Investigating High Speed Deflagrations through Rock Rubble Resulting from Methane Gas Explosions in Confined Spaces

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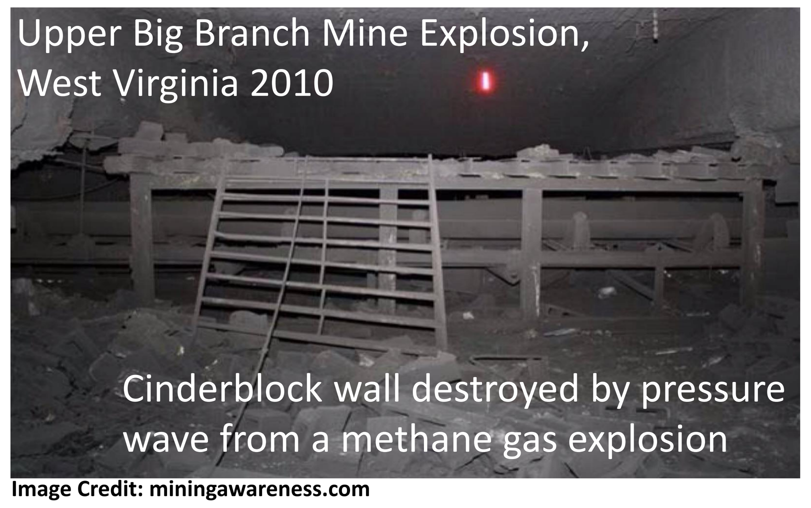
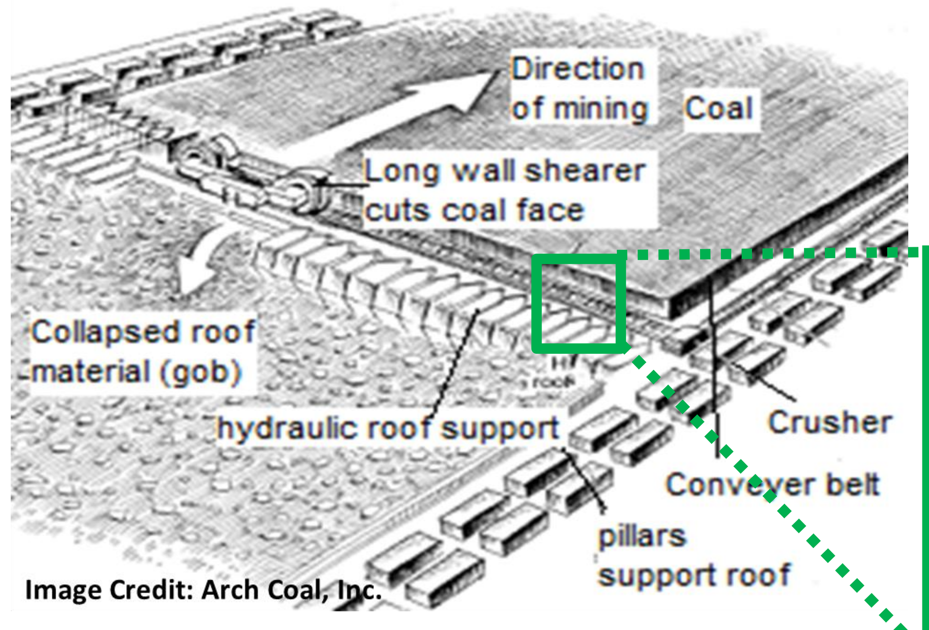
Mitigating Methane Explosion Hazards

The World Relies On Coal…

- Second largest source of global energy[1]
- Provides 41% of the world's electricity[1]
- Each person in the U.S. uses around 3.4 tons of coal per year[1]

…However, Methane Explosions Pose a Significant Risk to Workers





- Longwall coal mine explosions usually occur in or around the gob[2]
- Strata above leaks methane through the gob
- Methane mixes with air to create explosive gas zones (EGZs)[2]
- EGZs may ignite from: machine friction, falling rocks, or spontaneous combustion

Project Objective

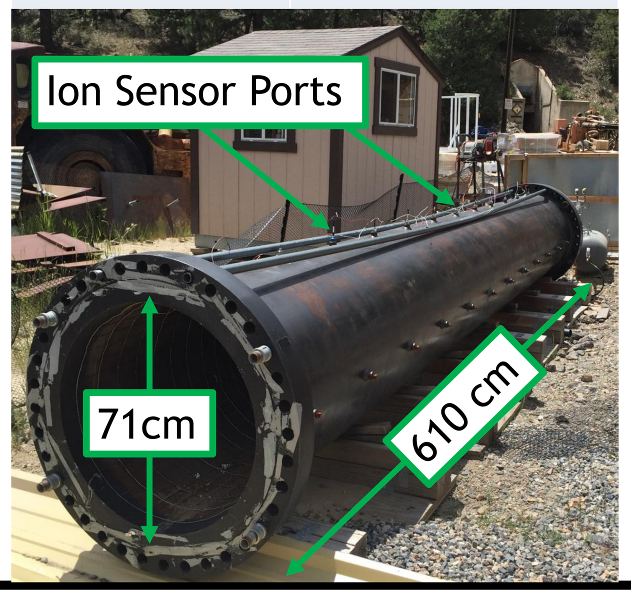
To provide insight into the complex behavior of methane gas explosions in confined spaces with the goal of developing mitigation strategies to reduce physical harm to workers and damage to facilities.

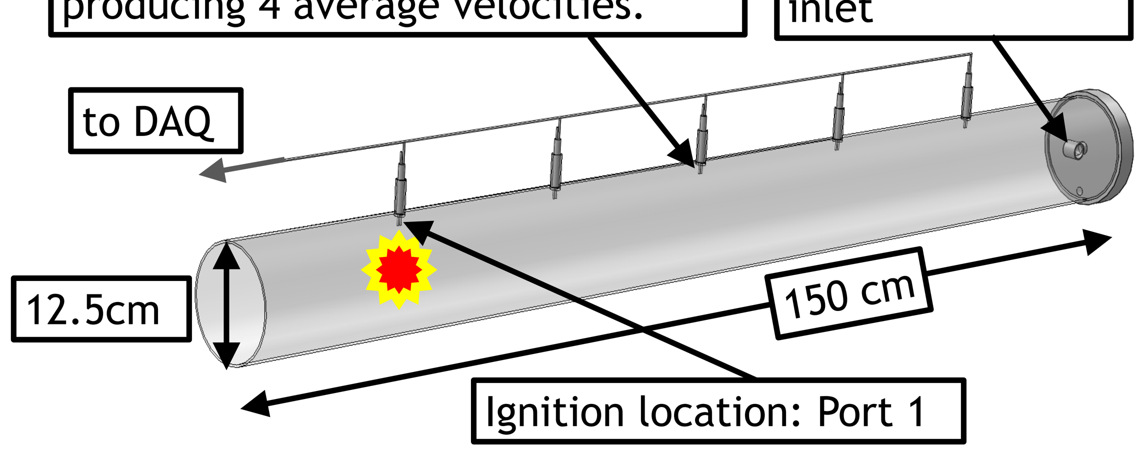
Small & Large Explosion Reactors

Small and large-scale explosion reactors were used for increased safety compared to actual mine-scale testing; the use of two reactors provided insight into the scalability of methane flame properties (propagation velocity, pressure, etc.).

Steel Reactor	
Advantages:	Disadvantages:
Gob and rock material size are more similar to a real mine	Requires large amounts of compressed gases → increases cost

Quartz Reactor	
Advantages:	Disadvantages:
• Less resources required • Less expensive • Full visualization of flame • High speed imaging allows further CFD model validation	Smaller tube → cannot withstand high pressures





Simulated Gob Characteristics

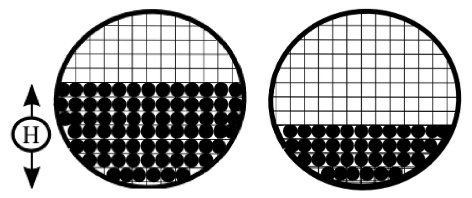
To build a comprehensive physical CFD model, it is important to understand the effects of each parameter on methane flame propagation.

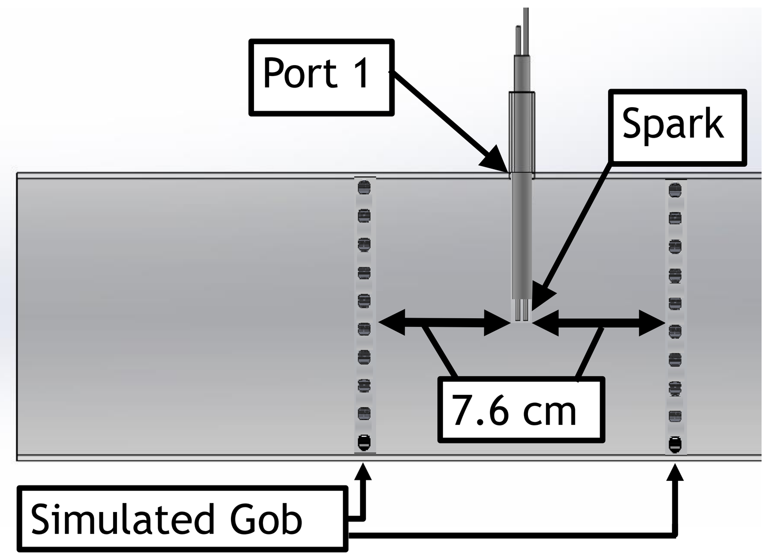
Complexities of Rock Gob:

- Variable rock size/shape/material
- Non-uniform porosity
- Varying void size/location

Gob Parameters Tested:

- Gob distance from spark (7.6 or 15.2 cm)
- Void spacing



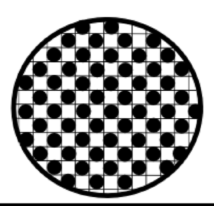


- Material & Shape of Gob (Table 1)

Table 1

Material	Shape	Specific Heat (J/kg-°C)
Granite	Non-uniform[2]	790
Glass	Sphere[1]	753
Stainless Steel	Sphere[1]	490
Brass	Sphere[1]	375

[1]Spheres are 6.35mm in diameter
[2]Approximately 6.35mm in diameter



All material was tested using a checkerboard gob geometry for uniformity.

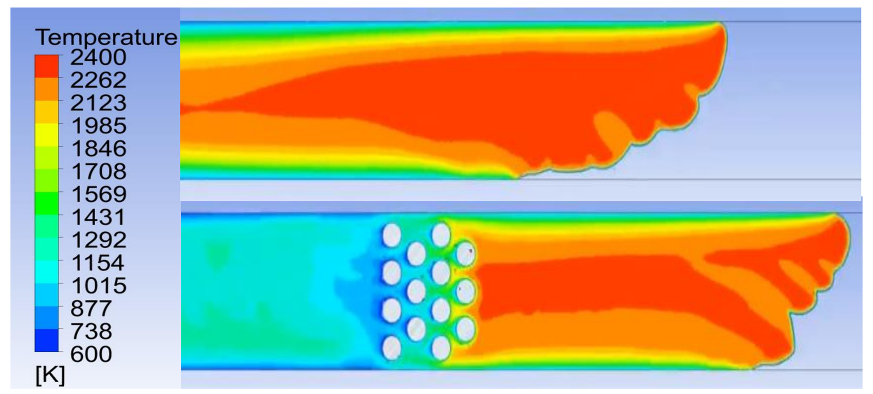
Modeling Deflagration Physics

ANSYS Fluent Settings:

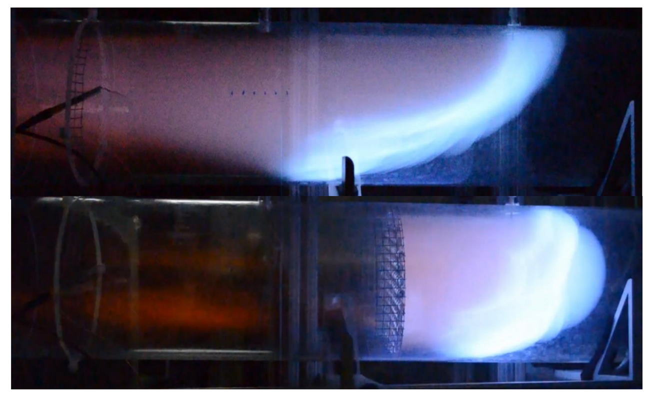
- 2-D, compressible flow
- Viscous-Standard k-ω model
- Time step 0.1 milliseconds
- Fluid body mesh size 1 mm
- Second order implicit time solver
- Methane-air 2 step mechanism
- SIMPLE pressure-velocity coupling

CFD model captures flame shape & acceleration of the flame due to the gob.

Numerical Results[3]



Experimental Results



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[4]Strebinger, C., Fig, M., Blackketter, K., Walz, L., Bogin, G.E., Brune, J., and Grubb, J.(2017) Effect of Simulated Longwall Coal Mine Gob Conditions on the Burning Velocity of Premixed Methane-Air Combustion. *Proceedings of the 16th North American Mine Ventilation Symposium* (pp. 1-7)

The National Science Foundation has generously supported this study through the award DMR-1461275 REU Site: Research Experiences for Undergraduates in Renewable Energy. This research is made possible with support from the National Institute for Occupational Safety and Health (NIOSH) Contract # 211-2014-60050.

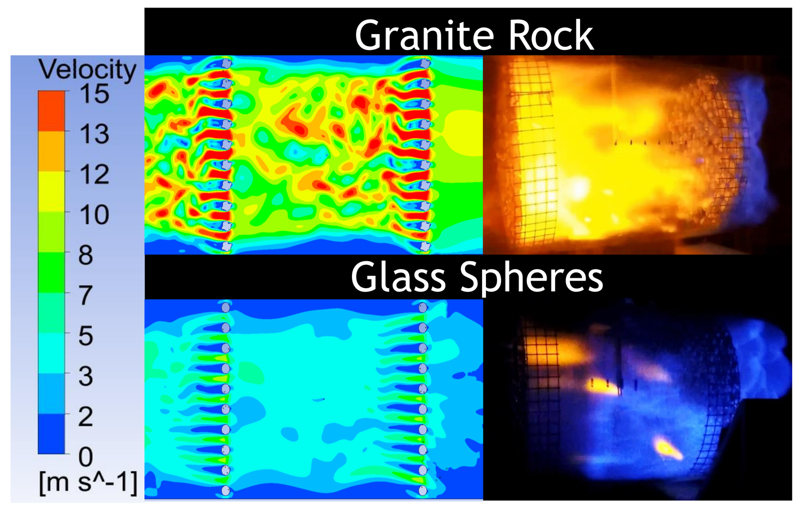
Flame Behavior with Simulated Gob

	No Gob	Gob
Open End Ignition	1.3 m/s	1.4 m/s
Closed End Ignition	70 m/s	240 m/s

Ignition from a confined space **increases methane flame front velocity** due to the expansion of burned gases along with increased temperature, pressure, & fluid motion. Note: Impact of gob is greater at the larger scale.

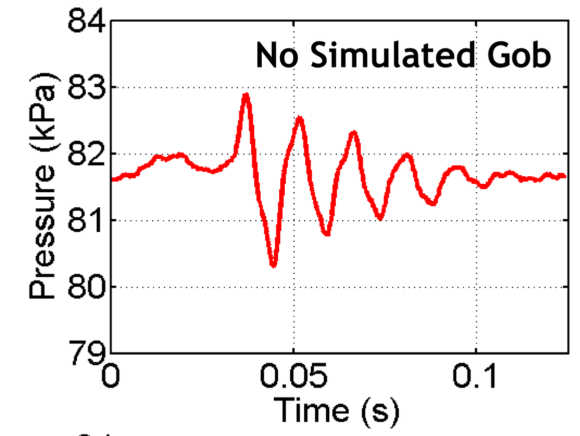
	Granite	Glass	Brass	Stainless Steel
Velocity Across Gob	130 cm/s	115 cm/s	112 cm/s	109 cm/s

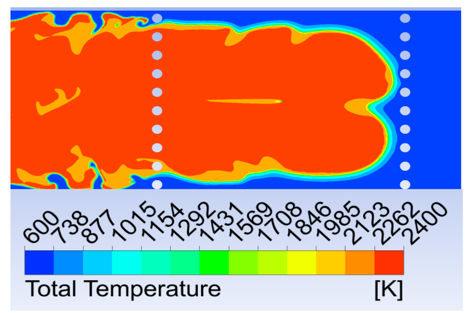
- Increased surface roughness helps accelerate the flame
- Materials with low specific heat absorb heat from the flame, slowing it down.

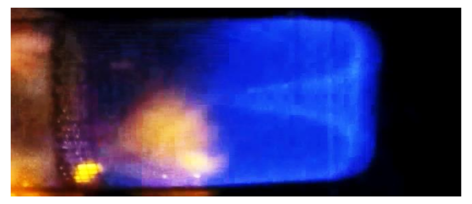


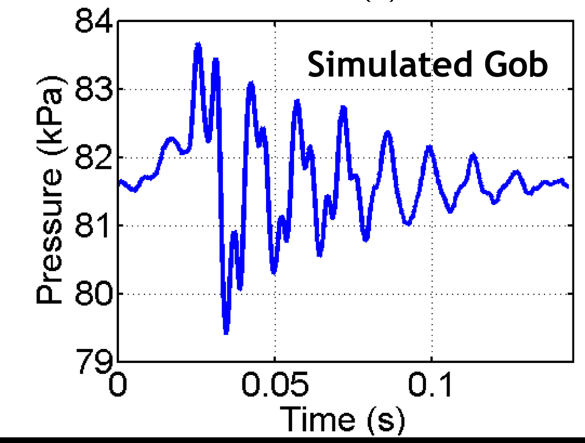
Simulated Gob (Glass Spheres)	Flame Front Velocity at 7.6 cm spacing	Flame Front Velocity at 15.2 cm spacing
Wall, H=8 cm	112 cm/s	149 cm/s
Wall, H=5 cm	112 cm/s	143 cm/s
Checkerboard	116 cm/s	127 cm/s

- Presence of a simulated gob increases pressure rise and overall average pressure.
- Pressure waves create instabilities that invert and stretch the flame front, allowing for more rapid combustion.









Conclusions

The research presented here shows that gob properties and mine layout can enhance methane gas explosions in a confined space, which could endanger workers and equipment. Building a CFD model that captures the fundamental physics of methane flame propagation allows this research to expand beyond experimental limits and model methane gas explosions on the mine-scale. It is the goal of this research to model these explosions in order to build stronger mitigation strategies to help improve the safety of workers.