West Virginia University

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Modeling Atmosphere Composition and Determining Explosibility in a Sealed Coal Mine Volume

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Presentation Outline

- Introduction
- Time-dependent Composition change model for sealed atmosphere
- Explosibility Triangle
- Model Demonstrations
- Conclusions

Introduction

- Sealing mined-out areas is a common practice to reduce ventilation requirement
- Critical time period for a sealed area: gas composition goes through the lower and upper explosion limits
- Injection of inert gas (N_2 or CO_2), if needed, could short the critical period

Introduction

- The atmosphere in the sealed areas should be well managed to ensure mine safety
  - Things to know……
    - Atmosphere composition (volumetric concentration of various gases) at any given time
    - Changing pattern of the atmosphere composition
    - Exposibility of the atmosphere
    - …….
  - It is better to know in advance for a better plan!

Introduction

Research objectives

- Development of a mathematical model to simulate the time-dependent atmosphere composition in a sealed mine area.
- Expand Coward method in defining the explosibility triangle to include more but common combustible gases
- Development of a computer program to facilitate the application of both the gas composition simulation model and determination of the explosibility.

Time-dependent Composition change model for sealed atmosphere

- ***Common combustibles in a sealed area***
  - Considering *gas explosion* and *coal oxidation:*

Gas explosion:	$CH_4+2O_2=CO_2+2H_2O$
Coal oxidation:	$aCoal+bO_2=cCO+dCO_2+eH_2O+fC_xH_y$

  - The byproduct gases includes CO_2, CO, and C_xH_y
  - In coal mine, products of slow oxidation, fires or explosions could produce C_2H_2, C_2H_4, and C_2H_6.

Time-dependent Composition change model for sealed atmosphere

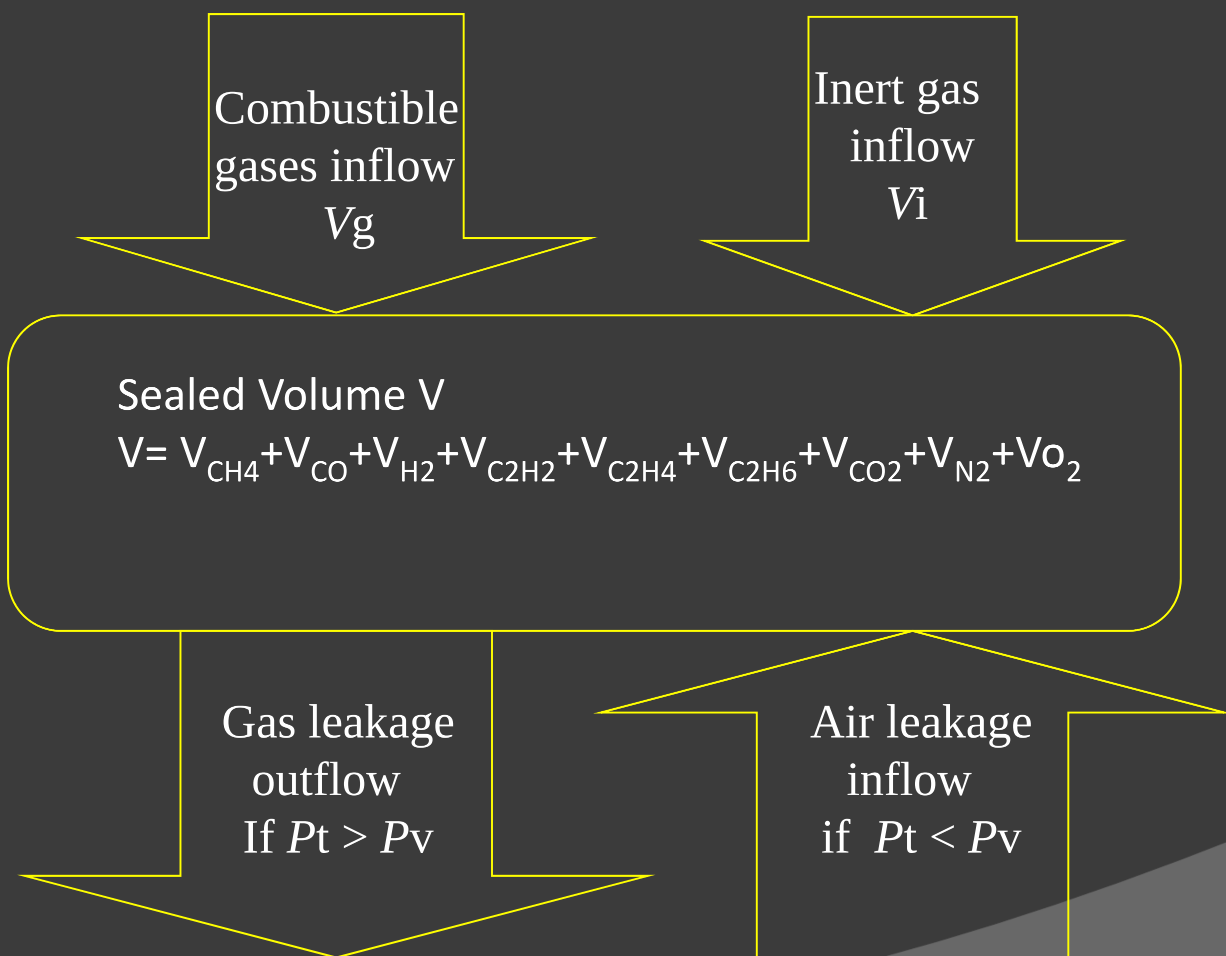
Composition change model

❖ The change of gas composition in a sealed volume is controlled by many independent variables :

- inflow of methane
- inflows of other combustible gases
- air leakage in and out
- inert gases injected
- change in atmospheric pressure (P_v)
- …..

❖ These factors should be considered in the mathematical model

Time-dependent Composition change model for sealed atmosphere



Time-dependent Composition change model for sealed atmosphere

- The law of mass conservation

$$M_t = M_0 + \int_0^t \Delta M dt$$

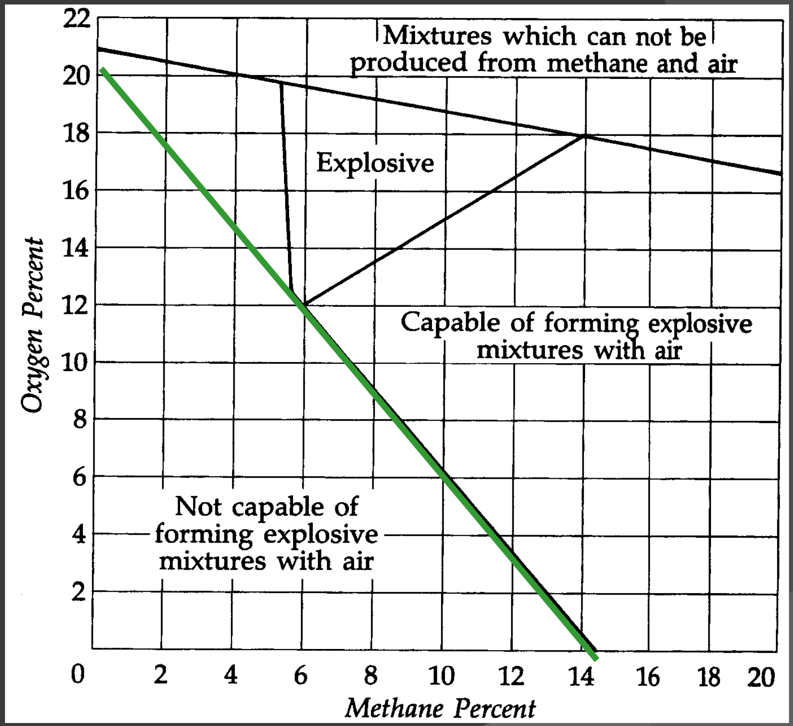
- The ideal gas law

$$PV = mR_g T$$

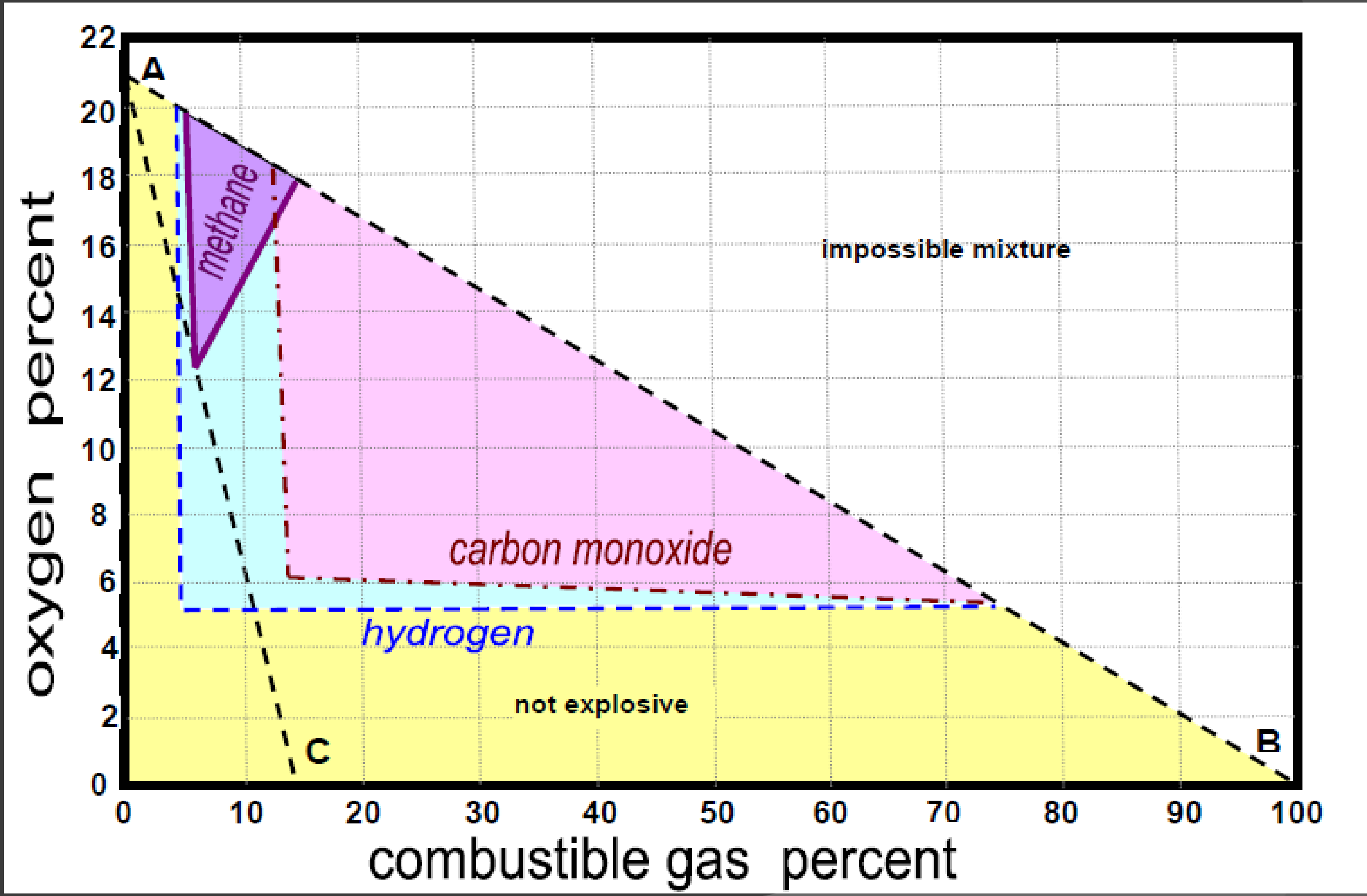
- Depending on the relationship between the barometric pressure(P_v) and the pressure in sealed volume (P_t).
  - $P_t < P_v$ Ingassing .
  - $P_t > P_v$ outgassing

Explosibility Triangle

- ***Coward Explosibility Triangle***
  - A method to determine the explosibility of the mixture of air and combustible gases developed by Coward in 1952.
  - Only considers three common combustible gases (CH_4, CO and H_2).
  - Explosibility triangle defined by three characteristic points
    - Lower flammable limit
    - Upper flammable limit
    - Nose limit.
  - Explosibility depends on the percents of the combustible gas, oxygen and inert gases.
  - Shows five distinctive zones



Explosibility Triangle



Explosibility Triangle

- ***Generating the resultant Coward triangle***
  - Considering an air mixture with three combustible gases of CH_4, CO and H_2.
  - The characteristic points are based on each individual flammable limits:

Table 1 Vertices of explosive triangles (percentages).

Gas	Flammable Limits		Nose Limits		Nitrogen to be added to make mixture extinctive: (N+ m^3 of nitrogen per m^3 of combustible gas)
	Lower	Upper	Gas	Oxygen	
Methane (CH_4)	5.0	14.0	5.9	12.2	6.07
Carbon monoxide (CO)	12.5	74.2	13.8	6.1	4.13
Hydrogen (H_2)	4.0	74.2	4.3	5.1	16.59

Explosibility Triangle

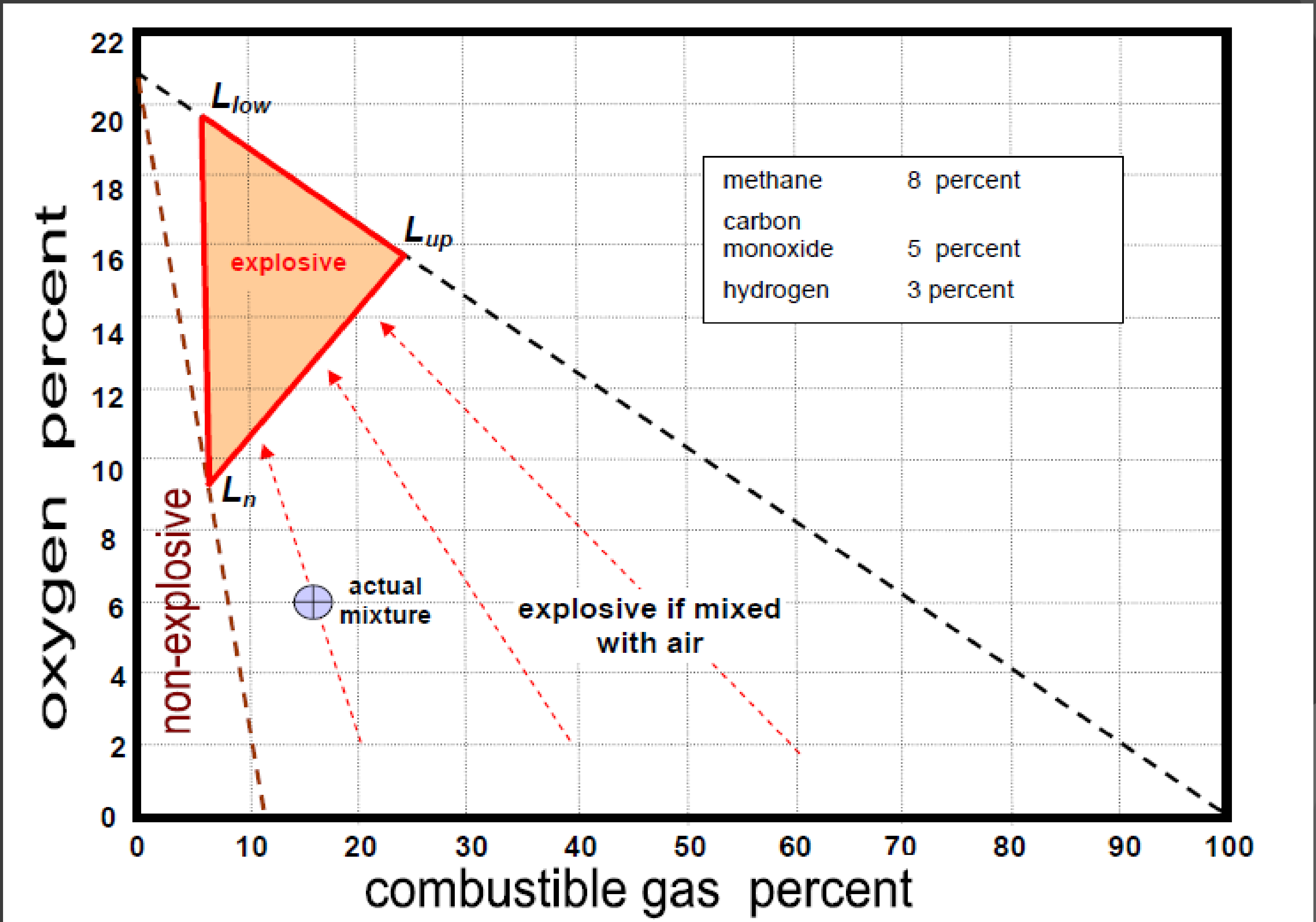
- Example:

A sample taken from a sealed area yields the following analysis.

methane	8 per cent	
carbon monoxide	5 per cent	p_t = 16 per cent
hydrogen	3 per cent	
oxygen	6 per cent	
inerts	78 per cent	

Construct the Coward diagram for this condition.

Explosibility Triangle



Explosibility Triangle

- ***Expanded Coward explosibility triangle***
- Why do we need to expand the triangle?
  - Low temperature oxidation of wood and coal in sealed area would likely occur to produce various hydrocarbon gases
  - Due to the large explosive range for hydrocarbon gases, their presence could significantly change the explosibility of the air-gas mixture.
  - The Coward triangle can be expanded to include more combustible gases as long as the characteristic points of these combustible gases are known.

Explosibility Triangle

- Three more hydrocarbon gases, acetylene (C_2H_2), ethylene (C_2H_4) and ethane (C_2H_6) are incorporated in addition to the original CH_4, CO and H_2 .

Table 2 Vertices of explosive triangles (percentages).

Gas	Flammable Limits		Nose Limits		Nitrogen to be added to make mixture extinctive: (*N*+ m^3 of nitrogen per m^3 of combustible gas)
	Lower	Upper	Gas	Oxygen	
Methane (CH_4)	5.00	14.00	5.90	12.20	6.07
Hydrogen (H_2)	4.00	74.20	4.30	5.10	4.13
Carbon monoxide (CO)	12.50	74.20	13.8	6.10	16.59
Ethylene (C_2H_4)	2.75	28.60	2.89	6.06	15.60
Ethane (C_2H_6)	3.00	12.50	3.12	8.41	12.80
Acetylene (C_2H_2)	2.50	80.00	2.67	5.07	28.91

Explosibility Triangle

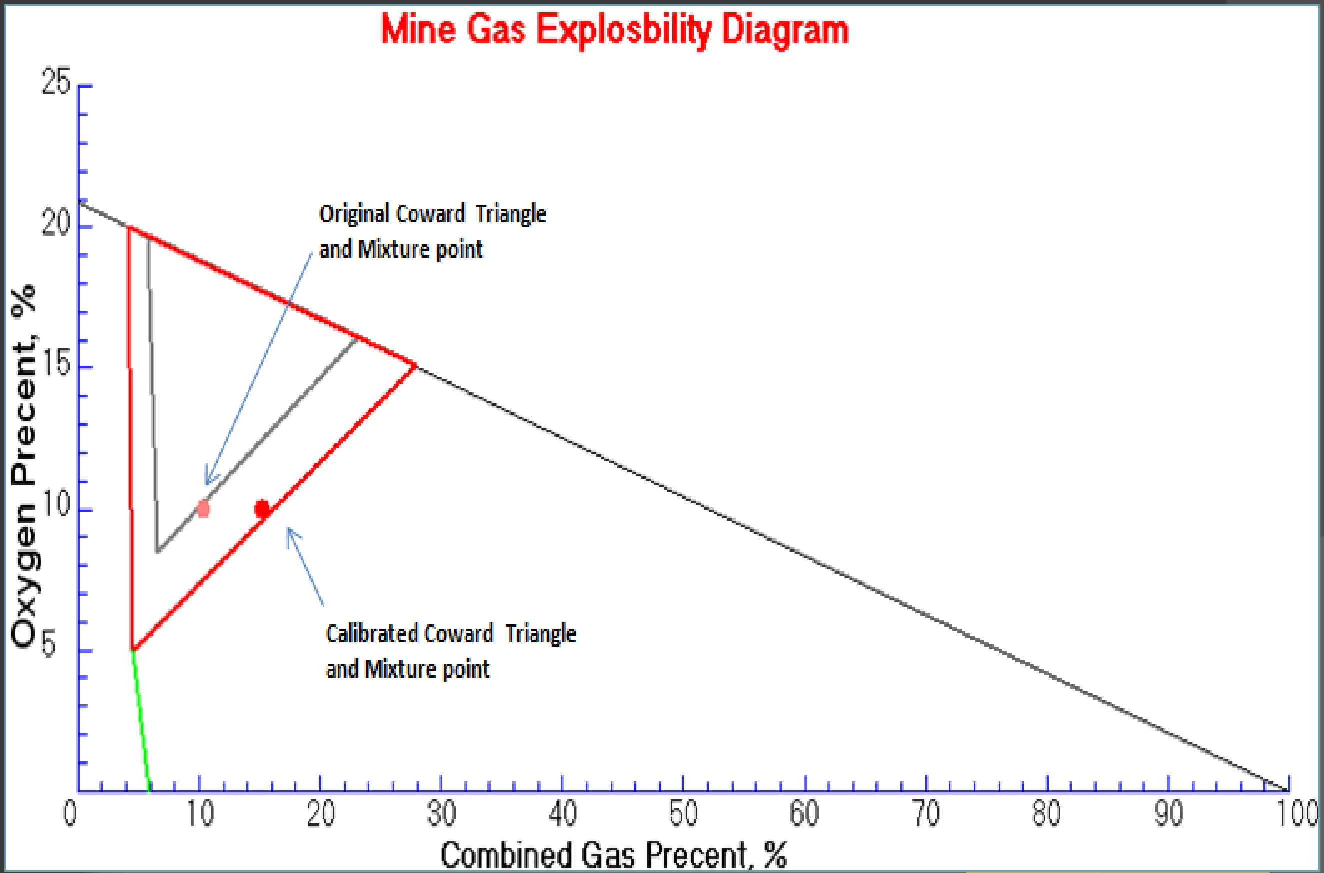
- A sample taken from a sealed area yields the mixture composition as follows:

CH_4: 5.3%
H_2: 2.00%
CO: 3.00%

C_2H_2: 4.00%
C_2H_4: 0.50%
C_2H_6: 0.40%

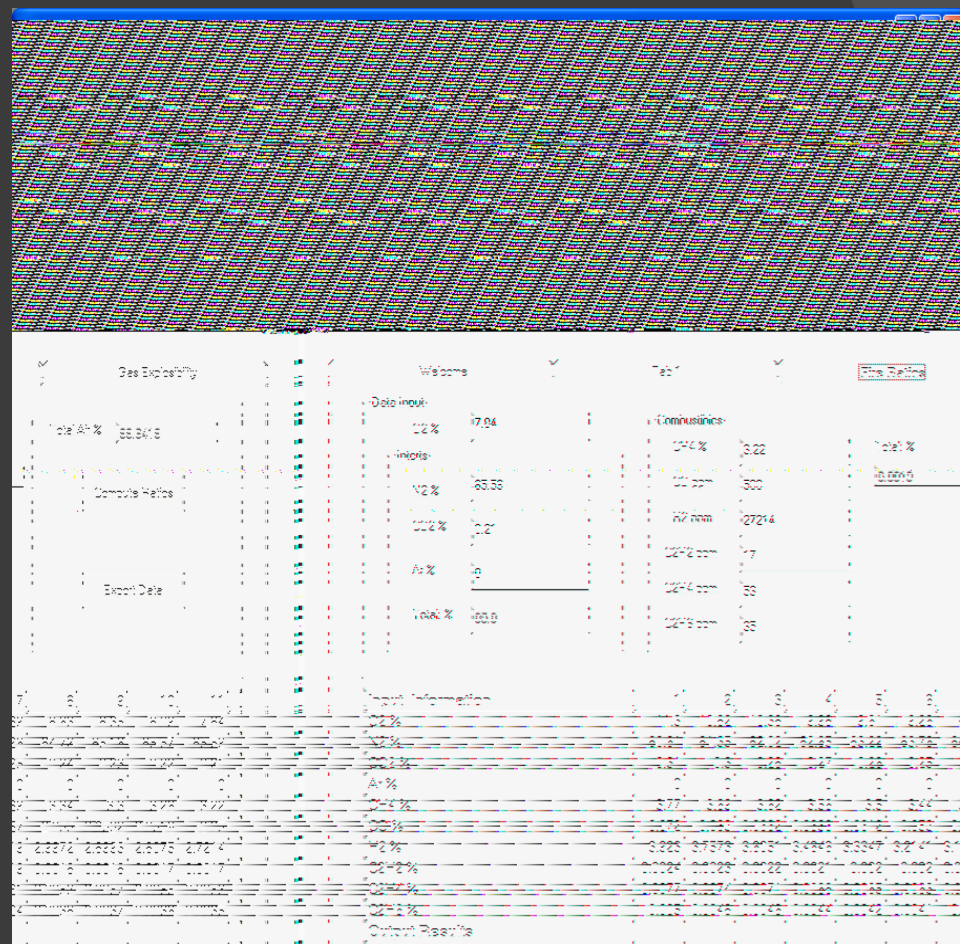
CO_2: 17.00%
N_2: 57.80%

O_2: 10%



Program development

- A computer program is developed in MathCAD® environment to model the atmosphere composition in an sealed mine area.
- A Visual Basic program has been developed to implement the expanded Coward explosibility triangle method.

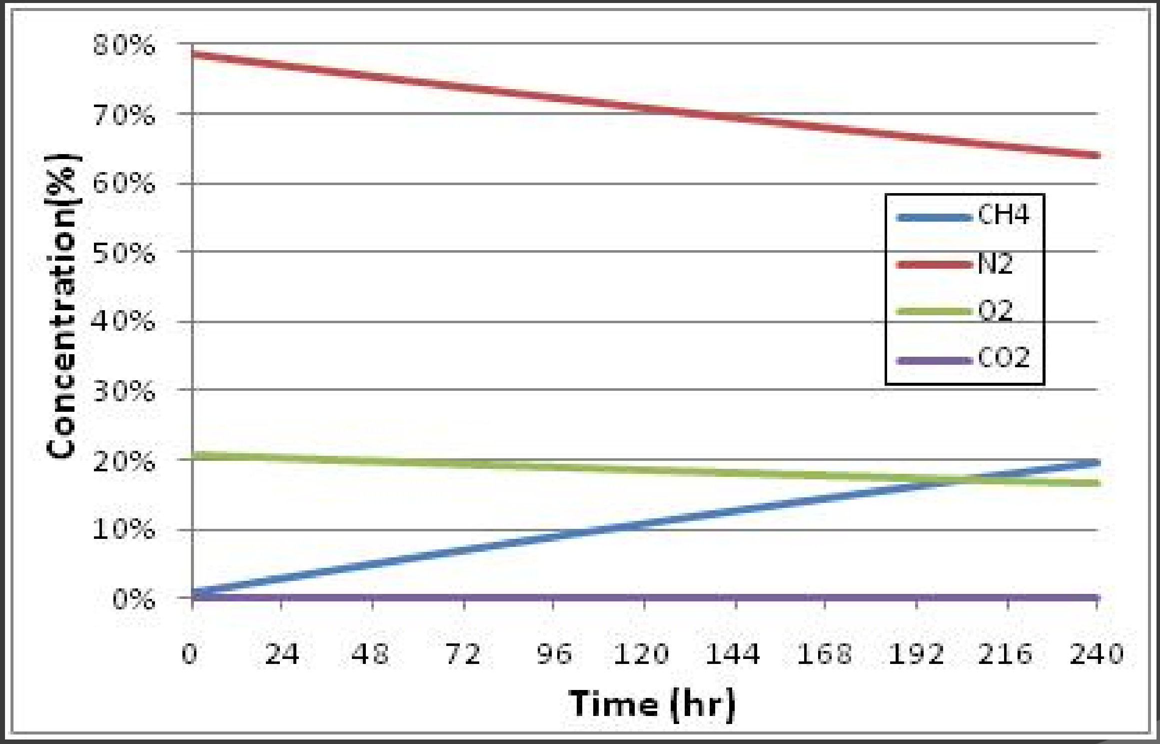


Model Demonstrations

- ***Case 1***
  - To find out the time needed for the sealed area to pass through the critical period
  - Outgassing condition
  - Initial Condition:
    - CH_4: 0.66%; N_2: 78.68%; O_2: 20.6%; CO: 1ppm; CO_2: 0.06%;
    - The sealed volume is 1,000,000 m^3
    - 0.25 m^3/s CH_4 inflow rate
    - No N_2 injected
    - The coefficient leakage 0.003 $m^3/s/Pa^{1/2}$
    - The environment temperature is 20℃.

Model Demonstrations

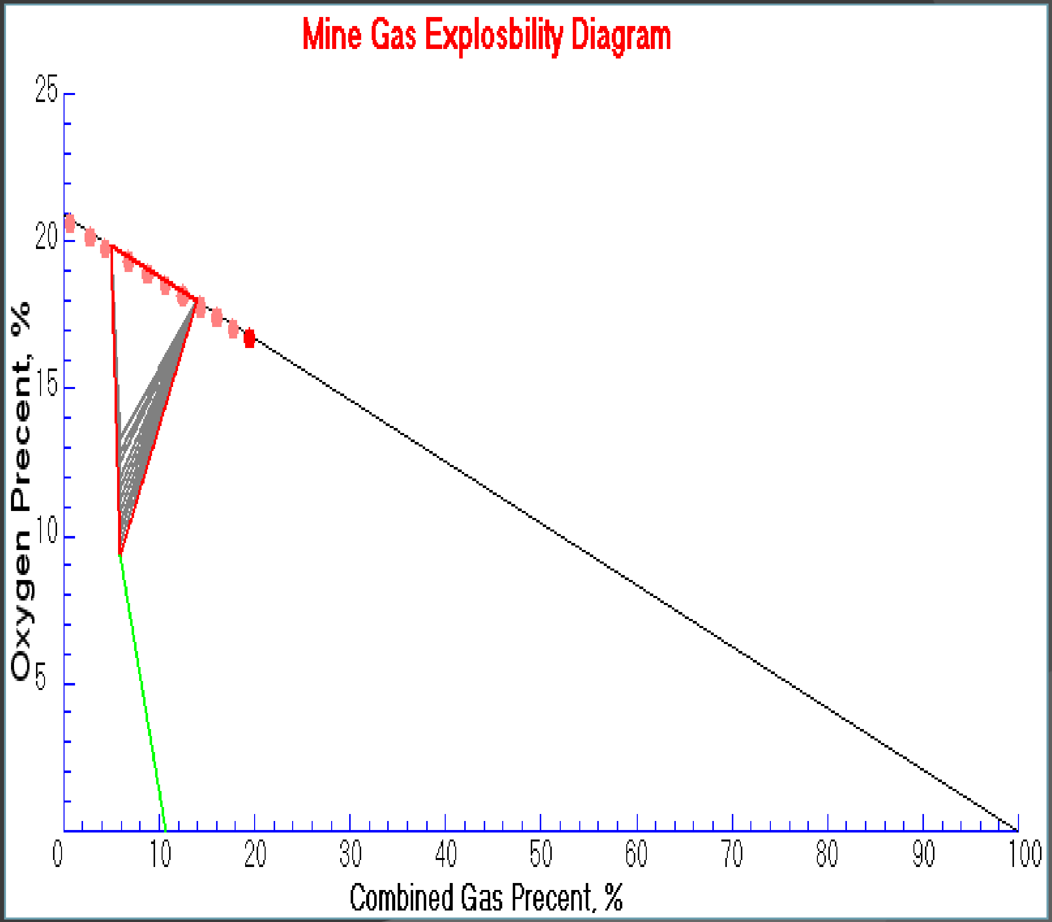
- **Different compositions change over time**



CH_4, N_2, O_2 and CO_2

Model Demonstrations

- **Explosbility Diagram**
  - Non-explosive at beginning.
  - Time step of 1 days.
  - Explosive between the second and the seventh day.
  - Need seven days to become non-explosive itself.

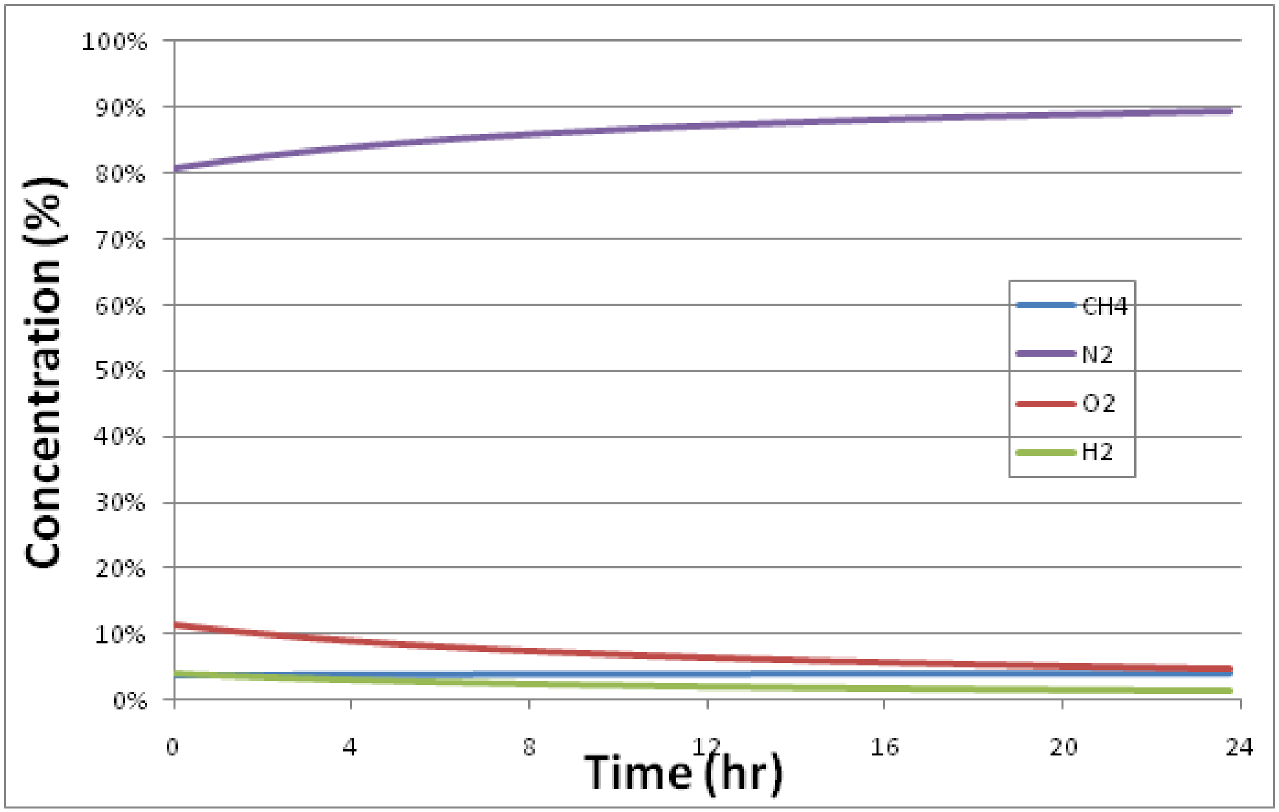


Model Demonstrations

- ***Case 2***
  - To check the effectiveness of N_2 inertization,
  - Ingassing condition
  - Initial Condition:
    - CH_4: 3.77%; N_2: 80.61%; O_2: 11.3%; CO_2: 0.31%; CO: 721ppm; C_2H_2: 24ppm; C_2H_4: 77ppm; C_2H_6: 50ppm; H_2: 39228ppm.
    - The sealed volume is 1,000,000 m^3
    - 1 m^3/s CH_4 inflow rate
    - 50m^3/s pure N_2 injected.
    - The coefficient leakage 0.003 $m^3/s/Pa^{1/2}$
    - The environment temperature is 20℃.

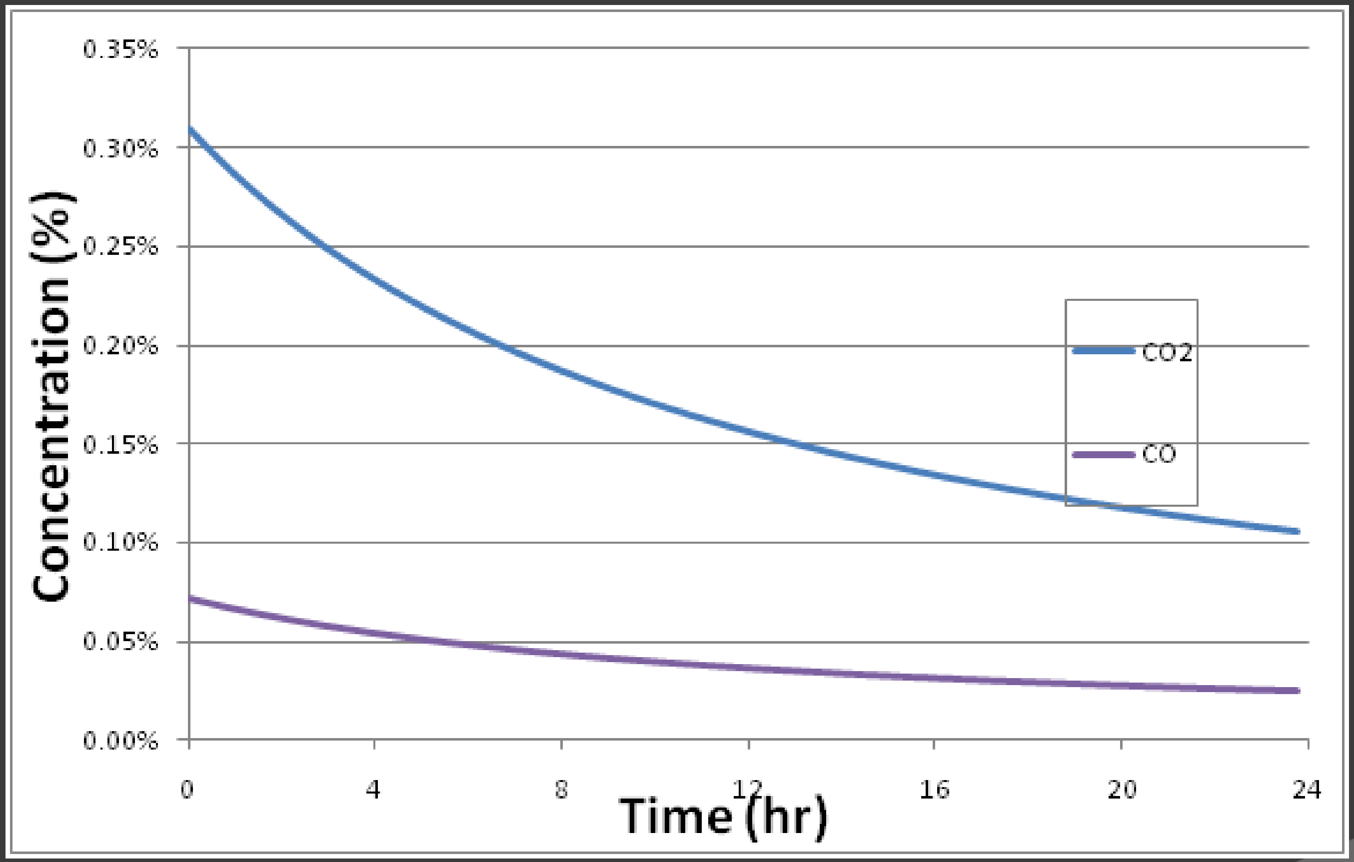
Model Demonstrations

- **Different compositions change over time**



CH_4, N_2, O_2 and H_2

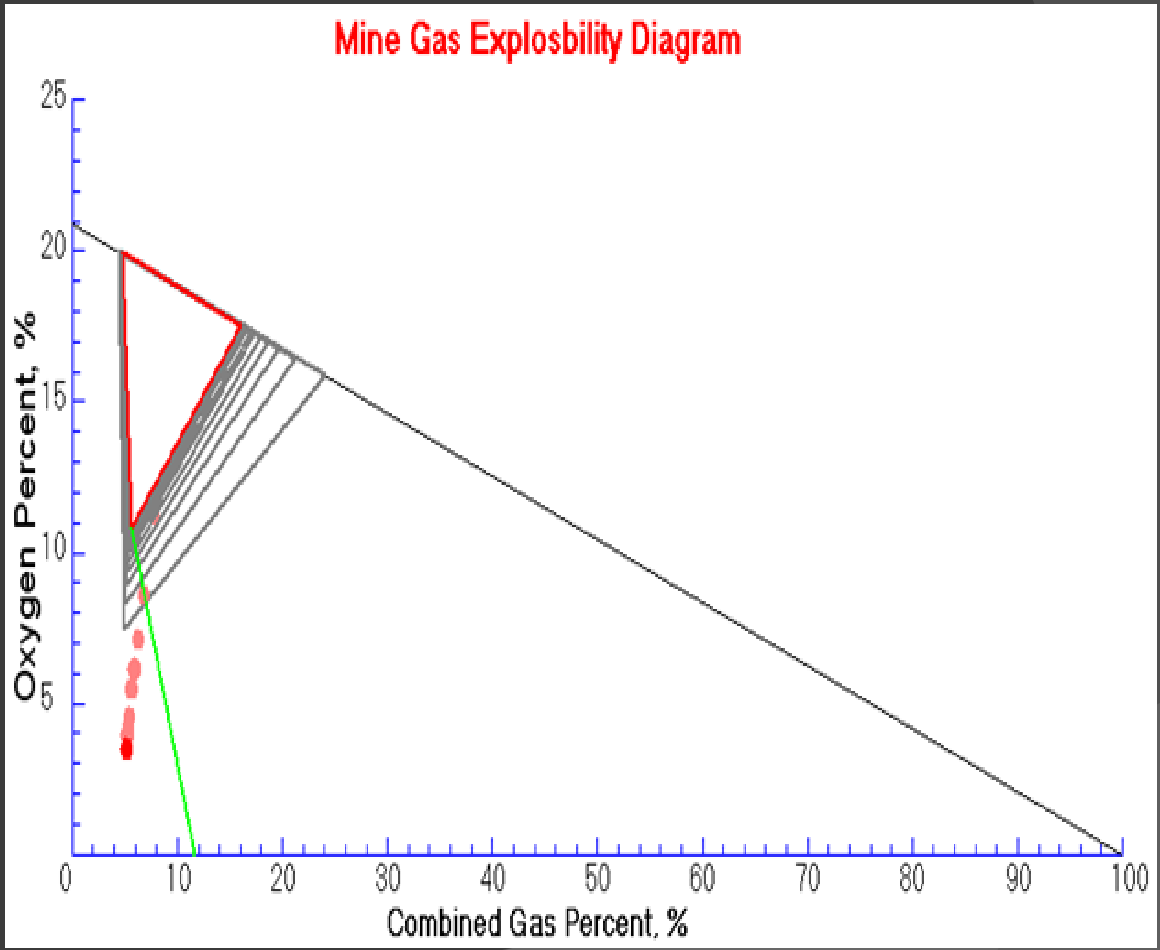
Model Demonstrations



CO_2 and CO

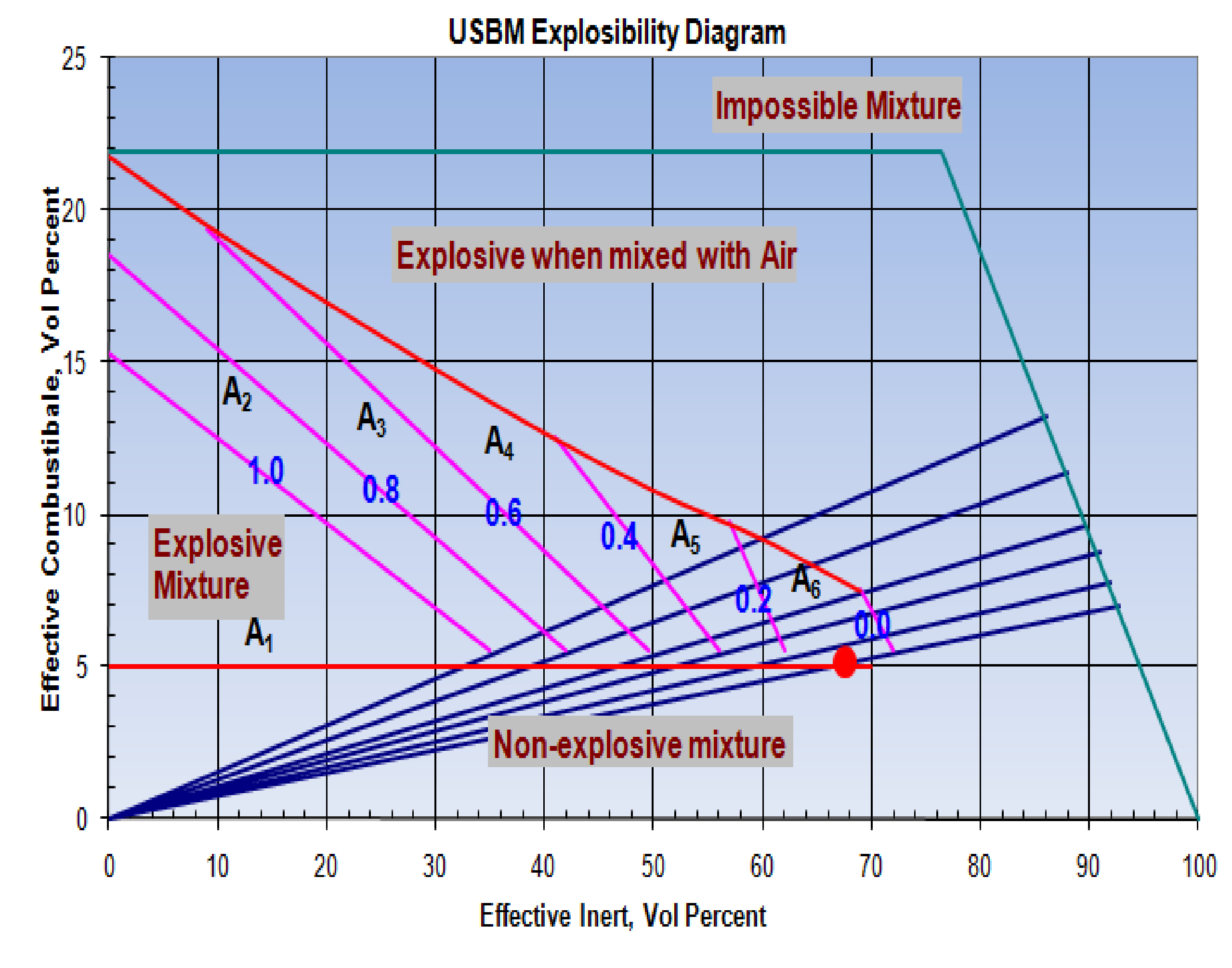
Model Demonstrations

- **Explosbility Diagram**
  - Explosible at beginning.
  - Time step of 0.24 hours.
  - The explosibility triangle shrinks.
  - The actual mixture point moves toward the lower edge of the triangle after 7 hours .



Model Demonstrations

- Double check using the USBM explosibility diagram.
- Based on the 6th hour data. (Calculated Ratio = 0.59)



Conclusions

- A time-dependent mathematical model to simulate the composition change in the sealed volume has been developed based on the law of mass conservation and the ideal gas law. It provides a useful tool for us to understand the behavior of the sealed volume.
- The original Coward method is also expanded to consider the hydrocarbon gases in drawing the explosibility triangle so more accurate explosibility assessment can be made.
- A computer program to incorporate the atmosphere composition model and the expanded Coward method has been developed.