Deflagration and Venting Test Work for RTOs

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Patented RTO Technology for fugitive methane emission abatement

Solving Unique Technical Problems

If VAM is such a large issue why has it not been solved before?

Unique technical restraints on technology:

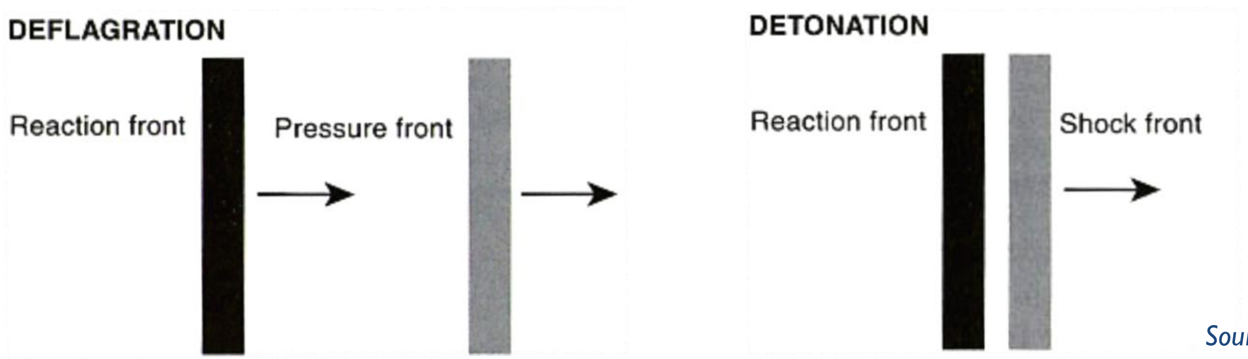
- Safety – must manage the system so there is no flame path between the reactor and the mine
- Mine dust may react with bricks
- Maintaining reactor temperature, VAM does not sustain oxidation easily, which is good for safety but poor for abatement
- Affordable cost of safely deploying “new technology”
- Footprint

Safe Connection to Mine - Concepts

Explosion: rupture of a vessel or equipment

Deflagration: subsonic flame propagation (often called the ‘rapid burn’)

Detonation: supersonic flame propagation (often called the ‘shock wave’)



Source: Crowl & Louvar, 2001, p. 254

Combustion (above the LEL) at a BBQ does not normally lead to an explosion, deflagration or detonation.

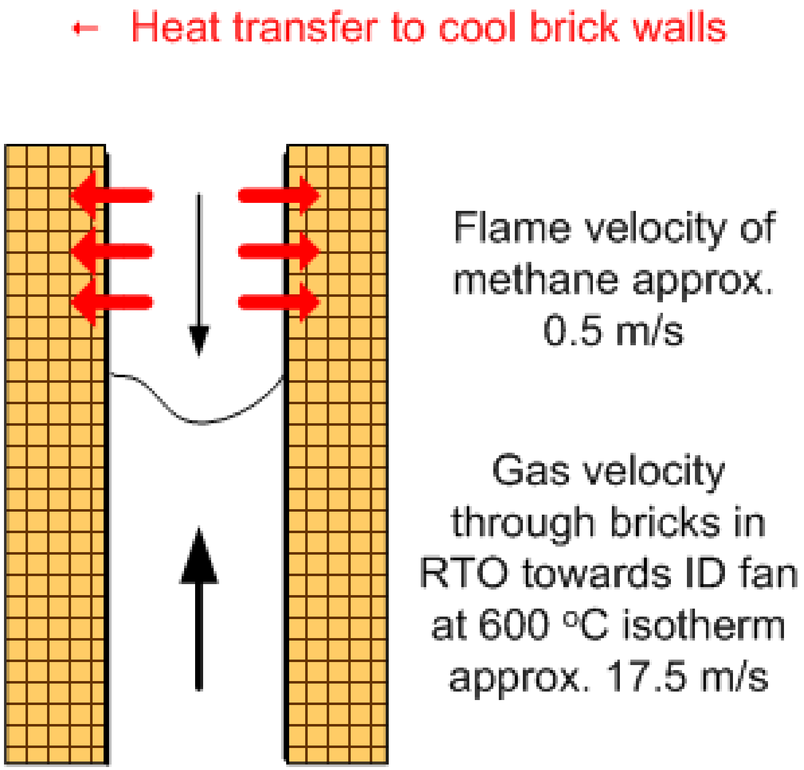
Safe Connection to Mine - Concepts

A gas BBQ uses combustion above the LEL and we happily stand next to it to cook our steak.

VAM RAB and gas BBQs are safe if the heat and pressure can be controlled. That is; they are safe if the heat and pressure do not build up.

Near Isothermal Combustion

- Spalding (1957) introduced isothermal combustion when there is enough mass and surface area.
- Flame stretching is when the flame burns in the opposite direction to the incoming air flue mixture.
- When heat loss is greater than the heat release by the flame, this effectively extinguishes the flame and quenches the reaction.
- As such, the Corky's designed RTO (or VAM RAB) has an in built flame arrestor due to the RTO height, high surface area and heat transfer properties of the bricks.



Experiments to help define Heat and Pressure Control

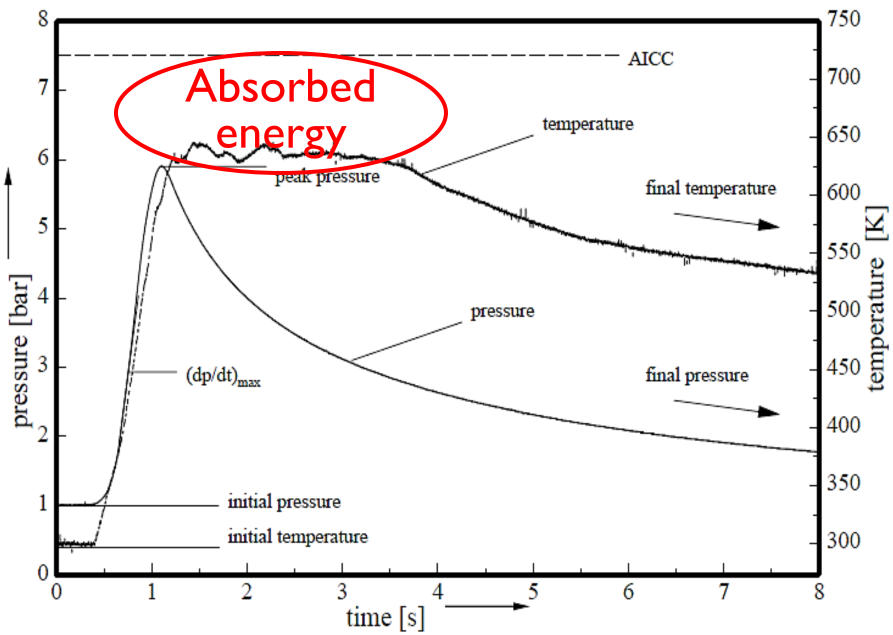
Above ground we can control heat and pressure by bypassing methane spikes to atmosphere and venting excess heat and pressure. This can not be easily done underground.

Experiments were designed to elicit key input design variables to heat control, and venting excess heat and pressure.

1. Hot deflagrations in an RTO using LPG

2. Cold venting study to help interpret hot deflagration results

Safe Connection to Mine - Concepts



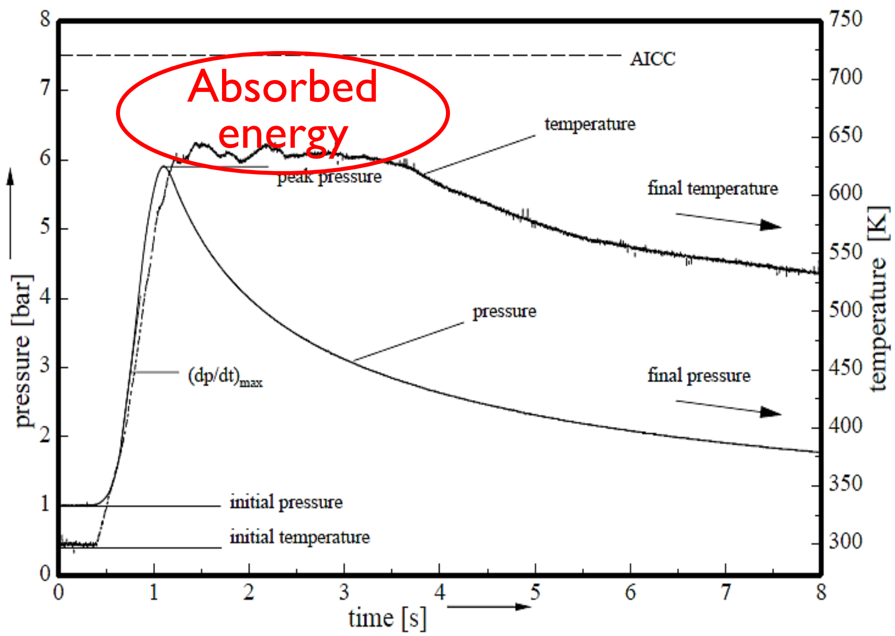
Main thermodynamic parameters for a closed vessel, unvented deflagration for $\phi = 0.7$, methane-air mixture at STP (Kunz, 1998)

Some of the energy released during the deflagration is absorbed by the reaction vessel resulting in lower temperature and slower, less intense pressure rise.

25% heat absorbed

Surface area to volume ratio for convol vessel = 7.25 m^2/m^3

Safe Connection to Mine - Concepts



Main thermodynamic parameters for a closed vessel, unvented deflagration for $\phi = 0.7$, methane-air mixture at STP (Kunz, 1998)

With increased thermal mass and surface area more energy can be adsorbed.

85% heat absorbed (when vented)

Surface area to volume ratio for RTO:

For the pilot plant 192 m^2/m^3 of flammable gas (26 times more)

Deflagration Test Work

With thermal media about 6 times the mass and twice the height of other RTO's, when RTO top temperature was above 850^{o}C and vented, then -

85 to 95% of the deflagration energy was absorbed by the thermal media for a period of at least one minute when using fireclay chequer bricks.



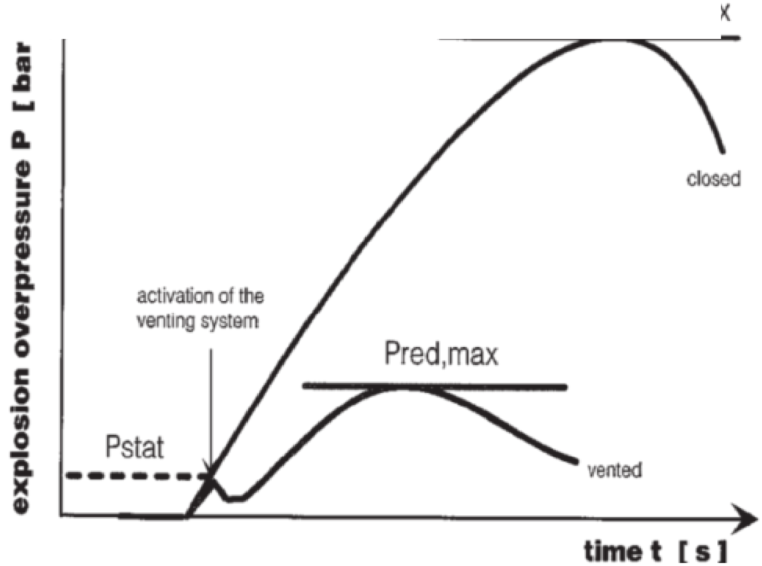
Venting Requirements

NFPA 68 – Guide for Venting of Deflagrations

- Vent area *(NFPA, 2002)* $A_v = (8.535x10^{-5})[1 + 1.75P_{stat}](K_G V_h{}^{0.75})\sqrt{\frac{1-\Pi}{\Pi}}$

$$\text{where, } \Pi = \frac{P_{red}}{P_{max}}$$

- NFPA 68 (2002) is a standard for vent design
- These assumptions may not be true in an RTO
  - full volume filled with fuel and gas,
  - full confinement and
  - no heat absorption

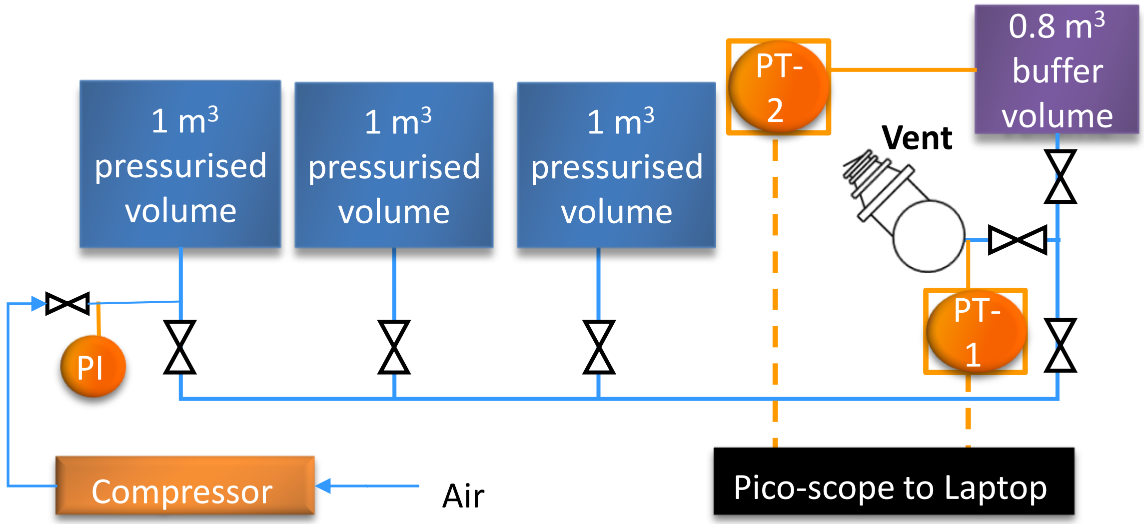


Source: Perry & Green, 1998

Venting Test Work

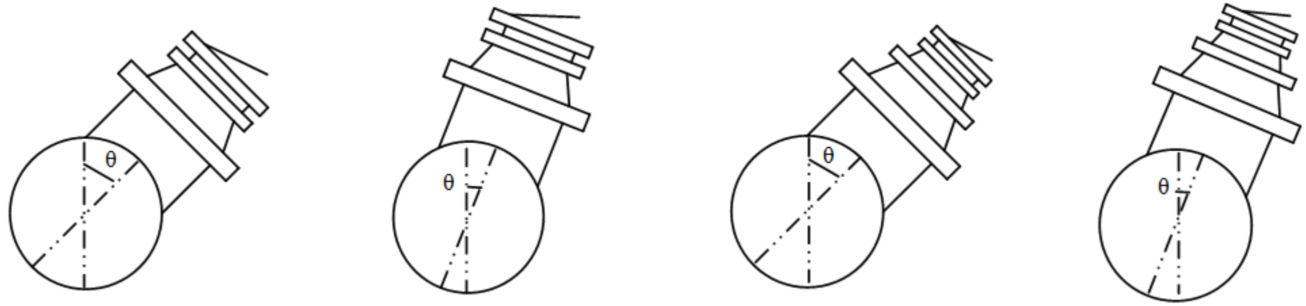
How is the remaining 5 to 15% energy not absorbed best vented?

Is “NFPA 68 – Guide for Venting Deflagrations” relevant for near isothermal combustion?



Venting Arrangements

- Vent area - A_v
  - 0.019 m^2 – c & d
  - 0.032 m^2 – a & b
- Vent opening pressure - P_{stat}
  - 0.35 kPa G – a & c (962 g)
  - 0.45 kPa G – b & d (1603 g)



a) 200NB, θ = 45°   b) 200NB, θ = 22.5°   c) 150NB, θ = 45°   d) 150NB, θ = 22.5°

Near Isothermal Venting Requirements

- Vent cross sectional area did not play a significant role provided the gas velocity through the vent was low. < 20 m/s

- The test work showed that the most important variable was the pressure at which the vent first opened.

- The missing energy from the hot test work (5 to 15%) could be shown to be consistent with the mass flow rate measured in the cold vent trials. That is the hypothesis that the energy was vented is credible.

- For scale up to the demonstration scale unit, using the cold vent tests an alternate vent geometry was found with even more favourable venting performance than was used on the hot pilot test work.

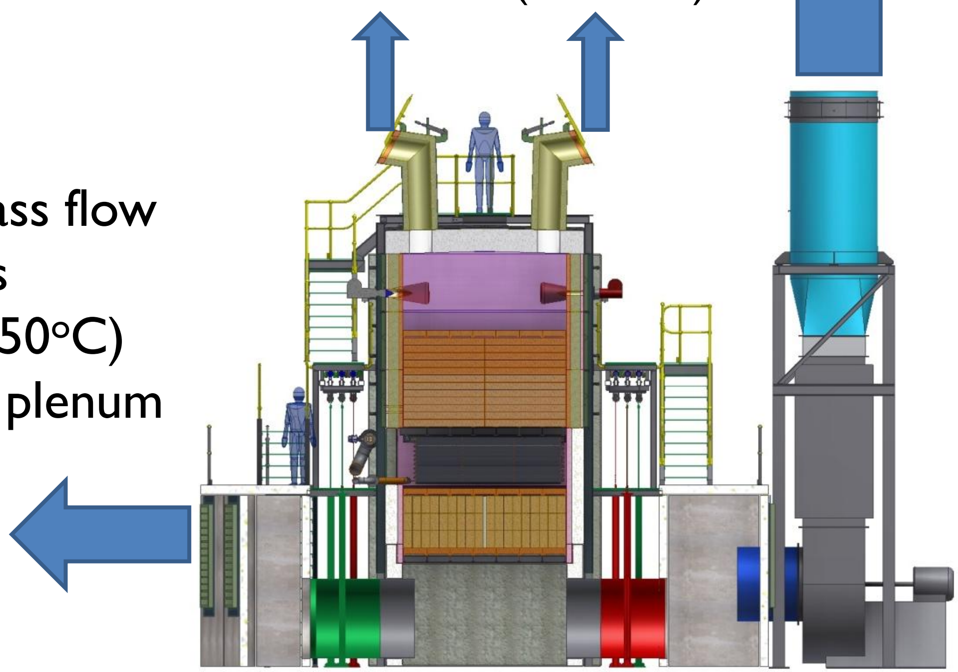
Energy Partition Applied to Demonstration Scale Plant

11% of total mass flow
1.11 kg/s
5.25 Am^3/s (1130°C)

76% of total mass flow
7.70 kg/s

101% of normal volume flow
12.09 Am^3/s (195°C)

13% of total mass flow
1.32 kg/s
2.53Am^3/s (250°C)
Mostly through plenum vents



Experiments to help define Heat and Pressure Control

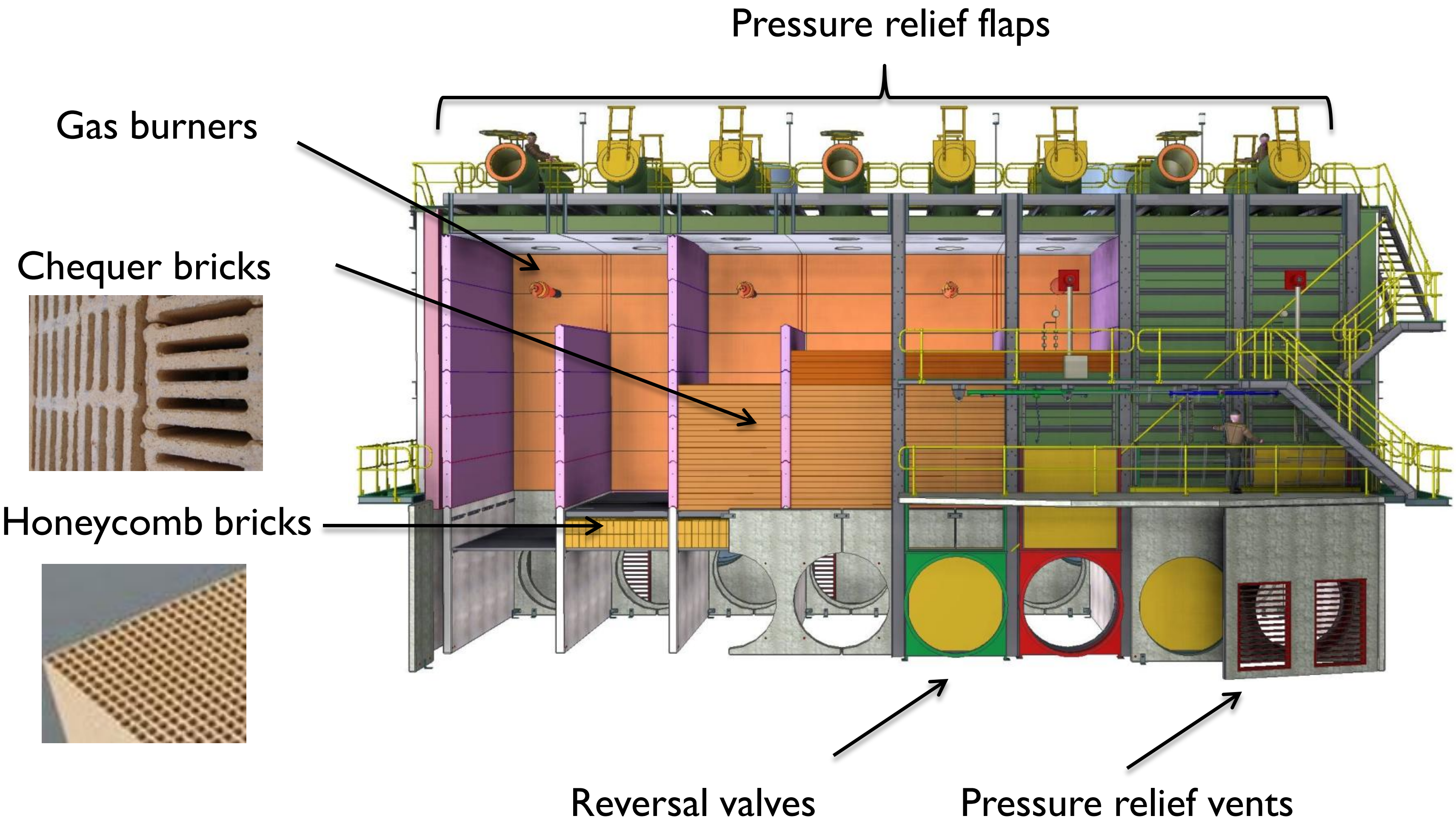
Does this mean that all RTO are safe? No.

When operating our RTO pilot at 3 quarter height, at 750^{o}C top temperature and with the vent blocked then a flash back was observed on some tests using LPG instead of Methane.

The concerns of the mining industry are real and the potential for flash back is there. This is especially true for the gassier mines.

Appropriate high thermal mass, high thermal media height, avoiding low operating temperature and **adequate** venting will eliminate flash back. An accepted definition of appropriate and adequate is needed.

Adequate Thermal Mass, Height and Vent Area Results in Large RTO Design

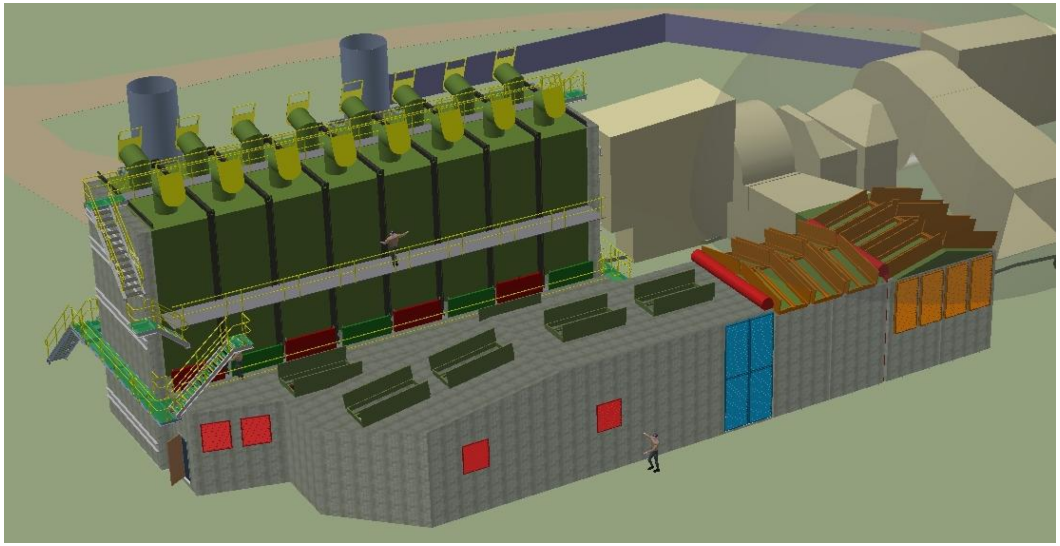


Safety Systems

Mitigation of a deflagration's impact within the RTO is possible and should be defined and mandated.

Such an RTO design should also have a safety duct to

1. Prevent the methane spike reaching the RTO,
2. Prevention of a flame path between the RTO and the mine



A design of a RTO with deflagration mitigation and safety duct has been prepared for the CMATSP grants in Australia

Technical paper describing experiments on website

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References

- Crowl, D. C. and Louvar, J. F. (2001). Chemical Process Safety: Fundamentals with Applications (2nd ed.). New Jersey: Prentice Hall.
- Kunz, O. (1998). Combustion characteristics of hydrogen- and hydrocarbon-air mixtures in closed vessels. University of Stuttgart, Germany.
- Spalding, D. B. (1957). 'A theory of inflammability limits and flame-quenching'. Mechanical Engineering Department, Imperial College, London S.W.7.