker 16
- **Mixed Coal-gas**: coal with propane or methane

**Modeling goals**

- Inform investigation team and support communication of physical observations (i.e., link observations with physics based model)
- Support refinement of origin & cause scenarios
- Support decisions regarding future operations

From these simulations, a number of conclusions about the event are drawn with varying degrees of confidence:

- Ignition likely occurred south of Shaker 4, likely within the “dead zone”, or before Shaker 20
- Coal dust contributed substantially to the explosion event in order to produce the large impulse (long blast duration) and large fireball observed at the south portal
- Fuel source configurations (i.e., coal and gas) were plausible to develop the necessary blast loading, either from a coal dust only cloud or a hybrid coal dust-gas cloud
- A small flammable gas cloud or less-than-flammable gas cloud could have “boosted” the blast event
- Simulations could be improved to better match damage indicators by varying coal dust and/or gas concentrations along the length of the tunnel
Thank you.

Questions?