RPC Flammable Gas Monitor Based on Gas Chromatography

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Overview

The RPC gas mixture, Ar/R134A/Isobutane/SF6(65.5/30/4/0.5,) is non-flammable, but it includes a component, Isobutane, than can be flammable in air.

⇒ The gas safety system must check for possible flammable gas mixtures in 2 ways:

1. Monitor leaks in the Isobutane storage bottles and in the Isobutane delivery lines to the gas mixing system.

   This is accomplished by Hazardous Gas Sensors (Rae-Guard, ~$1k each, DocDB #2324) that can detect flammable levels of Isobutane in air.

   It would be very expensive to use this technology to monitor the mixed gas in all locations.

2. Monitor that the mixed gas is nonflammable.

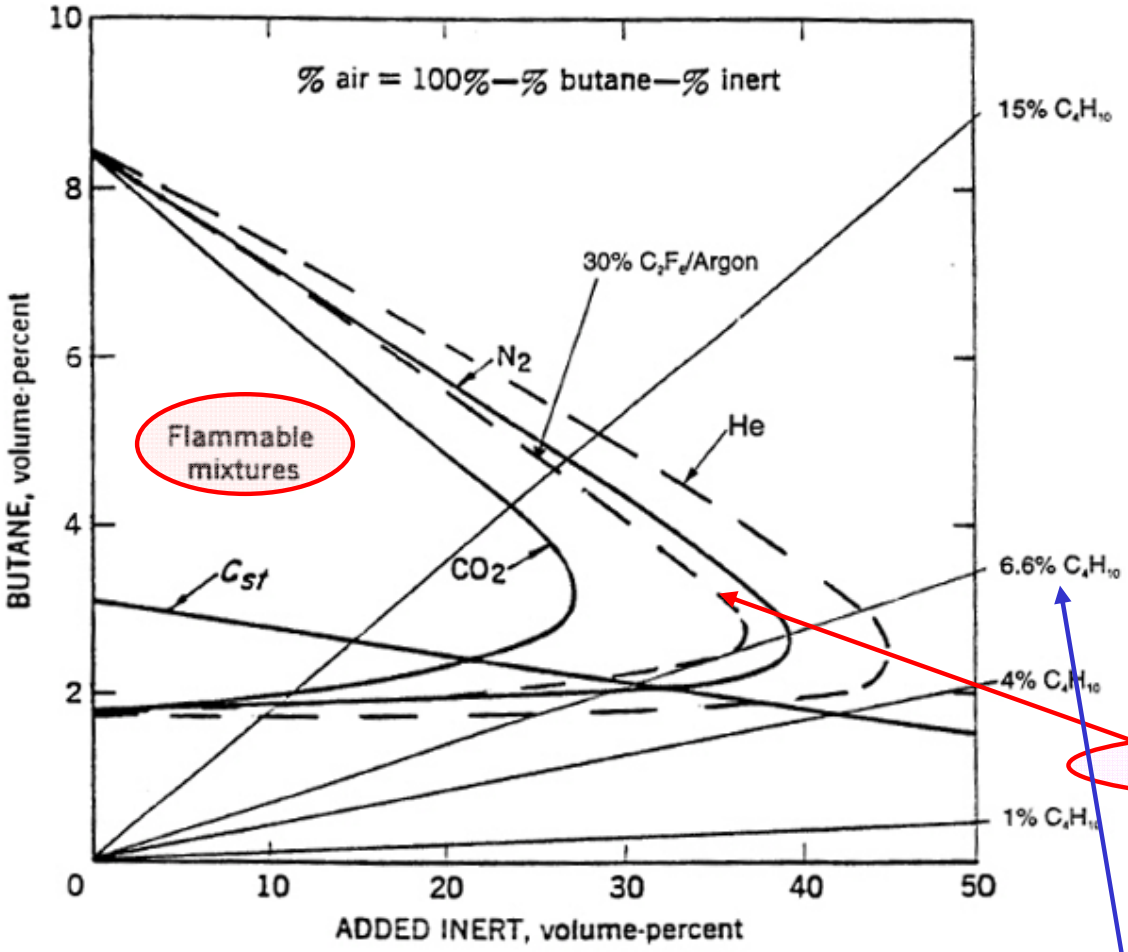
   We originally proposed (DocDB #2814) to accomplish this via infrared gas sensors that would continuously monitor the proportion of Isobutane in the output streams of the gas mixing panels. The cost for this was anticipated to be about $15k.

   However, two different vendors failed to produce sensors of the required sensitivity, which proved to be difficult because the IR absorption spectrum of the Freon R134A is too similar to that of Isobutane.

   ⇒ We now propose to monitor the Isobutane fraction in the mixed gas streams by gas chromatography, using one GC in each of the 3 Experimental Halls. *If instead only one GC were rotated between the Halls, the flammable gas safety system would be operated only intermittently at each Hall, and would depend on the reliability of the shift takers.* The cost of 3 Varian 430-GC's is $33k.

   Some months ago, the Collaboration chose not to monitor the mixed gas as done in the BaBar experiment, where the mixed gas was continuously monitored by a redundant set of mass flowmeters, and samples of the gas mixture was periodically sent to an external vendor for analysis by gas chromatography. This solution would have cost about $15k for the redundant flow meters, plus $50-60k for analysis of 2 samples per year for each of 3 Halls over 5 years.

Flammability of Butane/Argon/C_2F_6 Mixtures in Air



The figure shows the flammability regions for several butane/inert gas mixtures in the air.

The curves for butane/N_2 and butane/CO_2 are from lab tests by the, Bureau of Mines (Zabetakis, Bulletin 627).

Any point in the plot corresponds to a gas mixture of **butane/inert gas/air** with the mixing ratio of **y/x/(100-y-x)**.

If the point falls into the corresponding flammable region, this mixture is flammable.

Hughes **calculated** the gas mixture of 30% C_2F_6/balance Ar with Isobutane, because C_2F_6 is very similar to R134A ($C_2H_2F_4$), especially in heat capacity.

See DocDB #2324 for additional details.

The flammability limit of Isobutane in this gas mixture is 6.6%.

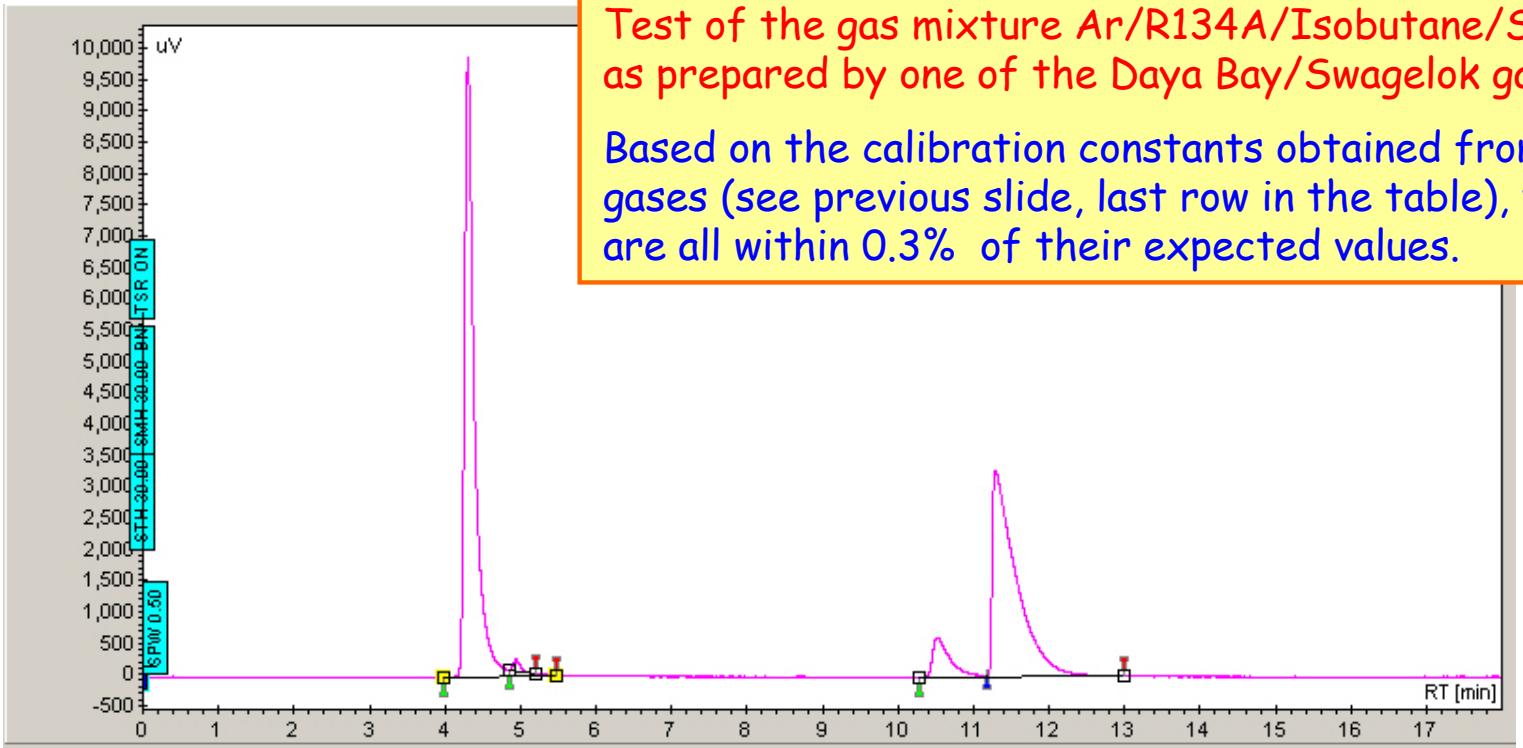
The Daya Bay RPC gas mixture will use only 4% Isobutane.

The flammable gas safety system will monitor that the Isobutane fraction never exceeds 4.5%, and will shut down the gas mixing system if it does.

How Well Can a GC Determine the Gas Components Fractions?

Test of the gas mixture Ar/R134A/Isobutane/SF6(65.5/30/4/0.5) as prepared by one of the Daya Bay/Swagelok gas mixing systems.

Based on the calibration constants obtained from studies of pure gases (see previous slide, last row in the table), the mixing fractions are all within 0.3% of their expected values.



#	Name	Time [Min]	Quantity [% Area]	Height [uV]	Area [uV.Min]	Area % [%]
1	UNKNOWN	4.30	52.58	9914.9	1553.2	52.576
2	UNKNOWN	4.94	0.70	187.1	20.6	0.698
3	UNKNOWN	10.52	5.77	629.9	170.4	5.767
4	UNKNOWN	11.29	40.96	3289.8	1210.0	40.959
Total			100.00	14021.6	2954.1	100.000

See DocDB #3485 for additional details.

DayaBay 2009-3-13 13_13_5028.DATA	1553.2	1210	170.4	20.6	
	1553.2	718.69	94.81	12.00	2378.71
mixing ratio (measured)	65.30	30.21	3.99	0.50	100.00
Calibration					
Ar 2_25_2008 2_12_24 PM20	1099.9				
R134A 2_25_2008 9_11_13 AM20		1851.8			
C4H10 2_26_2008 4_47_33 PM31			1976.8		
SF6 2_27_2008 10_12_19 AM31				1888	
	1	0.593963	0.556404	0.582574	

Gas calibration constants (measured by us using pure gases)

Operational Issues for the Gas Chromatographs

It takes about 20 min for a sample of our gas mixture to be analyzed by a GC.

The analysis process can be fully automated, with the result used to set an alarm if the Isobutane fraction has risen above a specified value (such as 4.5%).

The GC's require continuous flow of helium at a low rate as the "carrier" gas,
$\Rightarrow$ One additional small gas bottle (sufficient for 5 years) in each Experimental Hall.

The operation of the GC valves requires compressed air/N_2, as also needed for operation of the gas-mixing panels.

The gas calibration constants of the GC should be redetermined every few months, using a small custom cylinder of gas premixed to the RPC baseline mixture.

The GCs should be under a service contract (Varian provides this in China) at a cost of ~$3k/year (to be confirmed).

Besides serving as the flammable gas monitor for the gas-mixing system, the GCs serve to check all four gas-component fractions, permitting adjustment of the gas mixture if drifts have occurred in the mass flow controllers.